An on-line tutor for warehouse design [*]

T. Govindaraj, Edgar E. Blanco, Douglas A. Bodner,
Marc Goetschalckx, Leon F. McGinnis, and Gunter P. Sharp
Industrial and Systems Engineering, Georgia Institute of Technology
Atlanta, Georgia 30332-0205, USA
`t.govindaraj@ieee.org`

Abstract

Even though the methodologies for warehouse design are taught in traditional industrial engineering programs, students often find it difficult to develop the skills necessary to complete actual designs. The difficulty in translating the textbook knowledge of using the analytical and mathematical tools for design stem from their lack of experience in using such tools for designing warehouses of reasonable levels of fidelity compared to real systems. It is often very difficult to incorporate large datasets and the computational algorithms necessary during the different phases of warehouse design into the course material. As part of a larger research effort to develop a comprehensive collection of online teaching materials integrated into the undergraduate and graduate curricula, we have developed a warehouse design tutor in which additional functionality is constantly being added. Certain key details of the tutor are discussed in this paper.

1 Introduction

Warehouses and distribution systems no longer play their traditional roles of catering to a single corporate entity or division, even though such roles are still present. Most functions are contracted out, or “outsourced,” to third parties that handle goods from many different vendors or manufacturers, and service their clients. Therefore, warehouses must be designed so that they are flexible and often reconfigurable as the needs evolve.

From a design perspective, warehouses can be characterized by the primary functions they perform: receiving, storage, order picking and consolidation, packing, and shipping. In some cases, these are also value-added operations. Design is generally a two step process, the determination of the overall system architecture, followed by the detailed design of the components including the choice of relevant technologies and the computation of parameter values that satisfy constraints and result in optimal or acceptable performance.

A significant component of warehouse design is the gathering and processing of large volumes of data concerning orders. Designers often work with inadequate or uncertain data. These data are processed to extract information concerning relative sizes of various storage areas, technologies that are appropriate for efficient storage and order picking with a desired level of accuracy etc. While the processes by which expert designers arrive at the designs of actual warehouses are far from well known, several useful “tricks” can be identified for teaching novice designers, i.e., students with a basic background in warehouse terminology and operations.

Current courses on warehouse design focus on the operation of warehouse systems, such as storage or order-picking, with little attention to integrated design. Large-scale case studies are not feasible because there are no comprehensive computational tools to support them. However, the availability of emerging integrated warehouse design tools can potentially make it possible to teach subsystem optimization in the context of overall system design.

One approach to teaching design is to develop simple scenarios that are representative of actual designs, at least qualitatively, and take the student through the steps in a realistic, yet simplified, problem environment. Students are given the opportunity to explore the design problem by trying out their designs, assisted by an interactive system that guides them through constraints and performs routine, low level, computations, leaving the students to experiment with different configurations. We describe such a system in this paper.

A key motivation for our approach is to offer the student the rich context characteristic of actual warehouses by providing a range of scenarios that exemplify the general warehouse design problem. Information concerning data organization and processing, as well as appropriate design algorithms are integrated and made available during design.

A brief survey of computer-based tutoring systems is provided next, together with a discussion of factors that make the problem of teaching warehouse design somewhat unique. Description of a warehouse tutor module follows. We conclude with a discussion of the overall context in which this tutor is being implemented.

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2 Computer-Based Tutors

2.1 Background

Computer-based tutors or instructional systems have been in use for over thirty years (e.g., [1], [2], [3], [4], [5]). The technologies used and the methodologies on which the systems were based have followed the advances in computing, instructional systems design, artificial intelligence, and the cognitive sciences. With rare exceptions, the tutors were primarily concerned with instruction in basic arithmetic, humanities and social sciences, programming languages, and with imparting procedural or factual knowledge in a variety of domains. The exceptions have been in medicine ([6], [7]) and engineering systems ([8], [9]).

In our past work, we have developed intelligent tutoring systems (ITS) in complex engineering domains, such as steam power plants ([10], [11]) and glass cockpit aircraft [12]. With the rapid fall in the costs of computational equipment and increased affordability of multimedia capabilities, instructional materials are being developed in physical and biological sciences, and in many fields of engineering. These systems, employing educational technologies, have mostly dealt with simulations of processes to help visualize physical or natural phenomena, such as Newton's laws of motion and fluid flow, or with providing the software infrastructure to enable experimentation using computational tools for the solution of equations of dynamics.

Traditional computer based tutors (CBT) are not significantly different from simple programmed instructional systems that generate responses based on simple decision trees. Intelligent Computer Assisted Instruction (ICAI) systems are more sophisticated, and incorporate student models, instructor or pedagogical models, knowledge bases, and "user friendly" interfaces (e.g., [13]). Student actions are continuously monitored and responses are generated that are appropriate to the level of student's understanding and misconceptions. The instruction offered is tailored to each student, in a manner that is similar to what a live instructor or tutor would do.

