Electronic Documents: Saving Contractor's Time & Money

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Executive Summary

Electronic documents are become more widely distributed by designers and owners of construction projects. A factor behind the increased distribution of electronic documents is the cost savings to the designers/owners of these projects of document reproduction. While this may be a cost savings to the designers/owners, it increases the reproduction cost to the contractor for document reproduction.

An alternative to having the contractor reproduce the documents during the bidding stage of a project is to have the contractor estimate the project directly from the electronic documents. Takeoff Viewers are software packages that allow the estimator to perform their takeoffs directly from the electronic documents, saving the contractor the cost of reproducing the documents.

Interviews were conducted with estimators currently using electronic documents to perform their takeoffs. Most of the estimators currently using electronic documents were subcontractors. The estimators who had used the electronic documents preferred to use them over paper documents. When a couple of the estimators received paper documents they would pay to have the paper documents scanned allowing them to use the takeoff viewer software. The main benefits cited by these estimators were the following:

    The ability to have a complete set of documents.

    The ability to store the documents with their markups on the documents.

    Increased communication with project management.

Four takeoff viewers were examined to identify the features that are currently available. The features that most estimators require to perform their takeoffs are: count, line segment, continuous line, and area. These features provide the basis from which an estimator can quantify the project and then determine the project's cost. The various software packages offer different approaches to these features with various options in how to apply these features to the takeoff.

Monitor configurations of a 17", 20", a dual monitor system, and a projector were studied in the context of their effects on using takeoff viewers. While a single 17" monitor was acceptable, the larger the monitor the more comfortable the estimator was when performing the takeoff. A resolution setting on the monitor of 1600 x 1200 or above also aided the monitor in the takeoff process. A second monitor, while not required, made it more convenient for performing the takeoff because the takeoff viewer could be opened on one monitor while the estimating program was open on the other monitor.

The takeoff viewers were typically more accurate than digitizers. The takeoff viewer also allowed for the measurements to be altered whereas the digitizer input typically could not be stored.

One concern with using the electronic documents is the security of the documents. This came to the forefront on September 11, 2001 with the terrorist acts. While this is a valid concern, most of the projects built will most likely not be terrorist targets. This research was not focused on the

security concerns of electronic documents and needs to be studied further. However; through encryption and passwords most of these concerns could most likely be addressed.

When this software was shown to an estimator who had never been exposed to the takeoff viewers, he requested that the software be installed on six other estimators computers so they could also evaluate it. Within a matter of weeks, the company purchased a takeoff viewer.

The following is a list of benefits that come from using a takeoff viewer:

1. A better means of distributing the documents to subcontractors.

2. An alternate means of takeoff that operates similarly to a digitizer, yet more accurate and modifiable.

3. A means of archiving the plans for the projects that have been bid without requiring a warehouse for storage.

4. Easier archival of the plans for which the company has submitted estimates.

5. Improved coordination of estimating and project management.

Takeoff viewers are developed to a point that they can be used by estimators to perform takeoffs. With the advantages of using the takeoff viewers over the traditional methods using architectural/engineering scales and digitizers, takeoff viewers are ready for main stream use.

Acknowledgments

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Also, Thomas Mills at Virginia Tech provided additional insight which added depth and perspective to the report.

Kevin Miller PhD

Overview

This research project was performed for the Building Construction Industry Advisory Committee (BCIAC). The project analyzed the features available in various software packages that allow the estimator to perform a takeoff using electronic plans and specifications (electronic documents). Electronic documents for this project refers to computer image files that are identical to the paper construction documents with the only difference being that the documents are viewed on a computer screen.

One of the driving factors for this research is that electronic documents are becoming readily available. The Army Corps of Engineers distributes most of their documents electronically and F. W. Dodge, along with many other planrooms nationally, distributes many of their documents electronically. The Associated General Contractors (AGC) has also created alliances with companies that offer internet planrooms to better serve the members of their organization (Winston & Tuchman, 2001). This research project examined whether the use of electronic documents could truly be used by estimators to perform their takeoff from the electronic documents without having a paper set of the documents. To determine if electronic drawings were ready to be used by estimators the following was performed:

1. Estimators using electronic documents were interviewed.

2. Computer software and hardware was used to simulate the estimating environment with electronic documents.

3. Estimators who had never estimated with electronic documents were shown and then allowed to use electronic documents and then provided feedback about using electronic documents.

From previous research performed at Arizona State University (ASU) with electronic documents, it was found that using electronic documents made no significant differences in time or accuracy when compared to paper documents (Miller, 2001). The ASU study made several recommendations for software enhancements and listed many of the obstacles that prevented the participants of the study from receiving the benefits they felt they could have received from performing a takeoff using electronic documents. Since the ASU study, several software packages have become available that include many of the enhancements requested by the participants of the study. The number of electronic documents available since the study has also greatly increased.

This project studied the features available in the software packages that are currently available by interviewing estimators using the software packages, the researcher's own examination of the software, and by having an

estimator that has never used electronic documents provide feedback about the features of one of the software packages selected by the researcher.

A few definitions are presented to aid the reader throughout the remainder of the report.

Electronic Documents:	Computer image files that contain the same information as paper construction documents. The drawings, specifications, and other documents are included in the scope of the term electronic documents.
Markup:	Adding notes or calling attention to a particular area of a drawing. This is commonly performed on paper documents with colored markers or pencils. This may also refer to marking what has been taken off.
Takeoff:	The process of obtaining the dimensions and calculating the quantities from the plans and specifications (Chandler, Greene, Smit, & Willard, 1991).
Takeoff Viewer:	Software that is developed to aid the estimator in the takeoff process using electronic drawings. In addition to the viewing and marking up the documents the estimator can obtain counts, lineal foot, and square foot measurements that maintain a running total of these measurements.
Viewer:	Software that is developed to view electronic documents. The design intent of this software focuses solely on viewing and marking up the documents but typically not on measuring or quantifying the materials on a construction project.

The Takeoff Process

The fundamental core of estimating is the takeoff process. Without the information obtained from a takeoff, an estimate cannot be performed. This is true for all types of estimates. A conceptual estimate cannot be given without knowing a building type and an approximate building square footage. Similarly, a detailed metal stud estimate cannot be performed without knowing the lineal feet of a metal stud wall. While the level of detail varies, the need to know the information obtained in the takeoff process is still vital.

As the level of detail increases in documents, the estimator incorporates additional procedures and techniques to ensure that all the information that is available is taken into consideration for the estimate. These procedures and techniques include the following:

Checklists to ensure that items of work are not overlooked.

Colored pencils or markers to identify which items have been taken-off or require further evaluation.

Taking apart the documents so the plan view, elevation, and detailed sections can be hung on the wall to be readily viewed, allowing the estimator to visualize the items to be included in the takeoff.

These techniques and procedures assist the estimator in performing a complete and thorough takeoff to ensure that the estimate is complete.

Technology Assisting the Estimator

Since the 1980's, advances in computer technology have been assisting the estimator. Spreadsheets have assisted the estimator in calculating the quantities for items in the takeoff and then extending the pricing for the items faster than what an estimator could do manually. Christofferson reports that by using a spreadsheet, the amount of time required to generate an estimate could be reduced by approximately one-third when compared to manual methods (Christofferson, 2000). Digitizers have greatly decreased the amount of time required for the estimator to obtain the dimensions needed to perform a takeoff. Paul Elias of Morse Diesel International stated that, by using a digitizer, he was able to accomplish eight to ten hours of work in one-and-a-half hours (ENR, 1996).

One of the new technologies available to estimators is the use of electronic documents. The Corps of Engineers has endorsed electronic documents since the first pilot project saved the Corps $20,000 in reproduction costs (Peters, 1996). A concern of the Corps' approach was that while the Corps provided a viewer for the documents, the viewer did not operate in a manner that would allow the estimator to perform a takeoff from the documents without printing the documents to paper. Several companies in the private sector have realized this and have developed software that allow estimators to read the electronic documents and have the tools available to perform a quantity takeoff from the documents. Of the four takeoff viewers found, three of them are in version 1.x of the software with the fourth company at a 2.x version.

Viewers & Takeoff Viewers

Viewers are mainly used by designers to communicate with other designers for review and collaboration. This type of viewer typically allows for marking up, placing dimension lines, notes, and highlighting. The viewer serves the needs of the designers well, but estimators need additional tools to efficiently and effectively perform a takeoff. For instance, estimators do not need to place dimension lines; rather, they need to obtain running totals of measurements. The types of measurements that estimators typically need are counts, lineal feet, and areas. While the measurements are being performed, the estimator needs to mark the drawings to identify what has been measured. A takeoff

viewer meets the needs of the estimator. A takeoff viewer can obtain all the measurements while at the same time automatically mark what has been taken off.

CAD Integration

The research and development goal of integrating CAD with estimating is progressing. This integration is made by the designers drawing objects instead of lines that represent objects. Objects contain information regarding among other things, the dimensional information of the object. This dimensional information is then transferred to an estimate where the takeoffs are performed.

In special test cases, the integration of CAD with estimating has been successful (Staub, Fischer, & Spradlin, 1998). However, the standards for the CAD integration are still being developed by the International Alliance for Interoperability (IAI) (<u>International Alliance for Interoperability Home Page</u>, 1999) and the learning curve for both the designers and the constructors is still largely unknown. In the Associate General Contractors (AGC) estimating text Construction Estimating and Bidding, several concerns are mentioned concerning integrating CAD with estimating. These concerns are listed below:

Who is responsible for quantification errors?

What software will be universal enough for use?

How does the architect and /or engineer preserve its copyright when it distributes its total design in a form that can be easily modified and copied by others?
(Swenson, White, VanderBloemen, Carpenter, & Cecere, 1999)

Additionally, the AGC states that the technology may assist the estimator "but will always have many limitations" (Swenson et al., 1999). While the technology of CAD integration may in the future play a larger role in the takeoff process, the use of takeoff viewers studied in this project currently have several advantages. These advantages include the following:

The estimator obtains the measurements for the takeoff instead of relying on an automated process.

The file formats are widely accepted and read by multiple vendors' software.

The file formats are read-only.

The small learning curve.

The estimator can use same procedures and techniques that are currently used for estimating.

The cost of the technology is smaller than the CAD integration software.

The ability to create the electronic documents is readily available.

A large volume of construction project documents are currently available in electronic formats that can be read by multiple software vendors.

File Formats

The file format of the electronic drawings defines the attributes of the files given to the estimator. The main

differences in the attributes of the file formats are the image quality, file size, and color capabilities. The main file

formats used for electronic documents are as follows:

Continuous acquisitions and life-cycle support (CALS)

Tagged image file (TIF)

Drawing web format (DWF)

Drawing files (DWG)

The common file type supported by the takeoff viewer were TIFF and CALS. A couple of the packages stated that

they support the DXF and DWG file formats. When trying to open the DWG file format in the takeoff viewers, none

of the them would open an AutoCAD 2000i DWG. When the technical support departments were contacted, the

response was that they would read AutoCAD 14 files but that the 2000 version would be supported in the next

version of the software. Because none of the software packages read the DWG file format, the DWG file format is

only briefly covered in this research.

The file format of CALS, TIF, and DWF have attributes that are unique. These attributes are explained in the

following sections.

Image Quality

Image quality relates to the file format used and how the electronic drawings were created. The CALS and TIF file

formats are raster images and DWF format is a vector image. The raster file formats store the graphics at a

resolution of x number of dots per inch. If you zoom in on an area, the number of dots does not increase, rather, the

dots appear larger on the screen. Because of this, the raster format may lose image quality as the image is enlarged.

In contrast, the vector-based file format stores the end points of lines. When the vector-based image is enlarged, the

image is scaled and maintains its readability.

