# Development of an Integrated System for Design Evaluation

**Mark R. Rajai, Keith V. Johnson, Robert Matthews**
**East Tennessee State University/ University of Louisville**

Abstract

In this paper, two software packages (AutoCAD and Mannequin) are integrated to create an ergonomic CAD system. This developed system will provide designers with a powerful graphical tool to evaluate their design for human factors and safety criteria. An absence of a truly integrated ergonomic CAD system that has been desired by many researchers and designers was the motivating factor behind our efforts. Steps taken to integrate these two somewhat incompatible software is explained in this paper. Now designers have an ergonomic CAD system to assist them to design products according to physical abilities and characteristics of their human operators. Utilizing this type of technology could revolutionize the way products are designed and significantly reduce the alarming number of related injuries, thus saving millions of dollars. This integrated system could also substantially reduce the critical factor of time to market and lower overall cost of designing new products by allowing designers to test their products for human fit without having to build a prototype or using real subject.

## I. Introduction

If designers need to see how a human with a particular set of statistical characteristics might fit into a certain design environment without subjecting a real person to that environment, a PC-based ergonomic drawing and design program would be an ideal application. With such a program, a "human" of different size, gender, and nationality could be manipulated around a PC developed environment, such as an AutoCAD drawing of the work environment, to determine whether they could fit into that environment. One such software that can do that is Mannequin. With this software, the "human" is a Mannequin generated image that can have varying dimensions to suit the anticipated human it will portray. This software integrated with a CAD system can provide the designer with a powerful graphical tool to evaluate his or her design for human factors and safety.

We believe utilizing this relatively inexpensive tool will reduce the alarming number of related injuries from poorly designed products, thus saving millions of dollars.

## II. Literature Review

Several researchers have recently recommended that an ergonomic CAD system should be developed to assist the designer in evaluating their design for human factors, manufacturing, and safety. Quilter (1997) warned that due to lack of an inexpensive graphical tool companies are designing products without adequate concerns for their safeties. She also pointed out that the products that are ergonomically designed cost too much for users to buy.[1] Rajai and Karwowski (1998) reported in designing products that require constant interaction with their users, consideration must be given to their long-term effects.[2] Helander and Nagamachi (1992) in their studies of human factors and manufacturing aspect of product designs, suggested a system that integrates ergonomic analysis with CAD system should be developed.[3]

This ergonomic CAD system should provide designers with built-in knowledge to evaluate their designs. Using computer graphics in design process is recommended by other researchers.[4,5,6] However, a main problem of incompatibility between CAD systems and ergonomic systems has hindered the development of such integrated systems. Ortengren (1992) reported that, in order to use graphics-CAD system effectively, it should be possible to transfer geometric data between CAD system and graphics system. He stated that geometric transfer is difficult because each system has a different representation. Another problem noted by Ortengren was that each system has different command structures, making it cumbersome for users to work with the integrated system. He concluded that these problems make it difficult for design engineers to change between product description in CAD system and production simulations and ergonomic evaluation software in graphics system.[5] Many other researchers such as Zied (1991) discussed the problems for integrating CAD and ergonomic systems.[7]

Recently there has been some progress toward integrated systems. For instance, Zegrahm Space Voyages in Seattle is sponsoring the development of the Space Cruiser with the Helix Design System, from MICROCDAM Inc. The dVISE software can help companies leverage existing CAD data by creating digital products mockups that serve, in turn, as virtual providing grounds for complex design.[8] In response to a need for ergonomic CAD system we have integrated two software in order to provide designers with a graphical tool to evaluate their design for human factors and safety.

According to OSHA, 2,730,000 workers compensation claims for computer-related repetitive strain injury (RIS) were paid in 1993. These claims cost $20 billion; OSHA says indirect costs may reach $100 billion. We believe, utilizing this technology will results in safer products, thus reducing the number of injuries and saving millions of dollars. Brief descriptions of this software are presented next.

## III. AutoCAD

AutoCAD has been widely utilized since its introduction to the design engineering community in the late 1960s. AutoCAD has undergone major changes from being simply an automated 2D drafting board to a sophisticated interactive system. AutoCAD like most CAD systems, started with a basic wireframe system, then added surfaces and next solids.

