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Small & Medium Enterprises-Their Views of Product Data Management Tools

By Karen Waldenmeyer and Nathan Hartman

ABSTRACT

This study was conducted as a means to discover common traits associated with small and medium manufacturers, especially ones who have adopted product data management (PDM) systems as a method to control engineering design and manufacturing data. After qualitative interviews were conducted with leading experts across industry sectors, a survey was developed and sent to small and medium manufacturers in the United States. The study concludes a number of interesting findings about the state of PDM usage within various segments of the industry, including general uses for engineering design systems, level of data exchange with customers and suppliers, and satisfaction levels with information querying, concurrent engineering contributions, and imposed restrictions. The study concludes that there are a few major factors that determine a company's success with using design and data management systems, including frequency of data exchange, data reuse, digital data formats used, and employee counts and locations.

Keywords: Product data management (PDM); product lifecycle management (PLM); data exchange; small and medium enterprises; computer-aided design (CAD)

INTRODUCTION

Small engineering firms usually operate in challenging environments – many are subject to the whims of their customers, who are typically larger, more well-known manufacturers (Towers & Burnes, 2008). This changes the normal design process model, where the company must "talk to customers" and make sure they are producing a product "that customers want." Instead, these small and medium enterprises (SMEs) are usually given very specific details to which their product must conform in order to meet their customer's specifications (Arendt, 2006). Sometimes this requires SMEs to be very flexible in their choice of product lifecycle management (PLM) tools, based on how many different customers they are serving.

Products are increasingly being designed with three-dimensional (3D) tools that enable a host of different analyses, simulations, and design changes. Unfortunately, the software that enables this new design methodology is not nearly as accessible to SMEs as it is to larger, more robust manufacturers. Although their customers most likely have created the requisite network infrastructure for their 3D product data due to the sheer volume and breadth of the data, many SMEs have not yet adopted any formal strategy for managing their product data for their own smaller, yet complex, design methods (Hicks, Culley, & McMahon, 2006). This main impetus of this study was to examine the inexperience of SMEs in the use of 3D product design and data management tools, to understand the challenge SMEs face with regard to data management due to their inexperience, to identify their common product data management needs, and to better align technology with their core business goals.

The main research focus of this study was in product data management (PDM), which is a technology that seeks to manage, secure, control, and accelerate the product development process by ensuring that all product data, particularly product definition data, is stored in one secure, easily accessible and manageable location. Many PDM systems can be difficult and costly to install and implement, particularly in SMEs that have limited resources and potentially higher vulnerability to implementation failures (Chen, Huang, Yang, Lin, & Chen, 2007). Along with the use of these systems come many organizational changes to which SMEs may be unaccustomed, such as increased collaboration between areas of the business and entities outside the business. However, their smaller size tends to allow the SMEs to be somewhat flexible in their technology implementations.

SMEs are typically classified as employing less than 500 people each, and they employed approximately 6.1 million U.S. citizens in

2006 in the manufacturing industry alone (Statistics about Business Size from the Census Bureau, n.d.). At the same time, SMEs have to compete for resources and market share in a manufacturing industry that is struggling to stay afloat since the unstable economic environment of 2008 to present. Manufacturing SMEs are in a particularly unique situation because of limited resources, increased level of flexibility, high amount of personal relationships within the company, and relatively low levels of bureaucracy, among other things (Marri, Gunasekaran, & Grieve, 1998). These companies have been relatively slow to adopt new design technologies like 3D CAD, product lifecycle management philosophies, and product data management technology (Walters, 2007). Many manufacturing and design SMEs still have not updated their systems and processes for reasons such as cost, having simpler product lines, or simply not needing to because of the specific product or product lines that they manufacture and sell (Ayyagari, Beck, & Demirguc-Kunt, 2007). However, many SMEs have moved toward new methods of product design by doing the bulk of the design work with 3D CAD tools, and it is important to pinpoint the exact reasons why these organizations are updating and what levels of success they have had (Dibrell, Davis, & Craig, 2008).