The two sources of creating electronic drawings are scanning paper documents and CAD programs. The image quality of scanned documents cannot be better than the quality of the source documents. If the source document quality is poor, the quality of the scanned images will also be poor. The typical scanned file formats are TIF and CALS raster images, which may lose readability as the drawings are enlarged. The TIF and CALS electronic drawings created from CAD provide a good quality source for creating the drawings but still have the limitations of each file format. The DWF electronic documents created from CAD require significantly less disk space while maintaining readability equal to or better than the TIFF and CALS formats.

File Size

Below is a list of file sizes that all originated from one DWG file in AutoCAD® 2000i. To the right of each file type are the settings that were used to create the file with the resulting file size in terms of bytes.

DWG (446,464 bytes)

DWF   B-size paper, 32 bit color (65,199 bytes)

CALS D-size paper, monochrome, 300 DPI (205,824 bytes)

TIF (Compressed) (6016 x 8412) monochrome, 100 DPI (231,472 bytes)

The DWF file format is approximately seven times smaller than the native DWG file format. The next smallest file size, CALS, is 3.16 times larger than the size of the DWF file. The TIF file format is 3.55 times larger than the DWF file. This becomes important when considering the storage space and the speed of connection to the internet when using these file types.

The DWF, CALS, and TIF formats are read-only (Autodesk, 1997). By read-only it is meant that the outputted file could possibly be modified by another product, but that the modifications would not be made to the original drawing file (DWG). This is important because the designers do not want their designs to be copied, then slightly modified, and reused by competing designers or either intentionally or unintentionally modified by the contractor. The CALS, TIF, and DWF formats are not readily imported into CAD programs, therefore, designers are more willing to allow these file types to be widely distributed (Miller & Christofferson, 2001).

Color

DWF and TIF file formats allow for color whereas the CALS file format does not. Volo™ View (a viewer by Autodesk) can toggle between displaying either a color or monochrome image when using DWF files. This allows the user to use the color that is native in the drawings to understand the drawing better and then switch to a monochrome view when adding markup to the drawings, allowing the markups to stand out from the document. While Volo View™ is a viewer and not a takeoff viewer, the ability to toggle between color and black and white is a feature worthy of note.

The TIF-formatted electronic documents used in planrooms are nearly always black and white. While not everyone will see color as an advantage, it has been the researcher's experience that the use of colors will help the estimator identify various items on the drawings more rapidly.

Layers

When the drawings are cluttered, an additional feature offered by the Volo View viewer using the DWF file format is layers. Layers gives the estimator the ability to turn on and off layers drawn by the designer in the drawing. By turning off some of the layers, estimators then can find the items that they are taking off. This feature is not an option for CALS or TIFF file formats.

File Format Summary

The CALS file format is the file format used by the Corps for the electronic drawings and the TIF file format is the most common file format used by planrooms. The Corps chose this format because it was a popular file format when they began distributing documents electronically (Peters, 1996). The planrooms use the TIF file format because the scanning software that is used to scan the large format paper documents readily creates the raster TIF files.

The DWF file format is not currently supported by any of the takeoff viewers, but is commonly supported among the viewer software and is starting to become available at construction project websites such as Division of Facilities Construction and Management (DFCM) for the State of Utah (http://www.dfcm.state.ut.us/project_center.htm) and Buzzsaw.com. Additionally, many of the major CAD packages are now able to create the DWF file format which

should increase the industry's use of the format. Some of the CAD packages that are able to create the DWF file format include the following:

AutoCAD® by Autodesk (Autodesk.com, 2001)

TurboCAD by IMSI® (TurboCAD.com, 2001)

DataCAD® by DataCad LLC (DataCAD Plus, 2001)

ArchiCAD by Graphicsoft (ArchiCAD.com, 2001)

The DWF file format contains many advantages over the TIF and CALS format and in the future may be the file format of choice.

Takeoff Viewers Evaluated

The takeoff viewers used for this project are the following:

Product & Version	Company	URL
On-Screen Takeoff 2.2	On Center Software.	www.oncenter.com
BidScreen XL 1.0	Vertigraph Inc.	www.vertigraph.com
FastBid 1.48	Builders Exchange of Washington, Inc.	www.bxwa.com
Takeoff Tool 1.1	US Cost Inc.	www.uscost.com

These products were found by searching the internet and trade magazines. Each company offers a downloadable trial program that is typically usable for 30 days. The On-Screen takeoff required an activation code from the company that would make all the features of the software available. This code was easily obtained from them. This code can either be permanent in the event that the software is purchased or can be a short term code (30 days or more) to allow for complete evaluation of the software.

The purpose of this study is not to recommend one software package over another, but rather to determine:

What features are available in takeoff viewer software.

Whether the feature sets are developed to a point that they could be used in the real world application of takeoff.

Which features are critical in the takeoff process.

Which features are available that may not be required to perform the estimating process but may improve the estimator's productivity.

What size of monitor is needed to comfortably use the takeoff viewer.

What qualities are required of a graphics card to comfortably use the takeoff viewer.

To find answers to the above objectives, interviews were conducted with estimators currently using these types of software. The people interviewed for this study were located by contacting the software companies that produce the takeoff viewers and the planrooms that provide electronic documents. A request from each company was made to provide a couple of users who might be willing to be interviewed for this project. A copy of the questions asked are in Appendix 1. During the course of the telephone interviews, some of the questions were not asked because they had already been answered in response to previous questions.

Results From Interviews

Sixteen different companies were contacted by telephone and thirteen companies responded. Nine of the companies used electronic documents. Of the nine companies, three used the electronic documents to preview the projects to help determine if they wanted to pursue bidding them, one company used the electronic documents to print out the documents, and five of the companies performed takeoffs from the electronic documents. Three of the five companies using the electronic documents for estimating were roofing and drywall subcontractors and the other two were independent estimating firms with multiple estimators.

The five firms performed from 3 to 13 estimates a week with an average of 5.26 estimates per week. All the firms indicated that they were estimating some projects entirely from electronic documents. These firms also indicated that they used electronic documents for 50% to 100% of the projects they estimated. One firm purchased a scanner allowing them to convert the paper documents to electronic documents for estimating. Two of the other firms paid an average price of $1.25 per sheet so they could use electronic drawings for estimating.

The sources of the electronic documents for these firms are the internet, scanning, and then CD's. The features that were found most beneficial to them when using the takeoff viewers were the following:

"The color code markups that are generated during [the takeoff are printed and given to project management] which greatly enhances the communication between estimating and project management, saving a tremendous amount of time."

"The ability to reaffirm what was taken off a month ago."

"The measuring tools for area, counts, lengths, and the markup of the drawings"

"The autoscaling and measuring tools."

"The overall ease of use of the software."

"The cost savings of the copying and obtaining the plans. Also, the ability to store the project and because there is no guessing on what was taken off."

"The savings of time and the accessibility of the documents."

The drawbacks of using the electronic drawings were the following:

"The screen size and all the panning that is required. The panning makes the takeoff longer, but the colored printouts save time with the project management coordination."

"The initial learning curve, but now it is faster."

"It is tiresome looking at the screen."

"The time to download the documents."

Since the typical file formats are CALS and TIFF which are black and white file formats for construction documents,

only one of the estimators could be found that had used electronic drawings in color. This estimator indicated that

color in the electronic documents would be an advantage over black and white documents.   Four of the five

companies indicated that the electronic drawings were easier to distribute and three of the five indicated that

electronic drawings reduced the amount of travel time to obtain the project documents. Three of the five companies

also indicated that the electronic documents provided quicker access to the documents.

The question, "Are there any issues of clarity in the readability of the electronic project documents?" had the most

varied responses. Two of the estimators responded that there were no readability issues with the electronic

documents, one estimator said only minor readability issue had been encountered, and two estimators said sometimes

there were readability issues. One of the estimators who said that sometimes readability was an issue also stated that

the scale shown on the electronic drawings was not always correct. Therefore, the estimator used the autoscale

feature of the software rather than use the stated scale on the electronic drawings.

All five estimators responded that they stored the electronic documents for future reference. Four of them stored the

marked-up electronic drawings and the other estimator stated that he printed out the marked-up drawings for storage.

Two of the estimators stated that addenda are easier to receive by electronic documents. Two of the estimators also stated that their plan deposit fees had decreased because of electronic documents.

Three of the estimators stated that the use of electronic documents had reduced their overall financial overhead for estimating, one said that it could, and the other estimator was unsure if it had.

Frustrations that estimators have had with electronic documents include the following:

"The scanner breaks down and so it delays converting the paper documents to electronic documents."

"Handwritten changes to the documents are not shown on the electronic drawings."

"Losing data on the zip disk."

"Flipping through the pages on the screen."

To overcome the above frustrations, the estimator that commented on losing data on the disk now works from his hard drive rather than on an zip disk. The researcher suggests that the other frustrations could be overcome by rescanning the sheets with the handwritten changes. To overcome the frustration of flipping through the pages on the screen, one of the firms use paper copies as well as the electronic copies. They hang the sections or elevations on the wall next to the estimator while the estimator takes off the lineal measures from the floor plan on the screen. The frustration of flipping through the pages may also be overcome by using a second monitor and displaying the details and section on the second monitor.

One comment made by an estimator is that while the electronic documents have made it easier and faster to obtain the project documents, he misses the personal contact with the people when he received the documents.

Improvements that the estimators would like to see in electronic documents include the ability to read DWG files directly, more integration between the takeoff viewers and the estimating software, more patterns and colors available for markup, and details and sections that contain hyperlinks from the plan view.

None of the companies used multiple monitors. Two of the companies used 21" monitors, two firms used 19" monitors, and the remaining company used a 17" monitor. The computers used by these companies range from a Pentium to Pentium III computer with a minimum of 64 Meg of RAM.

Features of the Takeoff Viewers

The essential features of the takeoff viewer include the measurement of counts, line segments, continuous lines, and areas. As each measurement was taken, markup was placed on the documents indicating where the measurement had been taken. The markup typically consisted of symbols and/or text. The changeable attributes of the markup typically consisted of changing the font, shape, color, and size.

The ability to store the markups on electronic documents is a common feature that estimators currently using electronic documents cited as a major advantage of the takeoff viewer. Most of the software packages evaluated allowed the markups to be stored.

