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INTEGRATING SIMULATIONS WITH CAD TOOLS FOR EFFECTIVE FACILITY LAYOUT EVALUATION

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ABSTRACT

The lack of integration between simulation and Computer Aided Design (CAD) has limited the use of simulation in many facilities planning projects until now. In the past, the simulation modeler was given a facility layout drawn with a CAD system. Using this layout as a reference, the modeler built a simulation model and created a partial or complete animation layout. This was very time consuming, redundant, and sometimes technically impossible. Recent advances in hardware, operating systems, and simulation software technologies now provide opportunities for significant productivity and quality improvements in utilizing CAD drawings as backgrounds or icons for animation of simulation models. Modelers can not only drastically reduce the time to create animations but also reduce the time to incorporate frequent layout changes into a simulation model during the design phase of a project. This paper describes the process of integrating simulation models with CAD generated facility layouts and highlights the implementation issues such as file formats, scaling, model resolution, and dynamic depiction.

1. INTRODUCTION

According to Tompkins and White (1984), approximately 8 percent of the gross national product (GNP) is spent annually on new facilities in the United States. In the manufacturing industry, it has been estimated that between 20 and 50 percent of the total operating expenses are attributed to materials handling. Based on these estimates, facilities planning represents an extremely promising area for productivity improvements. Although the use of CAD and simulation technologies has increased in facilities planning projects, most applications of the technologies have been standalone thereby limiting the benefits to be gained.

The facilities planning process begins with the definition and analysis of the problem. Generation and evaluation of alternative designs lead to a selection of a preferred design and implementation of that design. The second phase of a facilities planning project is the most opportune time to benefit from an integration of CAD tools with simulation. Although one of the main objectives of manufacturing systems simulation is to minimize the time to evaluate alternative designs before implementing a new facility or changing it, most simulation projects are unfortunately conducted after a layout is designed and finalized. Due to market pressures and deadlines, usually a preferred or final layout is selected before simulation results are obtained. This means simulation is used as an after the fact tool rather than a design tool. This is analogous to trying to test product quality by testing a finished product and reworking it instead of building quality into the production processes.

2. BACKGROUND

Several Computer Aided Design (CAD) tools have been available for drawing facility layouts. Computervision, AutoCAD, Intergraph, CADAM, VersaCAD, etc. These software programs facilitate the generation of a layout to scale and development of a database (i.e. distances between equipment, size and shapes of equipment). A layout generated by a CAD system is a static drawing stored in a file. Layout files created by CAD systems are typically stored in proprietary formats but they can be converted to standard formats such as IGES or DXF.

The people who design factory layouts with CAD are often design engineers or architects while the engineers who conduct simulation studies are industrial or manufacturing engineers. While design engineers use CAD systems for detailed documentation of a facility layout for architechural requirements, construction, clearances, HVAC, etc., industrial and manufacturing engineers use simulation for detailed production systems performance analysis. To meet architectural requirements and building codes, a facility layout must contain exact geometry and dimensions. From the architects' point of view, the layout is a static drawing to serve as the blueprint for construction. On the other hand, to meet manufacturing requirements, a facility layout must address issues such as quantity and location of machines, size of queueing space (storage areas, in-process buffers), materials flow and handling equipment requirements.

Often a critical step in facility design, relationship diagramming and material flow analysis, is omitted before simulating a given facility layout. Several computerized techniques have been available for evaluating alternative layouts. These software programs require qualitative or quantitative material flow inputs and provide optimum layouts based on minimum material handling costs. The flows among routing locations may be in the form of a from-to matrix or in the form of a qualitative relationship chart. Some of these products can be used to generate a layout from scratch (i.e. PLANET, CORELAP, ALDEP, FACTORYPlan) while others can be used to improve an existing layout (i.e. CRAFT, COFAD, FACTORYFlow). The nature of a facilities planning project is such that frequent changes in product and process designs dictate inevitable and frequent changes to facility layouts and simulation models. If proper tools such as Computer Aided Layout techniques are not utilized up front, it becomes difficult and infeasible to modify simulation models to reflect the changes to facility layouts within project deadlines. The use of such Computer Aided Layout tools can significantly reduce the time in generating alternate layouts and significantly improve productivity in finalizing and simulating alternative layouts.