It is safe to assert that there have been no major conceptual advances or breakthroughs in tutoring or instructional systems for at least over a decade [1]. The only major change has to do with the falling prices for hardware, together with authoring systems, that has lead to the development of instructional material in a form that can be delivered on the computer. In the form of simulations, perhaps accompanied by means for visualizing difficult physical concepts or to complex procedural or process information, these systems or software can help augment traditional teaching. Such systems can possibly even substitute for teaching material that do not involve complex reasoning or problem solving skills that can only be taught in a traditional classroom. However, the tutors are generally stand-alone, and students interact with them individually. Their capabilities range from programmed instruction, not much different from computerized flash cards, to ICAI, where the tutor monitors student actions closely and offers advice and instruction based on an analysis of the student's level of understanding at any point in time. These advanced tutors are designed to incorporate good pedagogical principles to offer context-sensitive help and instruction tailored to each student in a way that mimics what a live instructor would provide. A number of tutors have been evaluated in real-life environments and found to be quite effective in providing instruction, comparable to traditional training.

2.2 What is different

Almost without exception, the tutoring or instructional systems have dealt with problems or domains in which the range of options available, or procedures and/or facts to be taught have been finite, even though the the knowledge itself can be very complex. For instance, in troubleshooting for problems and fault diagnosis in a power plant, or to teach pilots the correct procedures to perform a flight maneuver, the range of possibilities forms a closed set, even though the selection of the correct response or instruction is by no means trivial or straightforward. The "physics" the problem itself is well-understood; the difficulties arise from the "combinatorial explosion" of the interactions and the different ways to accomplish the same goals. The system or the concepts to be taught can be assumed to be in a "steady" state.

In contrast, there is a class of systems or problems where the concepts, processes, or procedures to be taught are much more open-ended and there is a lack of formal techniques or methodologies to guide automated instruction in computer-based, possibly "intelligent," tutoring systems. Design problems in logistics, for instance in warehousing and distribution systems, fall under this category. Even though there is a body of knowledge that is quite mature, especially for analysis and design when the components are well-defined, overall design itself continues to be more an art than science [16]. Expert designers of warehouses develop their insights after years of designing warehouses, learning from their mistakes as well as their successes, and employing analytical and computational tools only to solve well-defined sub-problems, e.g., optimizing the rack size or lane depth. In addition to the open-endedness of any design problem, warehouse design is complicated by the fact that there are many uncertainties and that the system is constantly evolving. Useful data are constantly changing, and e-commerce is exacerbating this trend. Data accumulate over a long period of time, and it is often difficult to clearly articulate and identify what characterizes usefulness.

The ability to design efficient warehouses is a key component of the expertise in industrial logistics. We are in the process of designing and implementing instructional modules that deal with the comprehensive set of design tasks. The instructional module described next, dealing with the relative sizing of the forward-reserve area in a warehouse, exemplifies the scope of the overall design problem and illustrates the range of data and student interactions necessary in the instructional modules.

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[1] A notable exception in complex engineering domains is an intelligent tutor for (airplane) pilot training that incorporates a rich pedagogical model based on a comprehensive intent inferencer with a high fidelity simulation and interactive interfaces ([14], [15]). What distinguishes this from the rest is the complexity, generality, and scale of the system.

3 A Design Tutor

In warehouse design, a key strategic design issue is the decision concerning the problem of forward and reserve storage areas. The primary consideration for the design of the reserve area is the efficiency of storage. The forward area, in contrast, is designed to facilitate faster, and cheaper, order picking of frequently ordered items, stock keeping units (skus), or item families, even though it incurs a replenishment cost to move material from the reserve storage to forward area as items are depleted. Therefore, there is often a trade-off between efficient storage, from which it may be expensive to fill an order, and efficient order picking from readily available storage area.

Even though analytical or heuristic algorithms may be available for optimizing design parameters, once the structure or architecture of the system is fixed, the most difficult design problem concerns the determination of appropriate parameter values for a given architecture. The structure can also be altered if it is determined that an alternate design can improve performance. What is needed, in actual designs, is a system that enables what-if analyses, facilitating interactive optimization.

We have developed a simple tutor that incorporates these ideas, by making it possible for the student to explore the possibilities, within the system constraints. The system provides the student with the relevant data, guides her in the steps required in the design process, provides information of different storage alternatives and allows her to investigate the cost structure of the design.

A student can, interacting with the tutor over the World Wide Web, select a design scenario for which he designs the relative sizes of forward pick area and reserve storage area, together with appropriate selections of storage technologies and the assignment of products to the forward pick area [2]. The scenarios include a computer distribution center, an apparel warehouse, and a grocery store, all at a low to moderate level of fidelity. The model evaluates the designs specified by the student and provides feedback in terms of cost and performance, based on models described in [17], and [18].