The takeoff viewers displayed the electronic drawings on the screen and some of the programs offered additional windows to assist the estimator. The first additional window is called the pan window; it is also referred to as an overview window or a thumb nail window. In Figure 1 it is labeled in red as a pan window. The black area in the pan windows show what is currently being displayed in the main drawings window. This was helpful in assisting the researcher to know what area of the drawings was currently being displayed and its relation to the entire drawing.
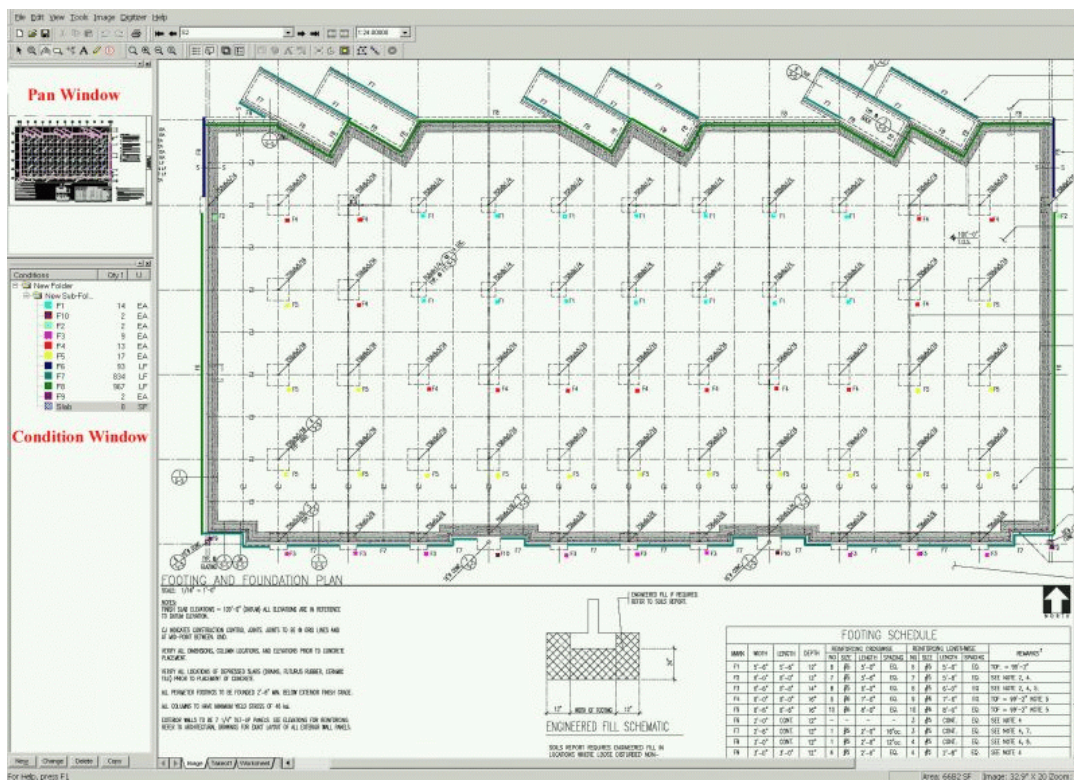

Figure 1 Screen of a Takeoff Viewer

Another window offered by one of the programs is the conditions window. This allows the estimator to keep a running total of the items measured by the estimator. These windows can be moved and turned on or off as desired by the estimator. Only one of the four programs reviewed in this research offered both windows.

Count

The first essential feature of takeoff viewer is the ability to mark items on the screen and have a count produced. The size, color, and the shape should be able to be modified by the estimator. By having this ability, the estimator will be able to perform multiple counts on the screen and clearly identify which items have been taken off.

With the count feature the estimator should also be able to move or delete an individual mark in the count. Some of the software packages did not allow this and this may require the count to be completely redone. All of the packages kept a running total of the count and one of the packages displayed the count number next to the count symbol. While this was not critical, it was a useful feature.

An example of what the count feature looks like on the screen is shown in Figure 2. If the reader is viewing this electronically, the outlets are color coded. The blue squares are typically outlets, the red squares indicate GFI outlets and the green squares indicate GFI weather protected outlets.
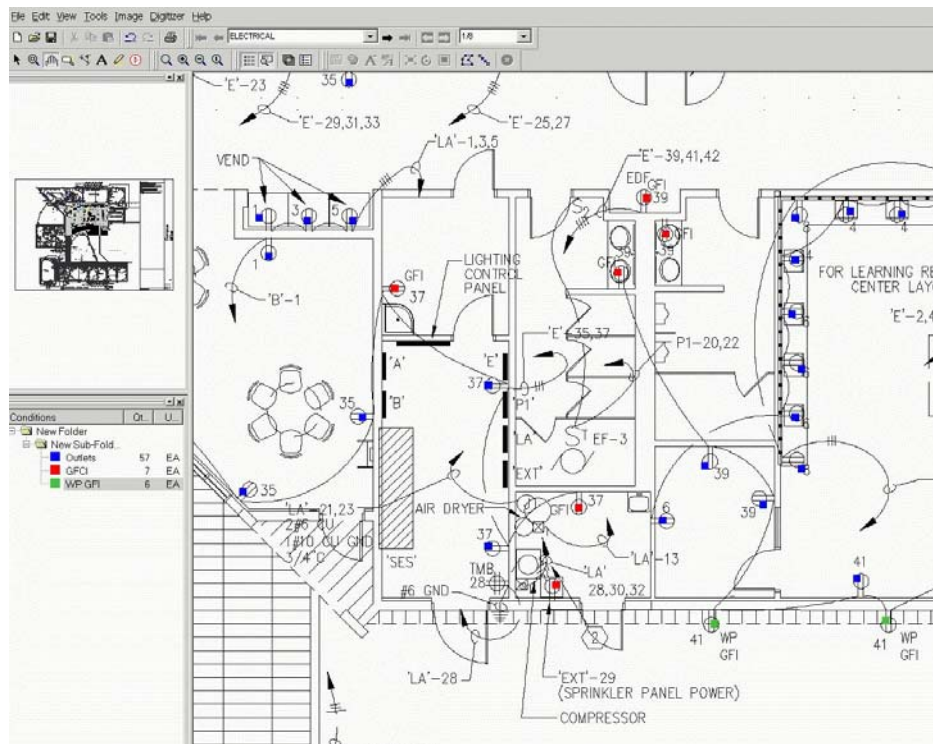

Figure 2 Electrical Outlet Counts

Line Segment

The ability to takeoff individual line segments was available in all the software packages. To measure a length, the mouse was used to click on the endpoints of the line. A colored line is then placed on the screen to indicate what has been taken off. A unique feature of one of the packages was that when you clicked the mouse a small window opened next to the pointer on the screen that zoomed in on the details of the drawing so that the endpoint of the line could be selected more precisely. This made selecting the endpoints much easier when viewing a large drawing.

The ability to change the color of the markup line was helpful when taking off several different lengths on the same screen and the ability to change the width of the line kept the markup line from being too dominating or too small on the screen. One of the packages displayed the length of each line next to or on the mark-up line. While this was not a critical feature it was helpful. A displayed running total of the line segments was also helpful.

The ability to change or delete a line segment is an important feature. This became obvious as sometimes a left click on the mouse was accidently performed instead of right clicking to see a pop up menu and a stray line was created. Sometimes the undo feature would allow the researcher to erase the line and other times the line had to be deleted. It is important that the delete feature allows the deletion of an individual line rather than all the lines that have been taken off, otherwise, all the lines will need to be remeasured.

Another feature that may be found useful is the ability to enter the width and height of the items being measured. This allows the estimator to know the lineal footage of what is being measured as well as the square footage and cubic footing of the item being measured. Estimators however, may elect to enter this directly into their estimating software rather than the takeoff viewer.

Continuous Line

The feature of taking off a continuous line was not a standard feature in all of the software programs. The continuous line feature allows the estimator to takeoff a line by clicking on just the corners of the continuous line rather than the start and ending of each segment of the line. Similarly to the line segment feature, the estimator should be able to change the color and the width of the mark-up line. It is also helpful when a running total is displayed on the screen.

The ability to change or delete a continuous line is very helpful to the estimator. When changing a continuous line, the ability to modify the location of either the endpoints or corner points is an advantage. An example of what the screen looked like with counts, line segments and continuous lines is shown in Figure 3.
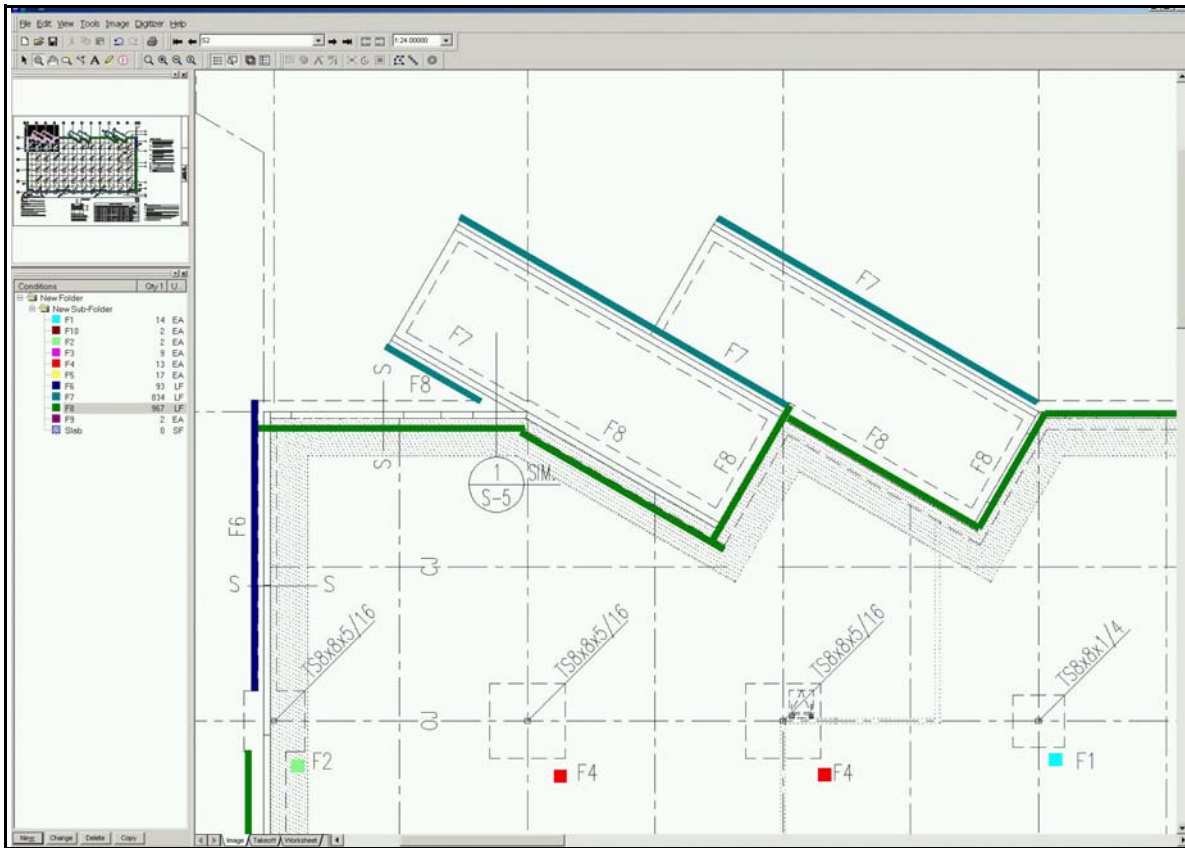

Figure 3 Lineal Feet of Continuous Footings and Counts of Spread Footings

Area

The area measurement feature was available in all of the software packages. The ability to mark the area that has been taken off is also shared by all the takeoff viewers reviewed. Different methods exist between the packages for marking the takeoff area. One method is to draw a colored line around the perimeter of the area. Another method is to fill the area with a color or colored pattern. This option was problematic because it covered the area entirely which prevent reading the document information under the area. The last method was to fill the area with a pattern which left the background transparent. This clearly identified the area and also kept the information contained in the document readable and not hidden. With all the methods of marking up the areas, the software should allow the user the ability to change the color and patterns of the mark-ups.

Another function to look for with area feature is the ability to takeoff a large area and then be able to subtract a small area from within the previously measured area. If the estimator commonly performs this type of measurement, this may be a key feature.

