OBJECT MODELS AND DESIGN DATABASES FOR WAREHOUSE APPLICATIONS

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Abstract. Design Decisions for warehouse applications require large amounts of data. In addition, these date typically have complex interrelations and constraints that must be represented for the design process to be successful. Object technology and database technology offer a way to manage design data and also provide a platform for integrating it into applications to automate the design process. This session will focus on the use of these technologies to support warehouse design.
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Introduction

Recent developments and trends in the global economy have dramatically increased the rate and speed at which warehouses and warehouse operations are designed. Some of the more prominent trends are the introduction of the Internet and Business-to-Business e-commerce, an increased use and reliance on outsourcing and third party logistics, and an increased rate of start-ups, mergers, and acquisitions.

In recent years many corporations have completely reengineered their supply chain to respond to increasing customer service demands and higher profitability requirements from their shareholders. While warehouses have become smaller, they remain a key component in the supply chain of most corporations. The requirements for the warehousing operations have significantly increased. Order accuracy, order response time, order frequency, and order size requirements are dramatically different then a decade ago. The advent of electronic Business-to-Customer commerce will introduce even more complications since a larger number of single customer, small orders will have to be processed on very tight deadlines.

Increasingly, engineers without formal education or experience in warehouse design are asked to design these warehouse operations and infrastructures and to provide a cost justification for their design.

To develop a feasible design and to derive the associate costs for the design, the engineer needs to access at least four types of data: customer demand and order data, product data, warehouse storage and handling equipment data, and location dependent cost data. These data can be design project specific, such as the order data, product, and localized cost data, or generic, such as the equipment and general cost data. These data may have to extracted for large transactional databases or collected from disperse sources such as material handling vendors and local chambers of commerce. The data typically have complex interrelations and joint constraints that must be observed for the design to be successful. For example, a warehouse with a higher storage density may require a smaller footprint area, but this may increase labor cost because of more time consuming storage and extraction operations. Designing the warehouse operations, infrastructure, and deriving the cost justification typically are repeated in an iterative process until all feasibility constraints and cost objectives are met. At the same time, the allowed time for the warehouse design is cut significantly since the overall time-to-market is large determinant of the success of the product.

The result is that many warehouse operations are design as modifications and extensions of previous designs to reduce the development time. This "incremental" design methodology may ignore significant alternative designs and cost savings opportunities.

Clearly, there is a need to formalize the warehouse design methodology, manage the warehouse design, provide a set of tools to synthesize the data, and to automate parts of the design process. We believe that object models and object-oriented design databases allow the development of such tools and in turn the enable more efficient, cost effective warehouse design in a shorter amount of time. The ultimate goal is the integration of the object models, design algorithms, and design databases into a design environment.

Current State of Warehouse Design

It is our opinion that until very recently the state of warehouse design was very ad hoc and strongly dependent on the level of expertise of the warehouse designer. In industrial practice, experienced designers were asked to design more and more facilities in shorter amounts of time, which led to an incremental design philosophy. At the same time more and more inexperienced engineers were designing warehouses, which tended to ignore innovative and more cost efficient designs in favor of successfully implemented designs.

Academic research in the areas of warehousing, storage systems, and order picking systems was not very helpful to practitioners during warehouse design. The research tended to focus on highly detailed analysis of sub-components of the warehousing system. Graves (1998) has compiled a recent survey of academic research in this area. However, there does not appear to exist a single research publication on the overall design procedure for a warehousing system that goes beyond the overall and general introductory framework.

Very recently papers by Mantel et al. (1998) and Stadtler et al. (1998) have attempted to provide a framework for design decisions to be made during warehouse design. In 1999 a project was started by a group of researchers at the Georgia Institute of Technology to develop a science-based design methodology for warehouse operations that would used by academic researchers, industrial practitioners, and in the education of engineering students. This work was based on a long history of research and tool development in the areas of material handling, facilities design, and warehouse operations by these researches. For example, on design tool design by McGinnis and Goetschalckx (1989) and on designing order picking systems by Sharp and Yoon (1996). Recent results of this research are given in Bodner et al (2000), McGinnis et al. (2000), and Goetschalckx et al. (2000) and also described further in these proceedings, Bodner (2000).