Through PLM an organization in the manufacturing sector is encouraged to consider work in terms of a product, instead of a process (Ameri & Dutta, 2005). This usually means a reorganization to distance itself from a “departmental” environment where each department is like an isolated island and communication is deemed “over the wall” to a newer, more flexible design process that focuses on a single product or family of them, with specialists from different backgrounds collaborating together from the beginning of the product’s design phase all the way through its disposal (Sääksvuori, & Immonen, 2005). Thus, it is useful to get a better picture of what drove manufacturing SMEs to make such drastic changes to their business processes, adopt new PDM technology to manage all the newly generated data, and how this worked out. This research can be a good resource for small companies who are considering the same processes to remain competitive in their industry.

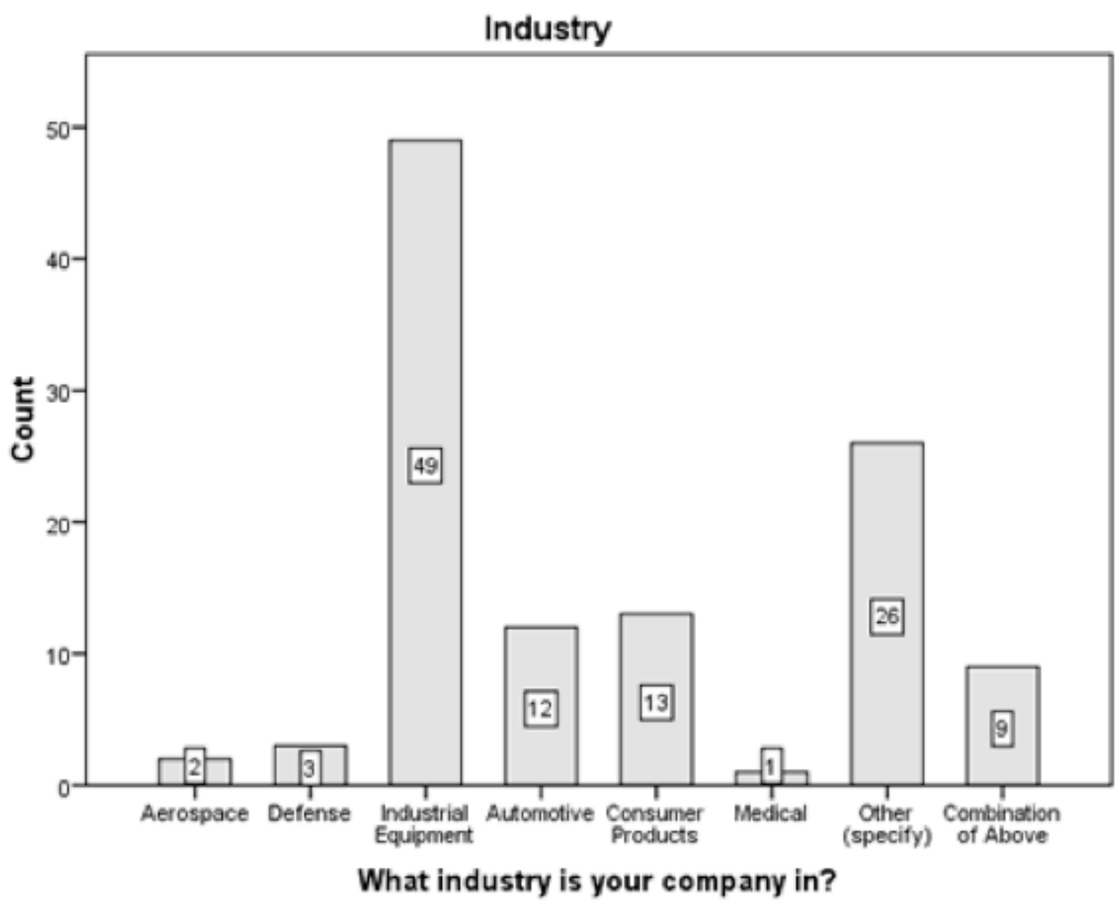
RESEARCH METHODOLOGY

In an effort to investigate the transition of SMEs toward integrated product lifecycle technologies and systems, two simple research questions were developed. What are the common traits of small and medium manufacturing businesses that have adopted a digital product data management (PDM) system? Furthermore, how has this PDM technology affected them? This study used mixed-method data collection schemes because of the complex nature of the research questions and the number of variables. Because the subjects are companies, which even on a small scale can be incredibly complex, a combination of preliminary interview feedback and broader survey methods proved to be the most useful strategy to employ. The study consisted of four preliminary interviews with targeted PDM experts that covered broader PDM issues relative to communication with suppliers and customers; it also considered how PDM technology has affected those processes. From these interviews, a survey was developed, which was validated by a PDM expert in the aerospace industry because of the industry’s exposure to supply chain variation and small and medium enterprises. The survey included five-point Likert scale and multiple choice questions, as well as free-response questions (Dillman, 2007). The responses to these questions tended to illustrate the aspects of PDM implementation that SMEs benefit from, as well as the elements that they tended to have more difficulty getting through. From these responses, conclusions were made about the experiences SMEs have had relative to implementing and using PDM.