A feature that was unique to one program was the that the length of each of the legs of the perimeter was displayed. It also displayed the area on the area that was taken off. The text that was displayed could also have the font, color and size be modified so that it was readable and not dominating on the takeoff screen. Having a running total of multiple areas as well as the perimeter of the area was also beneficial. Another useful feature was that the area could be measured on the screen and the depth of the area could also be entered and the program would calculate the volume in units of either cubic feet or cubic yards. An example of what the screen looks like when an area is taken off is shown in Figure 4.
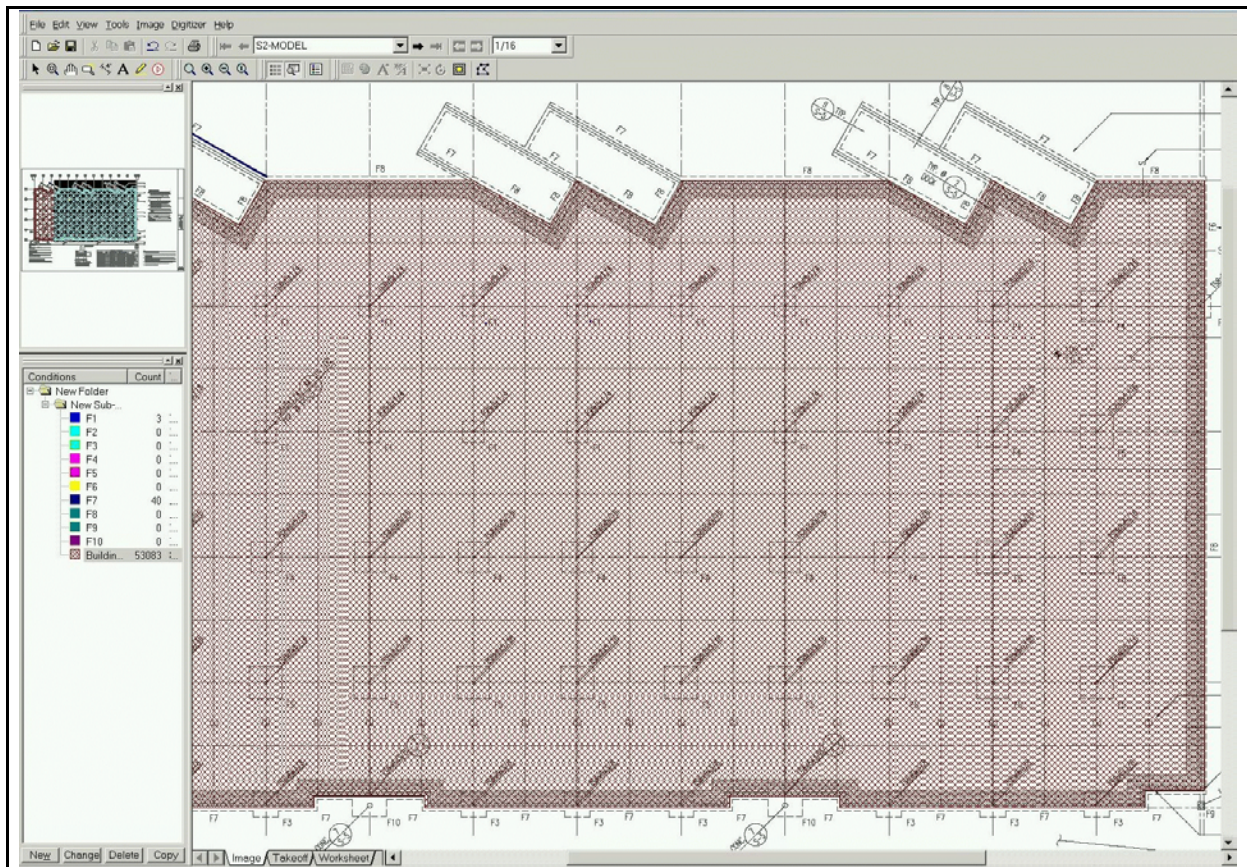
Figure 4 A Building Slab Area Takeoff

Setting the Scale

In addition to the standard scales, the takeoff tool needs the ability to scale a dimension line to determine the actual scale of the drawing. This feature becomes critical when the scale shown on the drawing does not match the scale of the electronic document. This was available in all the software packages. A unique feature that was discovered in one of the packages was that, in addition to the standard scales, the program allowed for additional scales to be defined and named by the user. This was helpful when working with drawings that were using a non-standard scale repetitively.

Advanced Features

The above features are essential. Without theses features, the takeoff process would be very frustrating to the estimator. The advanced features may not be essential features but they can increase the productivity of the estimator. To aid the reader, the advanced features are bolded in the section below

The ability to **place notes** on the electronic documents is an advanced feature. This would be comparable to an estimator writing notes on the documents. The ability to change the text's font, color, and size allows the estimator to emphasize various notes over other notes. Most of the software packages allowed for notes but not all of them allowed for the font's color and size to be modified.

The use of **layers** with the mark-ups helps prevent the drawings from becoming too cluttered with markups. For example, an estimator has taken off the footings on a project and now the markups from the footing takeoff are cluttering the drawings. The estimator would like to now takeoff the foundation but does not want to see all the markups from the footing takeoffs. If the software has the layer feature for the markups, the estimator can then turnoff markup for the footings and have clean screen for the foundation markups. If a question should arise about whether or not a particular footing has been taken off, the footing layer can be turned on again.

The ability to **rotate the drawings** is very close to a mission critical feature. The reason it is nearly an essential feature is that some designers plot the drawing files landscape and others plot the drawings files portrait. If you cannot rotate the drawings, the takeoff becomes challenging to read everything sideways or upside down. The takeoff tool should allow the drawings to be rotated so the documents can be read. However, if this feature is not available, the estimator can use a third party graphics application to rotate the documents, but this is an inconvenience.

The ability to **print the colored markups** on the electronic drawings to a printer was helpful to the estimators that were interviewed. One company stated that after the markup drawings had been printed they then transferred the color printouts to project management and it greatly helped the coordination between the estimating and project management departments. Another company stored the color printout for future reference.

The ability to **make a list of items** to takeoff and then takeoff each item was very helpful. For example, the researcher made a list of footings and then took off each footing. The list consisted of footings numbering F1 through F10. When the screen was zoomed so that only half the drawing was visible, all the footings could be measured. Then the drawing could be panned to the other half of the screen and the rest of the footings were taken off. Additionally, if it was found that a footing section had been missed, it could be added to the correct footing in the list. By doing this, the drawing could be completely color-coded and the measurements obtained prior to calculating quantities of materials. The process of obtaining all the measurements with the color markups on the drawings, followed by calculating the quantities of materials, may decrease the chances of items being overlooked in the takeoff process.

Once the dimensions have been taken off with the takeoff tool, some of the programs allow the dimensions to be automatically transferred to another estimating program. For example, one of the takeoff viewers allowed for the measurements to be automatically transferred to the correct variable in a third party estimating program. Another takeoff viewer allowed the measurements to be copied and then pasted to a third party estimating package. The copy and paste option was not noticeably more inconvenient than having the measurement directly transferred to other estimating packages. Other takeoff viewers integrate with only their in-house software packages and not with third party estimating packages.

As the researcher was learning the various software programs, one of the programs included mini **training videos** on the installation CD. This decreased the amount of time that was spent trying to learn the software and provided quick assistance in learning the how-to features of the software. Several of the companies provided getting started help over the phone which was helpful. The training videos, though, were not limited to work hours and provided immediate and succinct help.

Features Summary

Table 1 is a summary of the features in takeoff viewers. The table indicates an

recommendation of the importance of the

various features. The recommendations are

based upon the interviews with the estimators

currently using takeoff viewers and the

researcher's experience using the takeoff

viewers.

		HR	R	Not Required
Count	Change Symbol Color	X		
	Change Symbol Size	X		
	Change Text Size			X
	Change Text Color			X
	Running Total		X	
	Delete Selected Object	X		
	Displays Count on Markup			X
	Undo Feature			X
Line Segments	Change Line Color	X		
	Change Line Size	X		
	Change Text Size			X
	Change Text Color			X
	Segment Length Displayed			X
	Running Total Displayed		X	
	Display Individual Markup Line Lengths			X
	Modify Segment Length	X		
	Delete Individual Segment	X		
	Undo Feature	X		
Continuous Line	Change Line Color	X		
	Change Line Size	X		
	Change Text Size			X
	Change Text Color			X
	Running Total Displayed		X	
	Display Individual Markup Line Lengths			X
	Modify Length	X		
	Delete Individual Lines	X		
	Undo Feature	X		
Area	Change Area Color		X	
	Use Pattern	X		
	See Drawing Through Pattern	X		
	Change Text Size			X
	Change Text Color			X
	Running Total			X
	Displays Area Totals On Markup		X	
	Calculate Subtracted Areas	X		
	Undo Feature	X		
Miscellaneous Features	Ability to Adjust Markups/Measurements	X		
	Create Notes On Markup Page	X		
	Saves Markups	X		
	Uses Layering for Markups During Takeoff	X		
	Custom Scale	X		
	Zoom In When Picking Points		X	
	Rotate Drawings	X		
	Print Markups	X		
	Print to Scale	X		
	Overview Window	X		
	Markup Legend		X	
	Supports Multiple Monitors		X	
	Training Over the Phone		X	
	Training Video on Installation CD	X		
	Interfaces with Multiply Software Packages	X		
File Formats	TIF	X		
	CALS	X		
	DWF		X	
	DWG (2000i)	X		

HR = Highly Recommended

R = Recommended

Computer Hardware

The computer used by the researcher for this project was a Dell Precision 420 Workstation with the following specifications:

Pentium III, 850 Mhz Processor

256 Meg RAM

Matrox 450G video card with 32 Meg of RAM (Specification sheet in Appendix 2)

Viewsonic 21" (20" viewable) P225 Monitor (Specification sheet in Appendix 3)

Optiquest 17" (16" viewable) Q71 (Specification sheet in Appendix 3)

Proxima UltraLight LS1 Projector (Specification sheet in Appendix 3)

The takeoff viewers were first used at a resolution of 1600x1200 with a monitor refresh rate of 85 hz. When the monitor was set to a higher graphic resolution of 1920 x 1440 on the 21" monitor with a refresh rate of 75 hz, the readability remained the same but the viewable area on the screen increased by 20 percent. At both the 1600 x 1200 and the 1920 x 1440 resolution setting, the system font size was changed from small to large to make the text in the general windows environment readable.   When a second monitor was used, it operated at a resolution of 1024 x 768 with a refresh rate of 85 hz.

A projection system was also tested to determine if the larger project image would be a workable solution for an estimator. The highest resolution supported by the projector was 1024 x 768. The projected image was much larger than the monitor but the resolution support by the projector was significantly lower. Therefore, the readability of the plans was not as clear as the monitor. This required the researcher to zoom-in more on the drawings to make the text readable. As a result of being more zoomed-in, more panning was required on the drawings which was distracting to the takeoff process.

Display Device

Graphics Resolution

The higher the resolution of the display device, the greater the clarity of the image displayed. This helps the estimator to see more of the drawing on the screen and minimize the amount of panning on the document to read all the information on the display. When the estimator is required to pan, it interrupts the estimators train of thought

and as a result the estimator may feel lost on the drawing or feel like there is tunnel vision. To minimize or eliminate the feeling of being lost, the graphics card and monitor should display a of resolution 1600 x 1200 or greater with a refresh rate above 70 hz (preferably above 75hz). The higher refresh rates reduces the amount of eye strain which provides a better work environment for the estimator.