3. HOW DO WE GET FROM A CAD DRAWING TO A COMPLETE ANIMATION LAYOUT?

The process of moving CAD drawings of facilities can be somewhat confusing. In order to appreciate the challanges in interfacing CAD and simulation, we need to first define the various file formats, their characteristics and benefits. Graphical data can exist in one of two formats, bit map, raster, or vector. Each format has many different syntaxes that may or may not accomodate such characteristics as color, 3D, solids, surfacing, etc.

The Bit Map format is essentially a block of memory that contains information as to which pixels are in what color. In the case of black and white, this file simply determines if a pixel is on or off. Bit map formatted files can be recognized by file extentions such as filename.BMP.

Vector based graphics contain mathematical representations of the geometry contained. For example, most information is in terms of lines, circles, arcs, where the file contains precise beginning and end points of lines and centers and radii of arcs and circles. Examples of vector type file formats are IGES and DXF. IGES (Initial Graphics Exchange Specification) is a format for describing product design and manufacturing information which has been created and stored in a CAD/CAM system in computer readable form. The IGES format is in the public domain and is designed to be independent of all CAD systems. DXF (Drawing Interchange Files) is a standard ASCII format which provides easy translation of AutoCAD data to the formats of other CAD systems or submitted to other programs. WMF (Windows Metafile) is a standard file format for exchanging vector based graphics information between Windows applications.

3.1 Tradeoffs with file formats

Since most CAD files are in proprietary formats, they need to be converted to IGES or DXF format before translation to simulation\animation usable form. Once a CAD file is in IGES or DXF format, the next step is to covert it to simulation\animation usable form. This means the file must be translated to the vector or bit mapped format recognized by the simulation\animation software. There are tradeoffs between using vector or bit mapped graphics for simulation and animation.

The advantages of using bit map format are:

1. The translation results in quality transfer of the images. This means what you see in the CAD drawing is what you get in the animation usable form.
2. The translation is easy-to-do with cut and paste functions.
3. The converted bit mapped files may be smaller in size than vector formatted files for very complex facility drawings.
4. The converted bit map usually results in fast animation execution speed during the simulation since background portions are constantly being refreshed.

The disadvantages of bit map transfer are:`

1. After the translation, bit mapped images can become distorted when scaled or zoomed.
2. Once converted , images contain no intelligence as to dimension, area, etc.

3. The bit map files are larger in size for drawings of simple layouts.
4. Once converted and edited, a bit map image cannot be converted back to a CAD drawing.

The advantages of vector based transfer are:
1. Images may be scaled up and still retain smooth diagonal lines and visual clarity.
2. Images are dimensionally correct and may be queried for distance, area, and intersection
3. The vector files are smaller in size for drawings of simple layouts.
4. Once converted and edited, the images, with some effort, can be converted back to a CAD drawing.

The disadvantages are :
1. The translation can take a considerable amount of time and the coverted files can be very large for complex facility layouts.
2. Due to incomplete adoptions of the typical standards, or incompatibilities in the base structure of the communication packages, some information about text fonts, line types, symbols, or attributes may be lost.
3. The translation process is difficult and usually requires significant expertise in CAD.
4. The converted vector file may result in slower animation (depending on animation software) due to potentially complex calculations for updating images.

3.2 Graphical depiction and data requirements for simulation/animation

Graphical depiction of simulation model elements can be classified into depiction of static backgrounds, static model elements and dynamic entities. Static backgrounds include building walls, aisles, columns, etc. Static model elements include machines, queues, transportation paths, etc. Since static backgrounds and static model elements do not possess motion characteristics, graphical depiction of them is trivial. On the other hand, graphical depiction and data requirements for dynamic entities present a complex problem.