Because of the relative lack of previous literature examining manufacturing SMEs in the United States, a short interview was held with four different experts in PDM implementation and management in companies where this has become prevalent (Myers & Newman, 2007). Although not all of the subject matter experts were employed by small or medium companies (in terms of the definition for this study) they were asked what their relationships were with their suppliers, who tended to be small or medium companies, and how they dealt with the differences in PDM capability. After the interview recordings were fully transcribed, qualitative discourse analysis methods were used to extract the main idea threads from the dialogue (Strauss & Corbin, 1998). The basic strategy for coding the transcribed interviews was to summarize general ideas, organize and rank these concepts based on frequency, and then create basic concepts for which quantitative survey questions would be based (Glaser & Strauss, 1967). This required approximately three to four passes through the transcript to both generate codes and group them appropriately. Major themes that emerged from these interview transcripts were issues around data retrieval, exchange, and formatting; PDM as a technology; and the information technology resources necessary for PDM care and maintenance; user interaction barriers; and levels of financial investment required to support the PDM environment. These main ideas were used to create survey questions that would best identify the important traits for SMEs that were either contemplating or currently using engineering design systems technology. For the purposes of this study, the label "engineering design system" was used in the survey to describe a digital system that is used to track, control, and secure product definition data. This choice was made for several reasons: (a) the term "PDM" is not common within the SME space, (b) to reduce confusion between the terms "PDM" and "PLM" and their use in the SME space, and (c) to prevent respondents from discounting their system if it happened to be informal or internally developed.

Survey questions were developed based on these themes. The initial subset of survey questions were meant to form a framework for the characteristics of a small manufacturer. Questions such as number of employees, industry, and level of digital design were meant to give background for each company and give statistics on the true characteristics of the sample responding to the survey. Questions also included whether or not a company had a system set up specifically for handling engineering design data. If a respondent reported that the company did not, that person was automatically taken to the end of the survey and thanked for their time. If the respondent answered that the