Dual Monitors

Dual monitors are by no means required to estimate using electronic documents. However, using dual monitors does provide a more productive work environment for the estimator. The productivity gains from using dual monitors stems from having the viewer software opened on the larger monitor and the application that is calculating the quantities based upon the measurements opened on the other monitor. This eliminates the need to toggle between applications on one screen, which makes the work flow smoother for the estimator and helps reduce distractions from performing the takeoff. A picture of using dual monitors is shown in Figure 6.
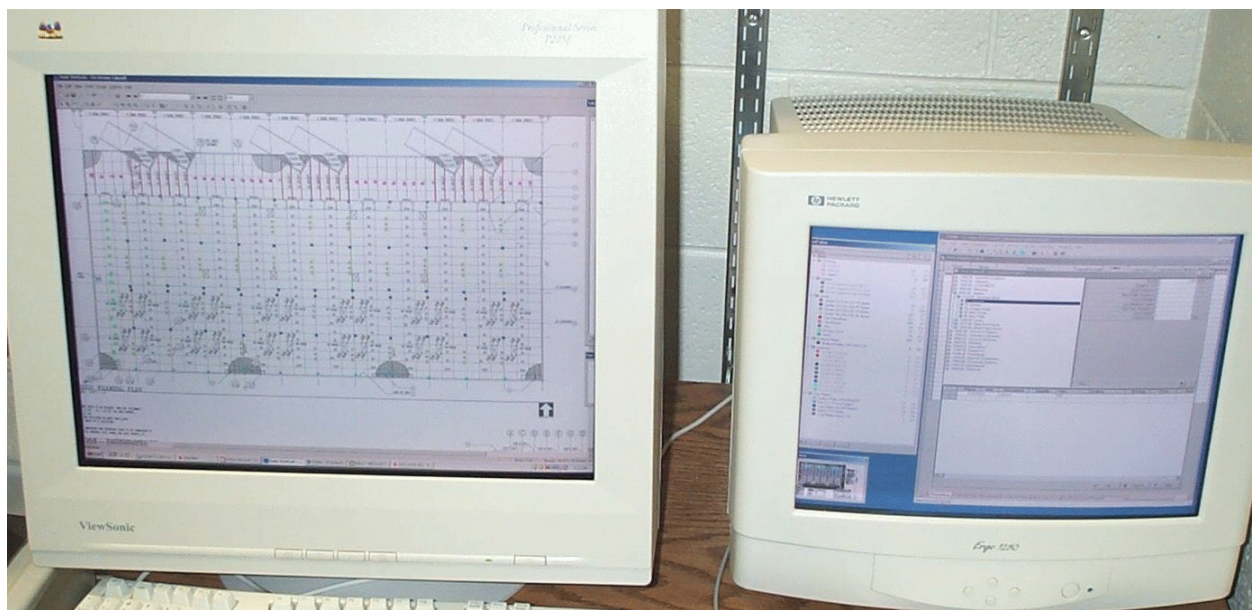

Figure 6   Picture of Dual Monitors during takeoff

Another use of dual monitors which is currently not supported by any of the takeoff viewers would be to have the plan view on the large main monitor, with a second window of the takeoff viewer opened on the second monitor that would show a different page with the elevation, section or detail being displayed. This would simulate taking the plans apart and hanging these sheets on the wall for reference as currently done using paper documents.

Measurements From the Takeoff Viewer

The files used for this research were generated from AutoCAD rather than scanned documents. This allowed the original drawings to be accurately measured in AutoCAD to produce the baseline from which to compare the findings of the research.

Dual monitors were used with the measurements taken on the 20" monitor and overview window (bird's eye view) and totals window were in place on the second monitor (the overview and totals windows are shown in Figure 4). This allowed the primary monitor to display more of the drawing which reduced the amount of panning required. To evaluate the accuracy of the takeoff tool, 2 projects were selected. The first project's actual SF was 13,441 SF (overall dimensions of 187' x 103') and the second project's SF was 52,947 SF (overall dimensions of 328' x 165'). The actual square footages were obtained from the area feature of AutoCAD.
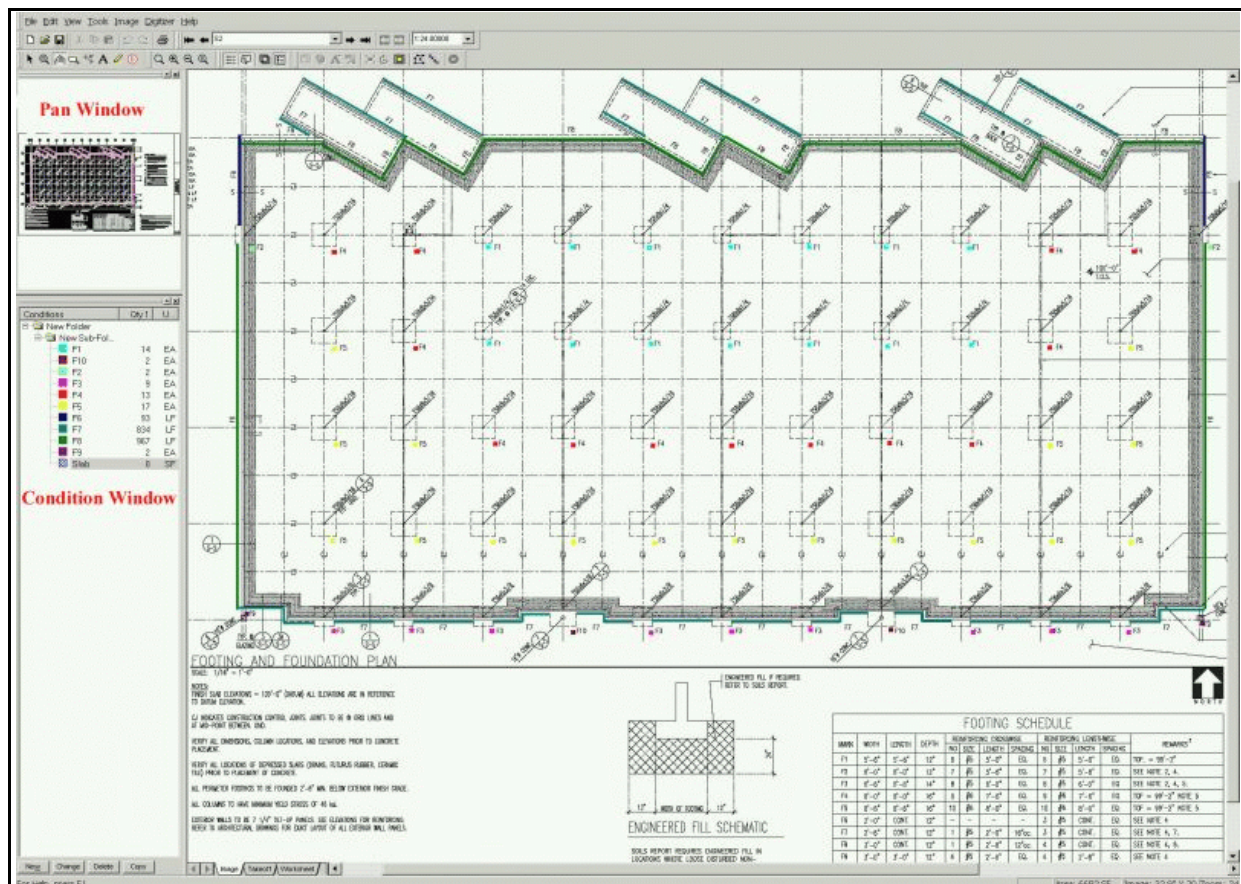

Figure 7

The areas obtained in AutoCAD used the SNAP features and the non essential layers were turned off to ensure that the object snap feature was snapping to the correct objects. The table below shows the areas obtained from two different zoom levels. The rows noted as Full had the entire floor plan shown on the screen with all the drawing layers turned on. At this zoom level, the notes and text on the plans were not readable except as noted on the table. At this zoom level panning around the drawings to obtain the measurements was not required.

The table below contains the results of the various combinations of hardware that was used for this research. The row labels zoomed were enlarged enough that the text and notes were readable but panning was required for the measurements obtained.

Monitor Type Viewable Screen (VS)	Dual Monitor	First Project	% Diff*	% Visible	Second Project	% Diff*	% Visible!
Baseline measurement (AutoCAD)		**13,441 SF**			**52,947 SF**		
20" VS 1600 x 1200 res Full	yes	13,447 SF	0.04%		52,980 SF	0.06%	
20" VS 1920 x 1440 res Full	yes	13,443 SF	0.01%		52,920 SF	0.05%	
20" VS 1920 x 1440 res Zoomed	yes	**	**	3/4	52,971 SF	0.05%	3/4
17" VS 1600 x 1200 res Full	no	13,500 SF	0.44%		52,955 SF	0.02%	
17" VS 1600 x 1200 res Zoomed	no	13,435 SF	0.04%	2/3	52,975 SF	0.05%	2/3
Projector 1,024 x 768	no	13,133 SF	0.10%		52,407 SF	1.02%	
Projector 1,024 x 768 Zoomed	no	13,456 SF	0.07%	1/4	52,939 SF	0.02%	1/6
Digitizer	no	13,551SF	0.82%		52,585 SF	0.68%	
Manual Calculation	D Size paper	13402.5 SF	0.29%		52,951 SF	0.01%	

* Percent difference from the actual measurements in AutoCad
** The image was clear enough that zooming was not needed to read the text on the drawings.
! % visible indicates the amount of the structure that was viewed on when zoomed in on the project.

In the majority of cases, the measurements obtained from the electronic drawings were more accurate than the measurements obtained from the digitizer. The only case for which this wasn't true was obtaining the overall area

using the projector. At the other extreme, when zoomed in on the drawings, the projector also yielded the most accurate results but required a lot more panning than any of the monitor configurations. An explanation for this is that the drawings had been enlarged so much in order to make the text readable that the accuracy increased for the measurement obtained. But being so zoomed in, it was easy to get the feeling of tunnel vision or being lost in the document.

The manual measurements of area were in the same range of accuracy as the other methods. The manual methods however, required more time and introduced more opportunities for error to occur. The manual calculation for project one required the structure to be broken up into 12 rectangles for the calculation to be performed. Before the 12 areas could be measured, the different areas had to be identified on the structure using colored pencils. To breakup the project into the 12 sections, perform all the measurements, and then perform Trade calculations required approximately 20 minutes, whereas using electronic documents or a digitizer required approximately 1 minute. Project two is more of a box type project so it was broken into 3 rectangles and 1 triangle. The rectangles followed the general shape of the building and were easily calculated. For project two the manual calculations required approximately 6 minutes. The electronic documents and digitizer required approximately a minute.

The areas reported above are the initial measurements taken. However, when the marked up areas were reviewed, modifications were made to the perimeter points of the area. The changes to the marked up area were automatically recalculated and the corrected measured area was displayed. When this was done, the area measurement became the baseline area measurement for all the measurements on the full view expect for the projector. On the projector, while viewing the full project, the adjusted area on the second project was 52,974 SF.

It is important to keep in mind that even though the areas could be adjusted to be the baseline measurement, at the full view, in most cases, the notes and section references were not readable. Therefore, the estimator should zoom in and read the notes and the section references to ensure an accurate takeoff.

Document Security

This study generally found the use of electronic documents a viable and possibly a preferred method for takeoff for construction estimates. A final consideration that should be given in light of the World Trade Center tragedy that

occurred on September 11, 2001 is for buildings that may be targets for terrorist activities. For buildings that may be a terrorist target the dissemination of the documents should be closely monitored to prevent the possibility of the documents falling into the wrong hands and assisting the terrorist. While this study did not focus on this aspect of using electronic documents, it should be an area of future study.

Estimator Feedback

An estimator for a general contractor was selected who had never used electronic documents prior to being contacted by the researcher. This contractor is listed by ENR as one of the top 150 contractors in 2001(2001 ENR Top 400 Contractors, 2001). The estimator was given an hour of demonstration and training at his office. After seeing the demonstration and using the software for a few minutes, he asked if the software could also be installed on other computers in the company. The software was installed on six other estimators' computers and one had an immediate use for the software because the designers had given them TIF images for the drawings and not hard copies. Prior to this estimator's use of the software he was plotting the documents from the TIF files onto full-sized sheets and then using a digitizer to obtain the measurements for the items he was taking off.