Dynamic entities include parts, unit loads, transporters, etc. Dynamic entities can be classified into 1) Parts, and 2) Material Handling Devices (i.e. people, forktrucks, AGVs, cranes, conveyors). Parts follow a sequence usually refered to as routing whereas material handling devices serve as means of movement for parts between routing locations. Since the movement of dynamic entities during a simulation run depend on various conditions, it is absolutely critical for the model to capture all possible routes a part or a material handling device can take. In order to completely define the data requirements for dynamic entities, let us classify the data into three areas:

1) Data for Part Movement

Part name, quantity of parts (especially important if the model contains assembly) , From-To relationship, routing conditions (probabilistic, deterministic, conditional), unit load for movement must be defined. Table 1 shows an example for part movement data.

Part Name	Qty	From	To	MH Device	Unit Load
ALUMINUM	2	RECEIVING	EXTRUDE	FORK	20
RAIL	2	EXTRUDE	HEAT	CONV1	1
RAIL	2	HEAT	RAILS	FORK	50
RAIL	2	RAILS	STEPS	FORK	50
STEP	3	STEPS	ASSEMBLY	FORK	65
LADDER	1	ASSEMBLY	ASSEMBLY	CONV2	1

Table 1. Typical data for Part Movement

2) Data for MHD Movement

MHD name, quantity of MHDs available, capacity of MHD (quantity of unit loads that it can carry at a time), speed (full or empty), acceleration, decelaration, home position, load\unload time, downtime characteristics, unit load selection rules, MHD allocation rules.

3) Interface between part routing and MHD (Path network)

Actual material movement paths, pickup and dropoff points (P&Ds) that provide interface points between routing locations and MHD, relationships between routing locations and P&D points.

Step 1) Conversion of CAD file to a simulation\animation useable format

Since a typical CAD file is in proprietary format and it contains large amount of unnecessary details for simulation\animation , the first step is to convert it to either a standard vector format (i.e. IGES or DXF) or a standard bit map format (i.e. *.BMP). The next step is to convert this file to simulation\animation usable format. There are three basic approaches for this conversion depending on the type of animation approach taken by the simulation\animation vendor: 1) A conversion utility or a CAD translator converts an IGES or DXF file to the custom format of the animation package. The converted file is in vector format. Some of the simulation\animation software products that use this approach are Proof Animation, AutoMod, and SIMAN\CINEMA. Of these products, AutoMod uses 3D surface based (polygons) graphics which allows toggling between wireframe and solid viewing during the animation 2) A built-in conversion utility within the CAD software converts a CAD file from its proprietary format directly to a bit map (i.e. *.BMP). The converted bit map file is used as a graphics background for simulation model development. Some of the simulation\animation software products using either this approach are SLAMSYSTEM, FACTOR\AIM, and ProModel\WINDOWS. 3) An off the shelf conversion utility or a built-in conversion utility converts the IGES or vector format (i.e. *.WMF). The vector formatted file is sized or rotated during model development and that file is treated as a bit map during animation. Table 2 shows the three types of procedures for converting a CAD file to simulation\animation usable format.

	Approach #1	Approach #2	Approach #3
Original CAD drawing file format	Proprietary	Proprietary	Proprietary
Common Graphics format	DXF, IGES	BMP	DXF
Model development format	Vector (Proprietary)	BMP	Vector (Metalife)
Animation compatible format	Vector (Proprietary)	BMP	BMP

Table 2. Procedures for conversion

Step 2) Logical linkage of the static modeling elements to the converted layout

Once the drawing is translated, static modeling elements such as machines and queues need to be logically linked with the drawing. Most simulation\animation products offering a CAD interface provide graphical ways to assign modeling elements to images in the converted layout. For example, you can select the modeling element by clicking on a list box containing machines in your model and then clicking on the machine icon in the facility layout. Another way is to draw a box around the machine icon on the translated layout and define that region inside the box as the location for the machine.

Other logical linkages that need to be completed are actual paths for parts, unit loads, mobile resources such as shop floor personnel, cranes, AGVS, robots, and conveyors. Once again, most simulation\animation software with a CAD interface provide graphical ways to assign paths and conveyor segments of the model to the images on the imported layout. If the converted file is in vector form, lengths of transporter paths and conveyors can be maintained. This may eliminate manual entry of distances for movement in the simulation model.