## IV. Mannequin

Mannequin is a revolutionary PC-based ergonomic drawing and design program that draws human likeness, and can be examined in the users guide.[9] The first version of the software was developed by HumanCAD Systems in 1991. HumanCAD Systems spent seven years incorporating feedback from many of the 10,000 users of the original software. In March 1997, they introduced ManneQuinPRO with major upgrade and enhancement over the original software. This innovative software contains an extensive library of ergonomic data for men, women, and children of different sizes, shapes and nationalities. User can choose specific body types based on gender, size, etc. and integrate them into an ergonomic equation, which can be graphically displayed in form of human likeness. Mannequin can walk, bend, see, reach and grasp objects. This software was, and sill is, the only Window-based application of its kind, with set of 2D/3D modeling and editing tools.

## V. Mannequin Integrated with CAD

Mannequin's real power is realized when it is integrated with CAD system. Mannequin was designed to be completely compatible with any CAD packages that can read or write DXF files. Our research showed that the problem of incompatibility between systems, as indicated by many researchers earlier, existed between these two as well. However, we were able to solve most of the problems, and effectively integrate these two. This integrated ergonomic CAD system will provide a powerful tool for the designer to test the functionality of the design for almost anything destined to be used by humans. For example, design students can use this software package in conjunction with a CAD package when designing a control panel for a piece of machinery. By including human likeness and mobility in the design process, the designer can avoid designing the panel in a location that may cause long-term injuries.

### Importing 2D files from CAD into Mannequin

The manual on Mannequin states that this software is compatible with the AutoCAD package. The manual suggests that all that is necessary to integrate an AutoCAD DXF file into Mannequin is to simply go to the pull down menu FILE, select the IMPORT option and click on the desired DXF file. However, several important steps, which were left out, are listed below:

1. Bring up the drawing in AutoCAD. Make sure the drawing units are in decimal form.
2. Use the command DXFOUT and save the file onto either a floppy disk or hard drive, then exit AutoCAD.
3. Copy the DXF file created in step 2 into the directory-containing Mannequin.
4. Change the default directory to the directory-containing Mannequin. Load the software by typing MA.
5. Select FILE under the pull down menu; click on the IMPORT option. Click on the DXF button. Check the directory of files, which now should display the AutoCAD file with the DXF extension.
6. If the AutoCAD drawing is in the directory of files, select it and click on OK.

The next screen will display the DXF files' units. Here, we encountered the problem of incompatibility between software. We imported several files created with five available units in AutoCAD. Mannequin had difficulty in transferring units in most cases. We recommend the

decimal units to be used in AutoCAD to create the drawing. If the intended dimensions are inch, feet, or millimeter in AutoCAD, then same units must be selected in Mannequin before the transfer.

VI. Incompatibility in Displaying views

After transferring the file to Mannequin there is a problem in displaying the drawing on the screen because the x and y axis in AutoCAD are not the same axis in Mannequin. The top view in Mannequin is the front view in AutoCAD. Most CAD systems use the top view as the default view, while Mannequin considers the front view as default. Obviously, the drawing cannot be seen after it is imported into Mannequin. This was a main problem in our integration effort, and a solution is presented below:

Solution: After trying to rotate the drawing in AutoCAD using rotation commands, the results were still unsatisfactory. However, using the ROTATE commands in Mannequin (make sure the user option is selected first, to view the drawing) produced better results. Select the rotation command and pick a point approximately in the center of object as the rotation center. Rotate the drawing around the x-axis for approximately $-90^{o}$. The drawing will now be displayed in the front view. Now a Mannequin may be inserted and manipulated in order to evaluate a design. A great deal of care must be applied when rotating the drawing in Mannequin. Several attempts may be required until the results are satisfactory. After importing the drawing, the dimension option can be used to see if the scale on the drawing is correct. Another problem after transfer is that often the transferred file is placed below where the floor of the stage is, and the REPOSITION command of Mannequin has to be used to move the drawing to the floor level. Now that the drawing is displayed correctly in front view and placed on the floor, a human figure can be inserted and used to evaluate the design for human factors and safety. An example of an integrated design is illustrated in Figure 1. Chair was created in AutoCAD and transferred and repositioned in Mannequin. Now the designer can use a number of "people" tools to see how humans fit his/her design. Will the seat be comfortable? Can people of different body type and gender use this chair with ease and safety?