In addition to the project that one of the estimators already had, they were provided with four other projects that they could experiment with. These four projects included the following:

A satellite classroom building for a two-year college (10 architectural sheets, 7 structural sheet, 3 site sheets)

A two-story office building (39 architectural sheets, 20 structural sheets)

A tilt-up concrete warehouse (8 architectural sheets, 6 structural sheets, 2 site sheets)

A campus dining facility (19 architectural sheets, 8 structural sheets, 6 site sheets)

While these projects were provided to the estimator, they were mainly used to become familiar with the software rather than to perform a complete takeoff. The project drawings that they were given from the designers of a project they were estimating was used for their takeoffs.

The feedback that was received from the contractor was the following:

"The main advantages I see using the on screen takeoff vs. the digitizer method is:

1. Reduced cost of printing.

2. Ease of storing plan documents.

3. Ease of referencing historical estimates.

4. Accuracy increases because there is no question as to what has been seen and taken off.

5. Accuracy increases also because each take off point is more precise.

6. Take off's are clean and presentable to owners for Design Build Competitions etc. (possibility of gaining more credibility by an owner and thus increasing your chances of winning work)

7. Easier to do a take off without looking at two objects (digitizer/screen). You can focus on the plan and screen at the same time.

8. Ability to hatch, color, and layer different items in an estimate.

9. Easier to cut and paste quantities into estimate.

Disadvantages:

1. Currently not able to read DWG files.

2. Digital plans are not always accessible. You can scan them in but on a large set of plans it could take a lot of time. Sometimes you get changes on a sheet of paper that require a digitizer take off (kind of like a typewriter, you always need at least one around).

3. Viewing can be cumbersome, sometimes it is difficult when you cannot see the whole plan at a time. Some takeoffs require constant cross referencing of drawings. Digital lookup can be a lot slower than flipping through plan sheets." (B. Briggs, personal communication, October 10, 2001)

In a follow-up interview with the estimator that had an immediate need for the software, he stated that on 50% of the projects he works on electronic documents are available. When he was asked about whether or not using electronic drawings was more difficult when performing the initial review of the drawing than using paper drawings he responded that it was. He went on and further explained that the name of the electronic document does not match the drawing sheet name. For example, the sheet name could be something like 000005.tif and that corresponded to sheet A2.1. Therefore, the estimator is required to rename the sheets so the detailed references are easier to locate. Even with the disadvantages and short comings mentioned above, he was given a choice by his company that he could either buy the takeoff viewer or a digitizer for his new computer and he chose the takeoff viewer. In a discussion after he had made this choice, it was found that his monitor was set at a resolution of 1152 x 864 which made the drawings more difficult to read. The researcher suggested that he change the screen resolution to 1600 x

1200 and then he responded that this improved the readability and the comfort level of using the electronic documents.

When performing a structural steel takeoff, he felt that he saved a day and a half by using the takeoff viewer over using a digitizer because of the stored markups and the running totals of the measurements.

Subcontracting

Commercial general contractors are typically provided with two or three sets of plans from designers from which they prepare an estimate for a project in about three weeks. During this three week period, the estimator performs takeoffs for the work that they self-perform and receives bids from subcontractors for other scopes of work. The subcontracting portion of the work commonly ranges from 75% to 100% of the project. In order to receive the subcontractor bids, the general contractor invites, provides plans, and receives bids from the subcontractors. The dilemma with only two or three sets of plans is the difficulty for the general contractor to provide each subcontractor with a set of plans to review. As a result, subcontractors have the following options:

1. If subcontractor are fortunate, they are able to borrow a set of plans overnight.
2. The general contractor gives the subcontractor the pages out of the plans that the general contractor thinks the subcontractor will need overnight.
3. The subcontractors visit a plan room for a few hours and perform their takeoffs.
4. The subcontractor purchases a set of plans.

The options above are not an ideal situation for the estimating process. The above options have the following problems:

1. If the plans need to be referenced again by the subcontractor, the sub needs to arrange another time to review the drawings.
2. The subcontractor may need to see more of the drawings than that with which they are provided..
3. The subcontractors may wait several hours for their turn to work on the drawings.
4. The subcontractors incur costs for bidding a project they may not be awarded.

5. The subcontractors do not have a set of drawings that they can mark up, which may mean items may be overlooked or double covered in their takeoff.

With the problems listed above, subcontractors may benefit from the use of electronic documents. The benefits to the subcontractors of using electronic documents with a takeoff viewer are the following:

1. The subcontractor can have a full set of the document which they can keep.

2. The subcontractor can mark on the drawings to identify what has been taken off.

3. Time is not spent waiting to use a set of documents.

4. Money is not spent on copying the documents.

5. The documents can be readily reviewed.

While general contractors will benefit from the use of electronic drawings, subcontractors stand to gain the most from the use of takeoff viewers. The benefits listed above should increase the productivity and accuracy of subcontractor estimators.

Recommendations

Designers should offer construction documents in an electronic format to contractors. The creation of the electronic documents is no more complex than creating paper documents but would allow for greater distribution of construction documents which should lower the project costs from the increased competition among subcontractors. Designers would also realize a cost savings in document reproduction.

Contractors should encourage designers to provide electronic documents. Electronic documents offer the following benefits to contractors:

1. A better means of distributing the documents to subcontractors.

2. An alternate means of takeoff that operates similarly to a digitizer, but is more accurate and modifiable.

3. A means of archiving the plans for the projects that have been bid without requiring a warehouse for storage.

4. Easier archival of the plans for which the company has submitted estimates.

5. Improved coordination of estimating and project management.

If the contractor and/or sub contractors feel they cannot afford to purchase estimating software to perform their takeoffs, they can download free viewers which will allow them to view the documents and then print them to scale if they require hard copies. A list of the free downloadable viewers that are available are the following:

On-Screen Takeoff Viewer   http://www.oncenter.com/products/ostVwr/default.htm

F.W. Dodge Plan Viewer   http://www.fwdodge.com/dodgeplans.asp

Although other companies provide viewers, these are the only two that have been found that allow for the CALS or TIFF file format to be read and printed to scale after a short duration trial period. A list of companies that offer takeoff viewers in addition to viewer-only software packages is included in Appendix 4.

Summary

Four takeoff viewers were used for this research to determine if electronic documents are a viable alternative to paper documents in the takeoff process.   The takeoff viewers function similarly to digitizers with additional features that aid the estimator in the takeoff process. The estimators that are currently using electronic documents are willing to pay to have access to electronic documents so they can benefit from the features that are available in the takeoff viewers. Estimators who have not been exposed to takeoff viewers and are shown them, want to learn more about them and show them to the other estimators in the company. This research indicates that electronic documents are a viable means of takeoff for construction estimators.

Most current computer hardware should work with the takeoff viewers. It is recommended that the graphics card and monitor be set to a resolution of 1600 x 1200 or higher and that the monitor refresh rate be above 70 Hz at this resolution. Dual monitors are not required to use the takeoff viewers, but may increase the estimator's productivity and comfort level when using the electronic documents.

The electronic documents generated directly from CAD have a higher image quality than electronic documents that are scanned. It also makes more sense for designers to create electronic documents for the contractor rather than creating printed copies of the documents which are then scanned by the contractor. The use of electronic documents should reduce reproduction costs for the designers and increase the accessibility to the documents for contractors and subcontractors.

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Appendix 1

Interview Questions

Electronic Documents: Saving Contractor's Time and Money

Company Name: _____
Phone: _____

Contact Name: _____
Date of Survey: _____

Survey Questions
Company Background
Would you describe your firm as a general contractor or sub contractor?

Approximate dollar volume of work annually?

Number of estimates performed per week/ month?

What type of work does your company self perform?

How long have you been using electronic documents?

General Use Questions
Do you estimate any projects solely from electronic documents?

What is the percentage of takeoffs performed from electronic documents versus paper documents?

Would you like to see more or less projects offered using the electronic document format?

Why?

How do you receive the electronic drawings? (Internet, CD, Disk)

Software Questions
What brand and version of the electronic document viewer software do you use?

How long have you used the software?

What software features have been most valuable to you when estimating with electronic documents?

What advantages have you found by estimating with electronic documents?

What drawbacks have you found by estimating with electronic documents?

What file types do you receive from the designers?

Hardware Questions
Do you use multiple monitors for your takeoffs when using electronic documents?

What size of monitor(s) do you use?

What monitor configuration have you tried?

CPU Type and Speed

Amount of RAM

Electronic Document Questions
Are any of the electronic documents that you estimate from in color?

Do you feel that using color in the document would assist you in your takeoff?

Estimating Process Questions
Have electronic documents made it easier to either obtain or to distribute the documents?

Have electronic documents reduced your travel time to obtain the project documents?

Do you have quicker access to the project documents when using electronic documents?

Are there any issues with clarity in the readability of the electronic project documents?

Do you store the electronic document after the bid?

Do electronic documents make it easier on you as the estimator when you receive addendums?

How?

Have electronic documents reduced the number of times that plan deposit fees have been required?

Overall, have electronic documents reduced the financial overhead in the estimating process?

What obstacles or frustrations have you had with estimating from electronic documents?
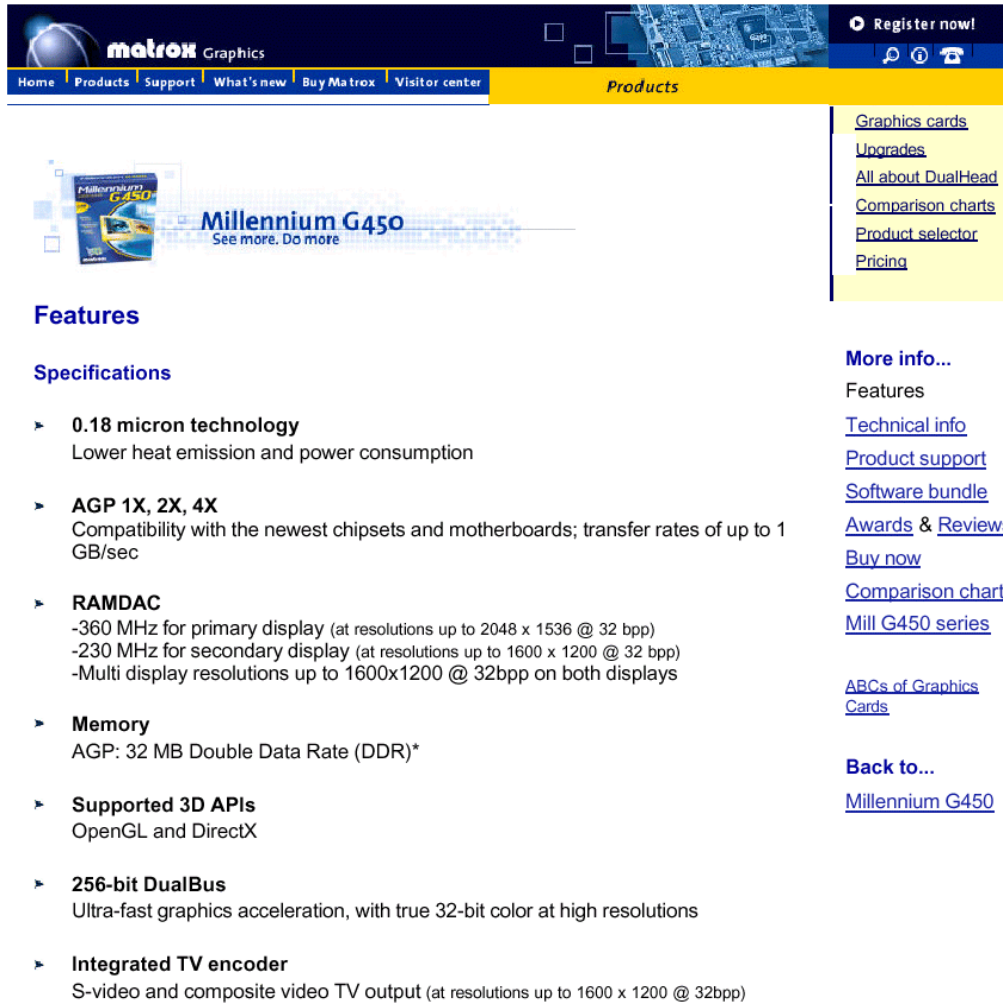
How have you overcome them or how could you overcome them?