Object Models and Object-Oriented Databases

It was decided early on in the research that the only information technology capable of handling the large databases generated by the transaction-oriented warehouse management systems and accommodating the ever changing material handling and storage technologies was the combination of the object models and object-oriented database.

As a first step the typical questions posed during warehouse design were capture in use-cases following the UML methodology as described by Fowler and Scott (2000). The primary reason for the selection of industry standards is a commitment to develop an infrastructure and methodology that is distributed, web-based, open, and extensible. Based on the use-cases an object model was derived. Limitations on the length of this article preclude a detailed description of the object model and associated database. The model contains data regarding orders, products (also called SKUs), material handling equipment such as forklift trucks, and material storage equipment such as racks and bin shelves, and material containers.

The various flow paths taken by different products through the warehouse from the receiving dock to the shipping dock are stored in a directed arc-node diagram, where the nodes correspond to the various departments in the warehouse. Objects are grouped in collections if this allows the designer to manipulate all objects in a similar and consistent manner. A department may have a collection of material handling trucks, a rack is a collection of storage locations, and an order is a collection of order lines for various products. All objects have also attributes and the values of the attributes distinguish the objects. A department may have a footprint area and a product has physical dimensions and weight. Operations use the attributes of the objects to compute performance characteristics of the warehouse operations and do design methods. Two of the most important performance characteristics for determining the warehouse costs are the required footprint area and the required number of employees in each labor grade. An example of a group of objects related to products and orders and their relationships are shown in the next figure. An example of the group of objects related to material handling and storage equipment is shown in Figure 2.

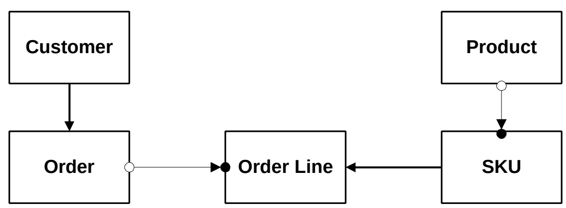

Figure 1. Product and Order Related Objects and Relations

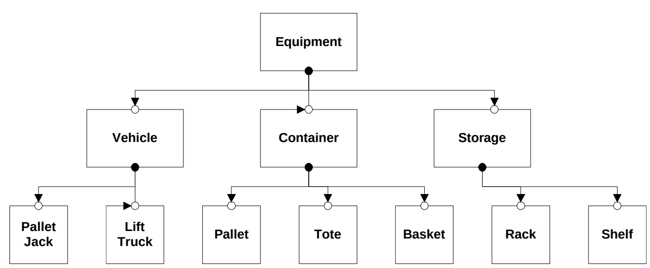

Figure 2. Equipment Related Objects and Relations

Example of operations are the computation to assign a particular SKU to a SKU family, to assign a storage technology to the SKU family, to geometrically configure the storage technology, and finally to compute the required space for storing the SKU family. Based on these operations warehouse methods are derived such as the slot assignment rule for a product being replenished.

At the current time a preliminary version of the object model has been defined and operations and methods are being implemented. The model, methods, and database will be further refined during the continuing development.

It should be observed that adding say a new type of truck or a new type of container does not change the fundamental structure of the object model, the object database, or the methods.

Computer Implementation

The principles described for the object model and object oriented database have formed the basis for two implementations for a design environment for warehouses. The first environment is the Logistics Engineering Analysis Package (LEAP) by UPS Worldwide Logistics (UPS WWL). LEAP was developed for the design, modeling, and analysis of warehousing systems and intended to be executed on personal computers. The overall goal was to make UPS WWL more competitive by enabling the faster and better design of warehousing systems. Typical questions to answered during a LEAP session are what equipment to use, how much space is required, how much labor is required, how much will the system cost, and what is an appropriate project budget. LEAP is implemented in Visual Basic and uses an underlying proprietary database. A few of the input screens are shown in the following figures.