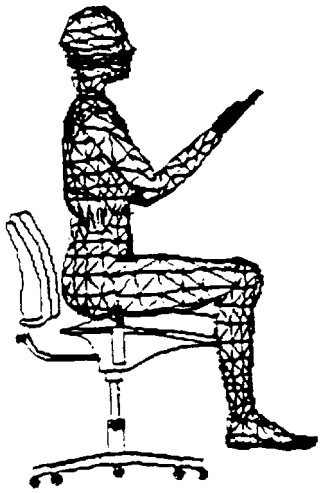

Figure 1. A 2-D Integration

VII. Importing 3-D files from CAD into Mannequin

Products, equipment, and machines can be more effectively evaluated if they are designed as true 3-D objects in CAD, and then transferred into Mannequin. Steps to transfer a 3-D file into Mannequin are listed below:

Step 1. Bring the drawing into the Mannequin, using the steps listed earlier.
Step 2. Again, because of incompatibility in displaying views, the transferred drawing is not displayed correctly. Click on right view to see the drawing and use the REPOSITION command to move the drawing to the floor.

In order to correctly position the 3-D drawing in Mannequin environment, we tried using ROTATE command as we did with 2-D drawing, but the results were unsatisfactory. However, through trial and error, we discovered other ways. Since in Mannequin, objects are positioned in a stage, it is easy to incorrectly insert a human figure into the drawing environment that looks right from some Viewports. For example, we created a 3-D drawing of a control panel in CAD and transferred it to Mannequin. In the right side view we inserted a human figure as shown in Figure 2. This figure gives a false Perception that the human is standing in front of the control panel, which in reality it is far from it. Some other Viewport options might give the same false impression.

The best view to see how the object and human figure are relatively positioned to each other is the top Viewport (looking at stage from above). So, after transferring the drawing from CAD, we recommend using the top Viewport to place a human figure in design environment (see Figure 3). However, because of view incompatibility, if you want to place a human figure in front of the object you have to use back body posture.

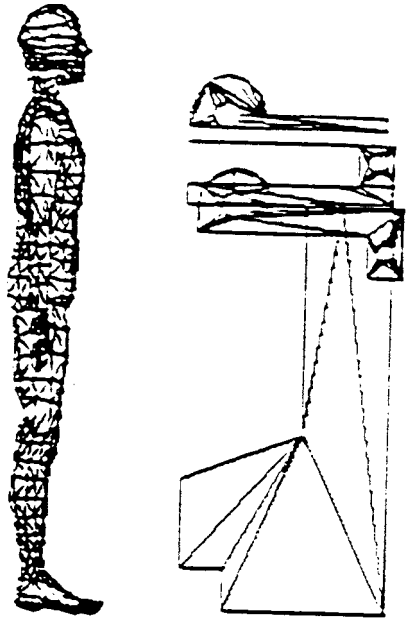

Figure 2. A false Perception

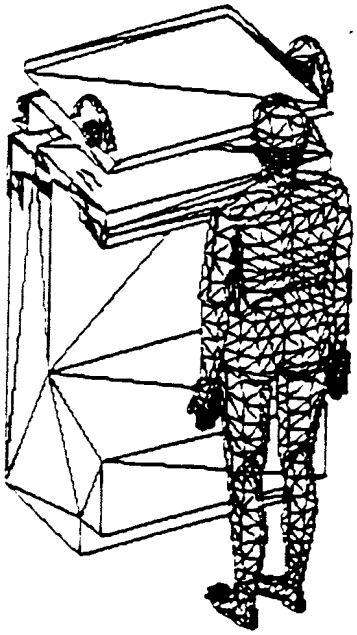

Figure 3. A correct Integration shows a human figure positioned correctly in front of the control panel.