What would improve the process of estimating from electronic documents?

Do you prefer to estimate from electronic documents or paper documents?

Email Address:

Appendix 2

matrox Graphics

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Register now!

Graphics cards
Upgrades
All about DualHead
Comparison charts
Product selector
Pricing

Millennium G450
See more. Do more.

Features

Specifications

- **0.18 micron technology**
  Lower heat emission and power consumption

- **AGP 1X, 2X, 4X**
  Compatibility with the newest chipsets and motherboards; transfer rates of up to 1 GB/sec

- **RAMDAC**
  -360 MHz for primary display (at resolutions up to 2048 x 1536 @ 32 bpp)
  -230 MHz for secondary display (at resolutions up to 1600 x 1200 @ 32 bpp)
  -Multi display resolutions up to 1600x1200 @ 32bpp on both displays

- **Memory**
  AGP: 32 MB Double Data Rate (DDR)*

- **Supported 3D APIs**
  OpenGL and DirectX

- **256-bit DualBus**
  Ultra-fast graphics acceleration, with true 32-bit color at high resolutions

- **Integrated TV encoder**
  S-video and composite video TV output (at resolutions up to 1600 x 1200 @ 32bpp)

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Features
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Comparison chart
Mill G450 series

ABCs of Graphics Cards

Back to...
Millennium G450

Features

➤ **DualHead® display technology****
Two independent displays powered by one chip, with a full range of configuration options (VGA, analog flat panel, and TV)
DualHead Demo

➤ **VCQ² rendering**
Eliminates artifacts and color banding in richly colored single- and multi-textured polygons

➤ **EMBM**
Integrated hardware support for DirectX Environment-Mapped Bump Mapping

➤ **UltraSharp DAC**
High-quality analog signal for crisp text and windows at the most demanding solutions

➤ **High-quality DVD playback**
Full-frame-rate DVD playback with superior image quality

➤ **3D rendering**
Full-featured 3D @ 2048 x 1536 in 32-bit color (16 million colors)

Color and refresh rates***

2D / 3D Colors	2D / 3D Resolutions
16 million	2048 x 1536

Resolution	Vertical (Hz)	Horizontal (kHz)
2048 x 1536	85	110
1920 x 1440	85	115
1800 x 1440	90	120
1600 x 1200	100	130
1280 x 1024	120	130
1152 x 864	140	130
1024 x 768	160	130
800 x 600	200	130
640 x 480	200	130

* All available retail boards use 32 MB DDR memory. Non-retail boards will have varying memory configurations. Click here for details.
** The level of DualHead® capability is determined by the operating system. Click here for details.
*** Primary display.

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Appendix 3

ViewSonic®

P225 Monitor

Professional Series

- **0.21mm Horizontal dot pitch**
  0.25mm Diagonal dot pitch
  This ultra fine dot pitch produces super clear, crisp images with great picture definition, even at the highest resolutions.

- **2,048 x 1,536 maximum resolution**
  Displays a maximum resolution of 2,048 x 1,536 at 79Hz flicker-free refresh rate for easy viewing.

  2,048 x 1,536 @ 79Hz
  1,920 x 1,440 @ 84Hz
  1,600 x 1,200 @ 99Hz
  1,280 x 1,024 @ 115Hz

- **SuperClear® screen**
  SuperClear screen technology incorporates enhanced phosphor treatment and optimized glass to deliver "vivid color" images clarity.

- **350MHz video input bandwidth**

- **E-Color's True Internet Color®**
  and Colorific®
  Color management software included for reliable colors when users visit E-Color Corrected™ web sites. Colorific ensures precise color matching from screen to other color peripherals.

- **Universal Serial Bus**
  This monitor has four powered accessory ports which allow the use of USB compliant peripherals without having to open your PC or worry about add-in cards or switch settings. And you don't even have to turn your system off.[1]

21" (20.0" viewable) Monitor

The ViewSonic P225 has the front screen performance that you've been dreaming of. This big and beautiful 21" (20.0" viewable) screen comes with razor sharp resolution of 2,048 x 1,536, the highest in the industry, 350MHz and a SuperClear® screen to give you sharp focus and crisp images. Designed with Shadow mask technology, the P225 does not have the damper wires often visible on aperture grille models, making this display perfect for high end CAD and Graphic design. Other features include a built in USB hub for easy connections with other USB compatible peripherals. and easy to use OnView® controls. The P225, it's the feature rich big screen that dreams are made of.

ViewSonic on top

ViewSonic.com

ViewSonic®

P225 Monitor

21" (20.0" VIEWABLE) ULTRA-HIGH RESOLUTION COLOR MONITOR

CRT	**Type**	21" (20.0" diagonal viewable area) 90° deflection
	Dot Pitch	0.21mm Horizontal, 0.13mm Vertical, 0.25mm Diagonal
	Phosphor	RGB medium-short persistence
	Glass Surface	Tint (TM=42.0%) Advanced ARAG screen treatment
INPUT SIGNAL	**Video**	RGB analog (0.7V/1.0Vp-p, 75 ohms)
	Sync	H/V Separate (TTL), composite, sync-on-green
	Frequency	F_h:30-127kHz, F_v:50-180Hz
COMPATIBILITY	**PC**	PC compatible from VGA up to 2048 x 1536
	Mac®*	Power Mac™ (from 640 x 480 up to 1,920 x 1,440)
CONNECTOR	**Signal**	BNC (x5) and 15-pin mini D-sub
	Power	3-pin plug (CEE22)
POWER	**Voltage**	AC 90–132V/198-264VAC (Auto switch)
	Consumption	148W (typ)
USER CONTROLS	**Basic**	Power ON/OFF, 1, down, up, 2
	OnView®	Contrast, brightness, H/V-position, H/V-size, V-pincushion, pin-balance, top hooking, bottom hooking, hourglass (S1), hourglass balance (S2), parallelogram, Trapezoid, H/V convergence, rotation, moiré, degauss, ViewMatch®, color temperature, ViewMeter® linearity-center, linearity edge, input select, zoom, OSD-language, OSD-position, recall
VIDEO INPUT	**Bandwidth**	350MHz (typ)
USB	**Up/DownStream**	1 connection, 4 connections
MISCONVERGENCE		0.3mm (max at center)
		0.4mm (max at corner)
DISPLAY AREA	**Factory Setting**	396mm (H) x 297mm (V) (Dependent upon
	Maximum Scan	406mm (H) x 304mm (V) signal timing used)
OPERATING CONDITION	**Temperature**	32°F to 95°F (0°C to 35°C)
	Humidity	5% to 90%
DIMENSIONS	**Physical**	498mm (W) x 502mm (H) x 486mm (D) (19.6" x 19.8" x 19.1")
WEIGHT	**Net**	27.3Kg (60.6 lbs.)
OTHER		DDC1 & DDC2B, GTF
REGULATIONS		UL, CSA, DHHS, MRP-II, FCC-B, DOC-B, TUV/GS, PTB, TCO'99, CE, CB, PCT, NOM, ENERGY STAR®, E2000,
POWER MANAGEMENT		Meets Energy Star®, VESA® DPMS*, TCO '99 and Energy 2000 standards
WARRANTY		Three year limited warranty on CRT, parts and labor 48 hour Express Exchange® service option available

• **Advanced ARAG® screen treatment**

This specially formulated anti-reflection, anti-glare screen treatment uses a multi-layer process to refract unwanted light away from the user while maintaining the highest quality of the displayed image.

• **OnView® controls including ViewMatch®**

All screen adjustments are made via an on-screen menu using simple controls. ViewMatch allows the user to adjust color temperature and individual color intensity for screen-to-print matching.

• **TCO '99 and Energy 2000 certified**

This monitor complies with the world's strictest standards of low radiation, safety, ergonomics, recycling and power management while saving costs through automatic power saving modes.

• *Plug & Play+*

• **PC and Mac® Compatible**

• **Three year warranty**

24/7 free technical and customer support.

ViewSonic on top™

ViewSonic.com

381 Brea Canyon Road, Walnut, CA 91789
Phone (800) 888-8583 • (909) 869-7976
Fax (909) 468-1202

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Optiquest

Q71 Monitor

Quality Choice Monitor.

Superior quality is what you can expect with the Optiquest Q71 monitor. This 17" (16.0" viewable) display rewards its users with advanced design to significantly improve image clarity. Featuring a fine 0.23mm horizontal (0.27mm diagonal) dot pitch and high resolutions with fast refresh rates to produce brilliant colors and vivid images. With all these benefits you still get an incredible Optiquest price! In short, the Q71 is the perfect choice for those who demand excellent quality in a 17" (variable viewable) CRT monitor.

Backed by a three year limited warranty, the Q71 delivers all the quality, performance and value you've come to expect from Optiquest.

- **0.23mm Horizontal dot pitch**
  0.27mm Diagonal dot pitch

- **OnView™ controls including ViewMatch™**

- **Plug & Play+**

- **MPR-II and Energy Star® certified**

- **PC and Mac™ compatible**

Powered by **ViewSonic®**

Optiquest
OPTIMIZE YOUR IMAGE™

Optiquest®

Q71 Monitor

17" (16.0" viewable) COLOR MONITOR WITH *Plug & Play+*

CRT	**Type**	17" (16.0" diagonal viewable area) 90° deflection
	Dot Pitch	0.23mm Horiz., 0.13mm Vert., 0.27mm Diagonal
	Phosphor	RGB medium/short persistance
	Glass Surface	Tint (TM=46%), Anti-static, anti-glare coating
INPUT SIGNAL	**Video**	RGB Analog (0.7/1.0Vp-p, 75 ohms)
	Sync	H/V separate
	Frequency	F_h:30-70kHz, F_v:50-120Hz
COMPATIBILITY	**PC**	IBM® and compatibles (VGA to 1,280 x 1,024)
	Mac®*	Power Mac™ (up to 1024 x 768)
CONNECTOR	**Signal**	15-pin mini D-sub (attached cable)
	Power	3-pin plug (IEC320)
POWER	**Voltage**	AC 100–240VAC (auto switch)50/60 (+/-2)Hz
	Consumption	85W (typ)
USER CONTROLS	**Basic**	Power on/off, 1, up, down, 2
	OnView®	Contrast, brightness, H/V-position, H/V-size, pincushion, trapezoid, pin balance, parallel, rotation, degauss, ViewMatch color, language, ViewMeter®, recall
VIDEO INPUT	**Bandwidth**	110MHz (typ)
MISCONVERGENCE		0.25mm (max) at center 0.35mm (max) at corner
DISPLAY AREA	**Factory Setting**	310mm (H) x 230mm (V)　(Dependent upon
	Maximum Scan	320mm (H) x 240mm (V)　 signal timing used)
OPERATING CONDITION	**Temperature**	41°F to 104°F (5°C to 40°C)
	Humidity	0% to 95% (non-condensing)
DIMENSIONS	**Physical**	405mm (W) x 421mm (H) x 418.5mm (D) (15.9" x 16.6" x 16.5")
WEIGHT	**Net**	16.5Kg (36.3 lbs.)
OTHER		DDC1, DDC2B
REGULATIONS		cUL, UL, DHHS, FCC, NOM, CE, MPR-II, ENERGY STAR®, DOC, CB, ISO9241-3, Energy 2000
POWER MANAGEMENT		Meets ENERGY STAR®, VESA® DPMS™ and MPR-II standards, Energy 2000
WARRANTY		Three year limited warranty on CRT, parts and labor. 48 hour Express Exchange® service option available

Powered by **ViewSonic®**

Features & Benefits

1,280 x 1,024 maximum resolution
Displays a maximum resolution of 1,280 x 1,024; 1,024 x 768 at 87Hz flicker-free refresh rate for easy viewing.