The student can alter his design based on the model results and attempts to reduce cost and/or improve performance. The design database used by the course module stores information about the warehouse, products, as well as student solutions. Multiple design sessions can be concurrently supported.

The design problem deals with a 150,000 square feet warehouse facility that houses different kinds of products. The facility has a forward area for full case picking and a unit load reserve area, which stores incoming receipt stock.

Schematically, the warehouse facility looks as follows: Products are picked within a flow rack, pick-to-belt operation in the forward area. Approximately 200 cu. ft. of space is available for storage within each 4-ft. x 7-ft. x 10-ft. flow rack bay. In the reserve area three different storage alternatives are available to store the product: block stacking, single-deep and double-deep rack. The load dimension of the pallets 48 in x 40 in. (the second dimension is measured along the pick face).

The decisions that the user need to make are: (1) the size of the forward area, (2) the number of flow rack bays assigned to each product, and (3) the storage equipment in the reserve area used by each product.

When the student specifies the design parameters, the system computes the overall operation cost and the used square footage of the facility. She can continue to explore different alternative designs until she is satisfied.

4 Discussion

Typical undergraduate curricula in industrial engineering are comprised of general courses on methodologies, followed by a few context-specific courses where the methodologies and tools are used. The methodologies include economic analysis and modeling, decision making, statistics, stochastic modeling and analysis, optimization, discrete event simulation, human performance and organizational behavior, and information systems. Students are exposed to the domain in the context of production planning and control, facility design, material handling systems, manufacturing processes and systems, warehousing and distribution, and logistics systems.

The methodologies and the context in which they are applied are generally taught separately, until perhaps a capstone design course that the students take during their last term or two. This makes it hard for students to appreciate the complexities or richness of real life problems, or the relevance of the methodologies and tools until after they take up real jobs. It is, therefore, very difficult for them to develop good insights about the applicability of the methodologies for analysis and design and the complex interactions among the variables that affect their decisions. In addition to system complexity that students generally do not experience during their studies, they lack a feel for how text book examples scale up to industrial systems.

The warehouse design tutor described above exemplifies the essential features of the other instructional modules that are under development. The overall goal is the development of a comprehensive set of well-integrated course modules for teaching industrial logistics. It is our objective to preserve the rich context characterizing the domain, while simultaneously making it possible to organize the modules flexibly to cater to multiple needs. As part of a larger, and more comprehensive, research program, computational tools and design environments are being designed in such a way to make the decision processes and issues that characterize the domain transparent by hiding the low level computational details.

This warehouse design tutor can more appropriately be characterized as an exploratory learning environment. This state of affairs, where the tutor affords an environment for exploration, instead of functioning as a coach or tutor, arises not from an inability to implement such a system for any

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[2] It is interesting to note that PLATO IV, the forerunner of computer-based instructional systems, was characterized by its developers as being a cost effective, distributed computer-based system for instruction [1]. Perhaps it was a bit ahead of its time. The web is now making it more affordable to develop and deploy computer-based systems for instruction.

methodological reasons. It is the result of inadequate understanding of the processes that characterize the "right" design process. In other words, the "physics" of design is not known or understood to the same level of "precision" with which a physical or engineered system such as an airplane or power plant are known. As a result, an exploratory environment, accompanied by gradual and continuing updates of knowledge, e.g., best practices, incorporated into a design guide, is more appropriate. This is the approach or philosophy that underlies the design of the tutor.

In spite of a long history of development, the impact of computer-based instructional systems is not commensurate with the amount of intellectual capital devoted or monetary resources expended towards their pursuit. One reason for their lack of impact is that by nature they are "desk top" systems, instead of being "distributed." This makes it difficult to keep current, manage them effectively etc. What is needed is a tutoring system built in conjunction with a distributed information system, where the tutor imparts critical thinking and problem solving skills while the distributed information system provides the rich context that significantly improves the fidelity while making it possible to keep it up to date [3]. The skills themselves are learned via exploratory learning environments.

In our current research, we are developing models of complex industrial systems (e.g., [20]) and implement appropriate combinations of simulation and emulation in the form *virtual industrial systems* (VIS) that function as exploratory learning environments. High degree of fidelity is achieved in terms of complexity, interconnectedness, and dynamic behavior, so as to provide integrated access to realistic engineering tools for visualization, representation, analysis, and synthesis.

The VIS are being designed and implemented by incorporating software tools that are likely to be used in practice to describe, characterize, analyze, and synthesize industrial systems, and to provide the rich context in the form of a sufficiently detailed large-scale case study. The goal is to support computational exercises for all the methodology-related topics contained in the curriculum, in a high fidelity environment that illustrates the concepts via guided exercises.

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