VIII. An Ergonomic CAD System and its Applications

Manufacturers of many products, from simple hand held tools to more complex machines such as plant control panel and factory equipment, are faced with the challenging task of designing products that are cost effective, user friendly, and safe. Because of intense global market, these products must be released into the market within an acceptable time frame. A successful integration of Mannequin software and AutoCAD, or any other CAD packages can result in the creation of an ergonomic CAD system that can be used for many applications. Some applications are listed below:

1. Products can be evaluated for various human factors attributes such as comfort, adjustability, and ease of operation.
2. A full ergonomic analysis can be conducted on the design with any type or size person needed.
3. Designs can be analyzed for short-term and long-term safety issues.
4. Products can be evaluated for stress and strength required by their operators. Designers can identify the stressful parts of human interaction with the product or environment.

IX. Conclusions

In this paper, two software were successfully integrated to create an ergonomic CAD system, which is recommended by many researchers. Designers now have a graphical tool they can use to design products according to physical abilities and characteristics of their human operators. Even though Mannequin has a set of its own tools, they have limited capabilities. We recommend designs be created and edited in CAD, then transferred into Mannequin according to the guidelines listed earlier. Then a study of human interactions with the designed products/systems can be conducted.

This ergonomic CAD system played an important role in recent inventions, which have received national and international coverage.[10,11] We believe, in the design of products or systems that require subjects of different characteristics for testing, this ergonomic CAD system can be a valuable tool. It can substantially reduce the critical factor of time to market and lower the overall cost of designing new products by allowing designers to test their products for human fit without having to build a prototype or using real subjects. Utilizing this technology can result in reduced number of RIS injuries and save millions of dollars.

Bibliography

1. Quilter, D., 1997, What Price Hands? Computer Current Magazine
2. Rajai M., and Karwowski W., 1998, AHuman Factors and Its Role in Product Safety will be submitted to a refereed journal
3. Helander, M., and Nagamachi, 1992, "Design for Manufacturing", Taylor & Francis
4. Bernnan, L., and Fallon, E.F., 1990, The Contribution of CAD to the Enhancement of the Ergonomic's role in the design process, in Karwowski, W.et al. Computer-Aided Ergonomic. Taylor & Francis
5. Ortengren, R., 1992, Computer Graphics Simulation for Ergonomic Evaluation in Work Design, Taylor & Francis
6. Nastali, W.F., 1985, "Ergonomics: Dynamic Interactions of Operator and Machine", Manufacturing Engineering
7. Zeid, I., 1991, CAD/CAM Theory and Practice, McGraw-Hill, NY, p 3-13, 975-980
8. Deitz, D., 1998 Manikins Fly High, Mechanical Engineering
9. Mannequin User Guide, 1997
10. Felps, B. "College Students, Professor Develop Child Safety Devices," Wireless Week, May 3, 1999.
11. AP News Services, Engineering Students, Professor Develop Baby Monitor Device," April 23, 1999.

MARK RAJAI

Mark R. Rajai is an Associate Professor/Director of Manufacturing Engineering Program at East Tennessee State University. He has a Ph.D. in Industrial Engineering and a Master of Engineering in Engineering Management from University of Louisville. He also has a B.S. and M.S. degree in Mechanical Engineering with highest honors from the University of Tennessee. He has more than 13 years of experience in academic and industrial arena. He is the recipient of a number of awards and a member of several national honor societies. He is also member of several professional societies. He is author and co-author of several books and peer reviewed journal articles. He is particularly noted for his several inventions that have resulted in national/international media coverage. He is also the founder and currently, president of Safety Edge Corporation; a company that designs and manufactures safety products.

KEITH V. JOHNSON

Keith V. Johnson is currently an associate professor and assistant chairman at East Tennessee State University in Johnson City, TN. He received his B.S. and M.S. in Technology (Drafting and Graphic Arts) from North Carolina Agricultural and Technical State University in Greensboro, NC. He also completed his Ph.D. from The Ohio State University, in Columbus Ohio. In addition to research, service, and administration he has taught courses in architecture, and mechanical design, freshman orientation, and a host of desktop publishing and other design courses.

ROBERT MATTHEWS

Professor Matthews earned his graduate degree from the University of Louisville. He is an associate professor of Engineering Graphics at the University of Louisville Speed Scientific School. He is published nationally and internationally in the areas of curriculum development, CADD, and design/manufacturing learning concepts. He is an active member of ASEE and the Engineering Design Graphics Division. His current activities include the development of courses for training, curriculum design for CADD, and continuing education training in CADD for business and industry.