　　1,280 x 1,024 @　66Hz
　　1,024 x　768 @　87Hz
　　　800 x　600 @ 110Hz

OnView® controls including ViewMatch®
All screen adjustments are made via an on-screen menu using simple controls. ViewMatch allows the user to adjust color temperature and individual color intensity for screen-to-print matching.

Anti-static, anti-glare screen
This anti-static, anti-glare coating refracts light away from the user while maintaining the highest quality of the displayed area.

Optiquest®
OPTIMIZE YOUR IMAGE™

381 Brea Canyon Road, Walnut, CA 91789
(800) 888-8583 • (909) 869-7976
Fax (909) 468-1202 • Internet: www.ViewSonic.com
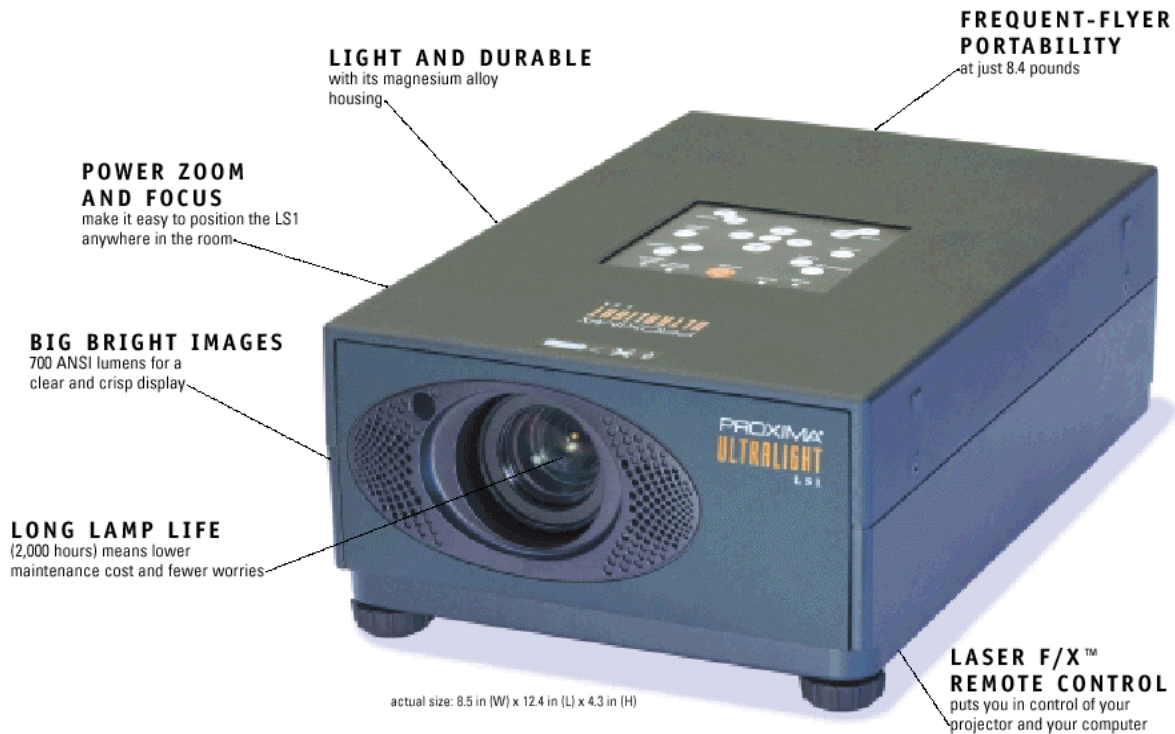
ISO 9001　　ISO 14001
TM 40167　　EMS 40093

ViewSonic Corporation's QMS\EMS has been registered to ISO 9001 & ISO 14001 by the British Standards Institution.

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UltraLight™ LS1
powered to go places

LIGHT AND DURABLE
with its magnesium alloy housing

FREQUENT-FLYER PORTABILITY
at just 8.4 pounds

POWER ZOOM AND FOCUS
make it easy to position the LS1 anywhere in the room

BIG BRIGHT IMAGES
700 ANSI lumens for a clear and crisp display

LONG LAMP LIFE
(2,000 hours) means lower maintenance cost and fewer worries

actual size: 8.5 in (W) x 12.4 in (L) x 4.3 in (H)

LASER F/X™ REMOTE CONTROL
puts you in control of your projector and your computer

ULTRALIGHT LS1

To have the winning edge in your next presentation, look to the Proxima UltraLight LS1 multimedia projector. Selected by *PC World* editors as the Best Projection System of '99, the LS1 offers big-projector features in a small, affordable package. You can count on the image quality, set-up flexibility, and durability of the award-winning UltraLight LS1 to ensure an unbeatable presentation wherever you go.

- exceptional image quality with 700 ANSI lumens of brightness, for lights-on presentations in any room
- broad range of compatibility with PC desktops, portables, Apple Macs and PowerBooks
- supports full-screen images from any notebook with VGA (640 x 480), SVGA (800 x 600) or XGA (1024 x 768) resolution
- magnesium alloy enclosure is both lightweight and extra durable, so it stands up to the rigors of the road
- 1.6:1 power zoom lens allows you to set up the LS1 anywhere in the room and adjust the image size accordingly
- Proxima's Laser F/X™ remote control with built-in laser pointer and mouse control puts you in command of the projector and your computer
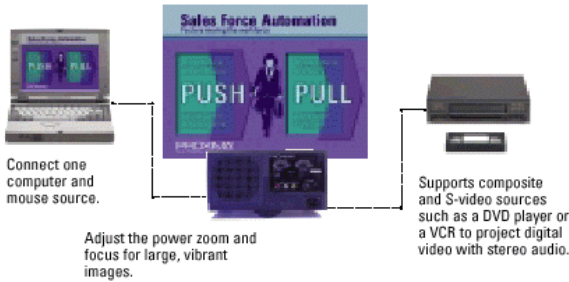
PROXIMA®
MULTIMEDIA PROJECTORS

PC WORLD
WORLD CLASS
Best Projection System.

UltraLight LS1

UltraLight LS1 Set Up.

Position the UltraLight LS1 anywhere in the room.

Connect one computer and mouse source.

Adjust the power zoom and focus for large, vibrant images.

Supports composite and S-video sources such as a DVD player or a VCR to project digital video with stereo audio.

LS1 Projection Distances/Image Sizes

Projection Distance		Image Size (Diagonal)			
		Minimum		Maximum	
4.3′	1.3 m	1.7′	0.5 m	2.9′	0.9 m
8.2′	2.5 m	3.5′	1.1 m	5.4′	1.7 m
16.4′	5 m	6.8′	2.1 m	11.0′	3.3 m
24.6′	7.5 m	10.2′	3.1 m	16.4′	5.0 m
32.8′	10 m	13.7′	4.2 m	21.9′	6.7 m
39.3′	12 m	16.4′	5.0 m	26.3′	8.0 m

PROXIMA®
MULTIMEDIA PROJECTORS

WHAT'S INCLUDED

Model LS1 includes:
- Laser F/X remote control with laser pointer
- U.S. and international power cords
- Product documentation
- Computer VGA cable, computer mini-plug to mini-plug audio cable, Mac adapter, PC and Mac control cables, AV cable, S-video cable
- Soft carrying case for projector and portable PC
- Lens cap

ORDERING INFORMATION

Model Number

LS1	For worldwide use

Optional Accessories

CASE-001	Carry-on rolling soft case
CASE-032	Carry-on rolling hard case (checkable/shippable)
CASE-033	Carry-on deluxe rolling hard case (checkable/shippable)
A650	50″ portable tabletop screen
L26	120-watt UHP lamp

TECHNICAL SPECIFICATIONS

Display Technology	= 0.9″ polysilicon TFT LCD x 3
Resolution	= SVGA (800 x 600)
Resolution Supported	= VGA (640 x 480) = SVGA (800 x 600) = XGA (1024 x 768, with Fit-to-View® intelligent digital scaling)
Number of Colors	= 16.7 million colors
Brightness	= 700 ANSI lumens (peak)
Contrast Ratio	= 100:1 ANSI; 200:1 full-on, full-off
Computer Compatibility	= IBM PC, PS/2, Pentium and compatibles = Apple Macintosh, Power Mac, PowerBook
Video Compatibility	= NTSC, NTSC 4.43, PAL, SECAM
Input Sources	= 1 computer, 1 video, 1 S-video, 1 audio (stereo)
H-Sync Range	= 15-80 kHz
V-Sync Range	= 50-100 Hz
Dot Clock	= 130 MHz
Horizontal Resolution	= 750 TV lines
Aspect Ratio	= Std: 4:3 - Wide: 16:9
Image Size (Diagonal)	= 1.7 ft. to 26.3 ft. (0.5 m to 8.0 m)
Projection Lens	= Motorized zoom lens 1.6:1 ratio = Focal length: 36 mm to 57.6 mm, f/2.3-3.0
Projection Distance	= 4.3 ft. to 39.3 ft. (1.3 m to 12 m)
Keystone Correction	= 11°
Projection Method	= front/rear, desktop/ceiling
Lamp (Life)	= 120 watt UHP (2,000 hours)
Audio	= 1 watt mono
Remote Control	= Proxima Laser F/X remote with mouse control and laser pointer
Dimensions	= 8.5 in. W x 12.4 in. L x 4.3 in. H 21.5 cm W x 31.5 cm L x 10.9 cm H
Weight	= 8.4 lb. (3.8 kg)
Power Consumption	= 190 watts
Power Requirements	= 110V-240V at 50 Hz/60 Hz auto change
Operating Temperature (Sea Level)	= 41-95° F (5-35° C)
On-Screen Menu Languages	= English, Japanese, German, French, Italian, Spanish
Audible Noise	= <47db
Approvals	= FCC Class A (U.S.); UL, C-UL (Canada); CE (Europe)
Warranty	= Two years on parts and labor (excluding lamp)

Appendix 4

Internet Website List

Takeoff Viewer Software Companies

Product & Version	Company	URL
On-Screen Takeoff 2.2	On Center Software.	www.oncenter.com
BidScreen XL 1.0	Vertigraph Inc.	www.vertigraph.com
FastBid 1.48	Builders Exchange of Washington, Inc.	www.bxwa.com
Takeoff Tool 1.1	US Cost Inc.	www.uscost.com

Other Viewers but Not evaluated in study

Max View	MaxView Corp.	http://www.maxview.com/

Electronic Planrooms

Company	URL
F.W. Dodge	www.fwdodge.com
Central Florida Builders Exchange	www.cfbe.net
Florida East Coast Builders Exchange Cocoa, Florida	www.fecbx.com
Builder's Exchange of Washington	www.bxwa.com
Division of Facilities Construction and Management (DFCM) State of Utah	www.dfcm.state.ut.us

CAD Software

Company	URL
AutoCAD	www.autodesk.com
DataCAD	www.datacad.com
TurboCAD	www.turbocad.com
ArchiCAD	www.graphisoft.com

Project Hosting Sites

Company	URL
Buzzsaw	www.buzzsaw.com

Computer Hardware Sites

Company	URL
Viewsonic	www.viewsonic.com
Matrox	www.matrox.com
Proxima	www.proxima.com