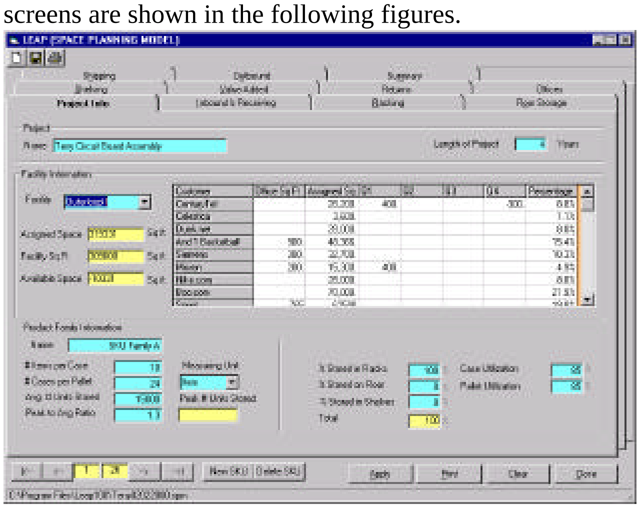

Figure 3. Leap Space Planning Model

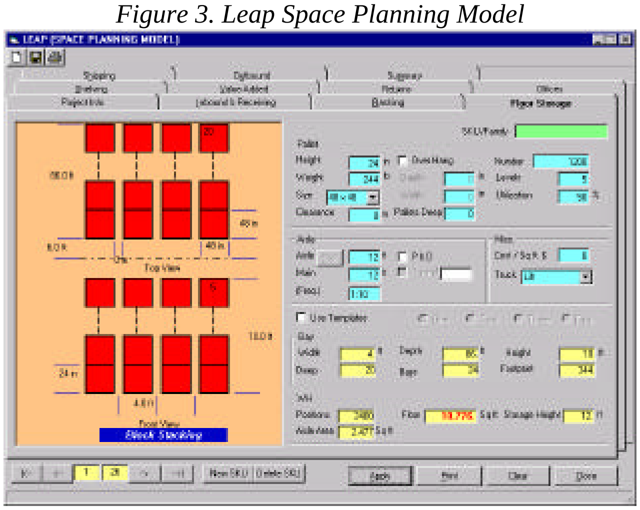

Figure 4. Leap Block Stacking Computations

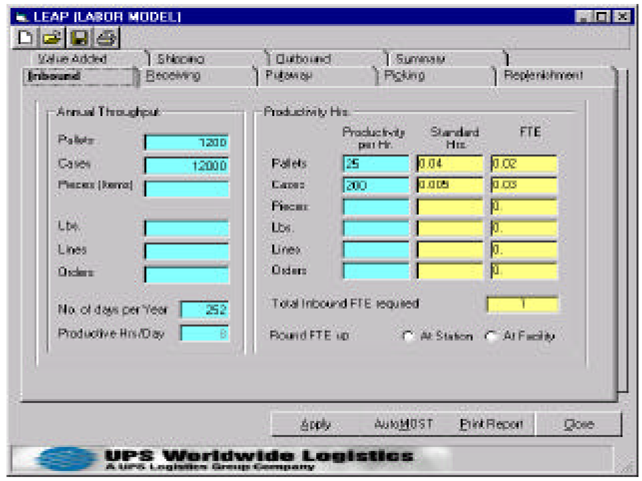

Figure 5. Leap Labor Computations

Concurrently a design environment has been under development by the authors in the Keck Virtual Factory Lab at the Georgia Institute of Technology. The object model and object oriented database were implemented in an object oriented database program. Visualization of the designs was implemented by creating a VRML file from the database, which then could be viewed by any contemporary browser. The next figures show the ability to visualize the warehouse from different angles and have a virtual drive through the warehouse. The viewing angles and zoom parameters are fully under user control through the browser.