Step 3) Completing other pertinent information for the animation

The final step in completing the animation is to define graphical depictions of dynamic entities during the simulation. Such questions as how do we show 10 parts queueing up in an area, where does a part show up on the machine icon when it gets there, what entity icon should be displayed during and after the assembly operation if the model has an assembly operation with 3 types of subassemblies being assembled into one final assembly, need to be answered to complete the model.

Other features such as definition and display of various orientations for dynamic entities, display of dynamic counters and graphs, display of changes in machine states using color codes are also helpful in making the animation realistic and meaningful during the simulation.

The three steps described above for interfacing CAD with simulation provide significant productivity improvements for generating animations over the old brute force approach. The time to create or modify custom made icons is eliminated. In addition, any changes to the CAD drawing can be immediately transferred to the animation layout. Users of the new integrated approach have reported 2-10 times reduction in total simulation project time over the old approach for animation development. Other benefits of the integration of CAD with simulation are high quality, accuracy and realism of the graphics and animation.

4. LET'S NOT LOSE SIGHT OF SIMULATION OBJECTIVES.

Interfacing CAD with simulation can provide significant productivity improvements as long as the overall objectives of a simulation study are kept in perspective. As Conway and Maxwell state, modeling is undertaken to guide one in making changes in the real facility or in the design of a new facility. If a modeling exercise does not suggest some improvement in the real factory, it is more likely a failure than a testimonial to the perfection of the real thing. Conway and Maxwell further question the value of being able to rotate the model in three-dimensional space and view it from any angle especially if the model results do not yield useful information.

The fact that we have a CAD drawing of an entire facility layout in a computer should not lead us to temptations to build a model of an entire factory at once, at least not at the beginning. A simulation model, to be useful, does not need to provide a one-to-one corresponce between the real facility and the model of the facility. Such important factors as the time to build a model, the time to run it, the time to conduct experiments with it and the time to undertand and explain the results must be taken into account before developing a full-scale model of a facility.

4. COMPUTER AND GRAPHICS HARDWARE CONSIDERATIONS

Interfacing CAD with simulation can be accomplished with off the shelf computers but users need to understand the basic computer hardware requirements and any additional graphics hardware.

In the past, engineering workstations running under Unix operating system provided the most appropriate platforms for graphics intensive applications such as CAD and animation. These workstations contain special graphics boards necessary to speed up the CAD to simulation translation and calculations for animation.

With the availability of 486-based machines and SVGA (Super Video Graphics Adapter), it is now more feasible to run graphics intensive applications on microcomputers than engineering workstations. Until recently, regardless of the clock speed on most microcomputers, the video graphics boards ran at 8MegaHertz speed. The availability of new local bus video graphics cards (1024*768 resolution) makes it possible for the video board to run at the same clock speed of a microcomputer.

5. CONCLUSIONS

Although there are still some minor technical challanges for integration of CAD and simulation tools, it is now technically feasible to integrate CAD and simulation tools for timely and cost effective facility planning. Most simulation/animation software products provide means to translate CAD generated facility layout files to animation usable formats. The availability and affordability of powerful microcomputers and engineering workstations, the capability to network computers and exchange data across applications present opportunities for broader and concurrent use of CAD and simulation technologies.

Future developments in simulation/animation software technology and developments in Computer Aided Layout technologies promise further improvements in quality and productivity by integration of CAD and simulation technologies.

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REFERENCES

Scott, D. C. 1983. Facilities and Manufacturing Planning Using Computerized Technologies. *CAD/CAM Integration and Innovation*, 443-447. 1st ed. Michigan.

Tompkins J., J. A. White. 1984. *Facilities Planning*. New York: John Wiley and Sons.

CIMTECHNOLOGIES Corporation. 1990. *FactoryFLOW Tutorial and Reference Manual*. Ames, Iowa.

AutoSimulations Inc. 1991. *IGES/SIM User's Guide*. Bountiful, Utah.

Wolverine Software Corporation. 1991. *CAD Translator Reference for Proof Animation*. Annendale, Virginia.

Conway R., W. Maxwell, J. O. McClain, and S. L. Worona. 1987. *User's Guide To XCELL+ Factory Modeling System*, 151. California. The Scientific Press.

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