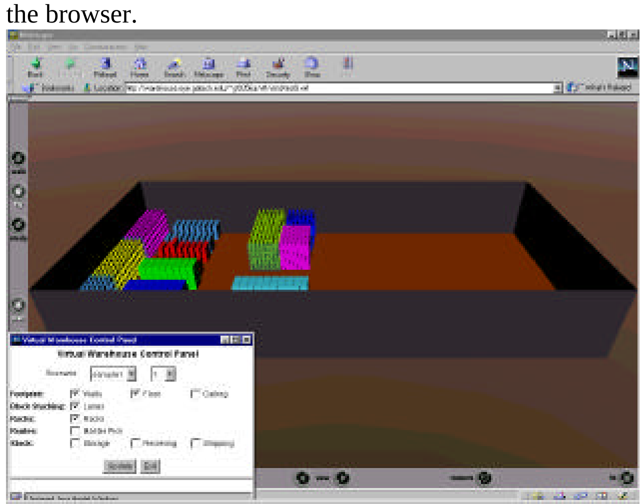

Figure 6. VRML-based Visualization of a Warehouse Design

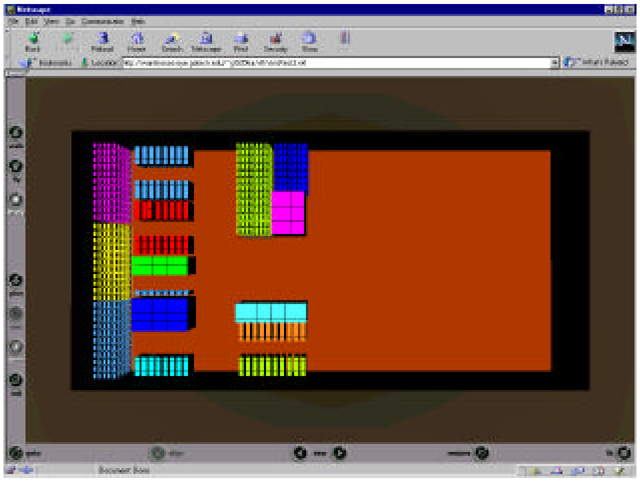

Figure 6. Top View of the Warehouse Design

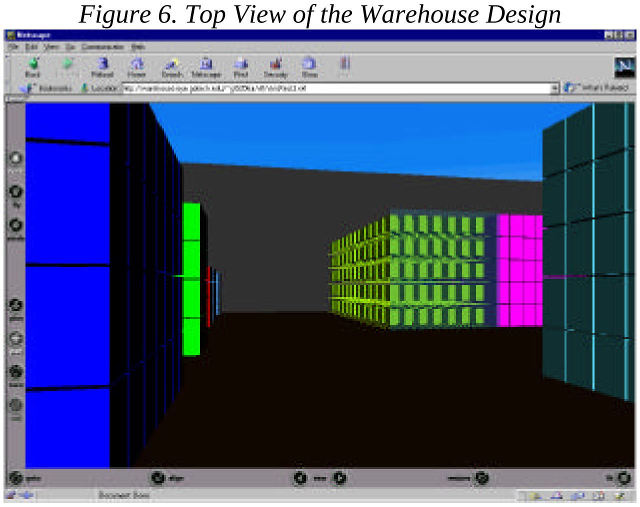

Figure 7. In the Aisle View of the Warehouse Design

Both implementations of the design environment are currently in full development and subject to change. The Leap program is used in industrial testing, while the environment at Georgia Tech is used and being evaluated for teaching warehouse design to undergraduate and Masters students.

Conclusion

This paper has discussed the need for a scientific methodology and robust set of tools for the design of warehousing systems. The use of object models and object oriented data bases coupled with the UML methodology allowed the synthesis of inherently complex and "messy" data and the answering of typical and fundamental design questions. Currently, two design environments that use these principles are being developed and tested in industrial and in educational settings. We are convinced that these design environments will enable the more efficient and more effective design of warehousing systems and simultaneously facilitate the education of future warehouse design engineers.

Further Reading

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