Figure 1. Industry Sectors Represented in This Study

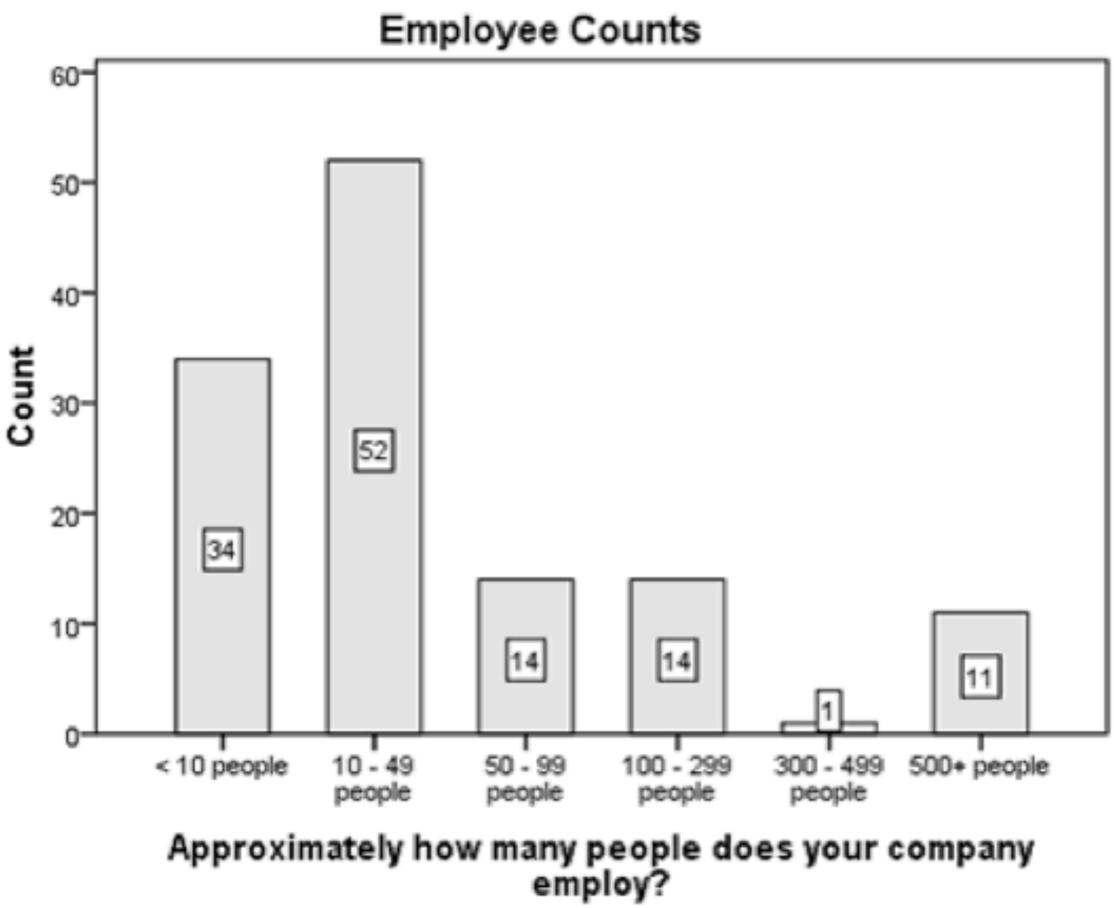


company did have an engineering data system of some sort, that person continued with the survey. Questions were also added to give a more accurate portrayal of the expertise of the survey taker by asking what their level of involvement was with the data management system. Other questions were based on the broader themes that were drawn from the qualitative interviews, such as methodologies for using the PDM system, workflow usage, opinions on how the PDM has affected the design process, and investment characteristics. Another major theme that generated a few different questions was the level of system integration between both the small manufacturers and their customers/suppliers, as well as within their own organizations.

DESCRIPTIONS OF SURVEY RESPONSES

Due to the nature of the data, the analysis includes discrete measures (averages and percentages of scores and frequency analyses). The large part of the analysis of quantitative data is the search for variable relationships and comparing and contrasting data between companies. This was accomplished using Pearson chi-square tests by comparing response levels between two independent variables, such as company size and PDM use. The overall goal of this research was to confirm similar studies to a degree while at the same time exploring critical factors about PDM implementation that have not yet been explored, specifically in the United States. Therefore, a survey was the most expeditious method to gain useful information from small manufacturers. The initial contact email was sent out to 2,200 potential participants across the United States. The majority of survey responses came during the first two days that the survey was opened. Within two weeks, 100 completed responses and 40 partial responses were received. The initial part of the survey asked general questions about the respondents' company's characteristics. Figure 1 explains the industry sector distribution for this study, and Figure 2 details the size of the companies that responded to the survey.

Figure 2. Size of Companies Responding to the Survey



Respondents who reported more than 500 employees in their businesses were removed from the sample. Of the completed responses, 42 respondents stated that the company used an engineering design (PDM) system. Despite the relatively low number of respondents for this portion of the survey, a number of interesting relationships were found that will be explored.

It is important to first discuss the business demographics from the survey sample because this provides a context for the results. These were not multinational companies with substantial IT resources. These were companies that often have people performing more than one organizational role without dedicated IT support. It quickly became clear that the majority of the small manufacturers classified themselves as being in the industrial equipment industry. They were about evenly split between having an engineering design (PDM) system and not having one, but the vast majority of them had fewer than 50 employees, versus some of the other industries such as companies in the automotive and other categories, which were more evenly dispersed in terms of employee counts. This is reflective of the manufacturing industry in the United States in general; whereas larger corporations make up the majority of the industry by sheer employee counts, there are far more individual smaller companies than large ones, and thus it makes sense that more small companies responded to the survey.

The final question targeted at the entire sample of survey respondents also caused the sample to be split into two specific groups: companies that have a digital design system of some sort, and those that do not. Respondents answering this question with a "no" were taken to the end of the survey and thanked for their time, since the subsequent questions would be about a system they did not have. Table 1 represents the relationship between presence of an engineering design system and basic company characteristics. The chi-square values indicate that there were no significant relationships between company characteristics and whether the company used an engineering design system.

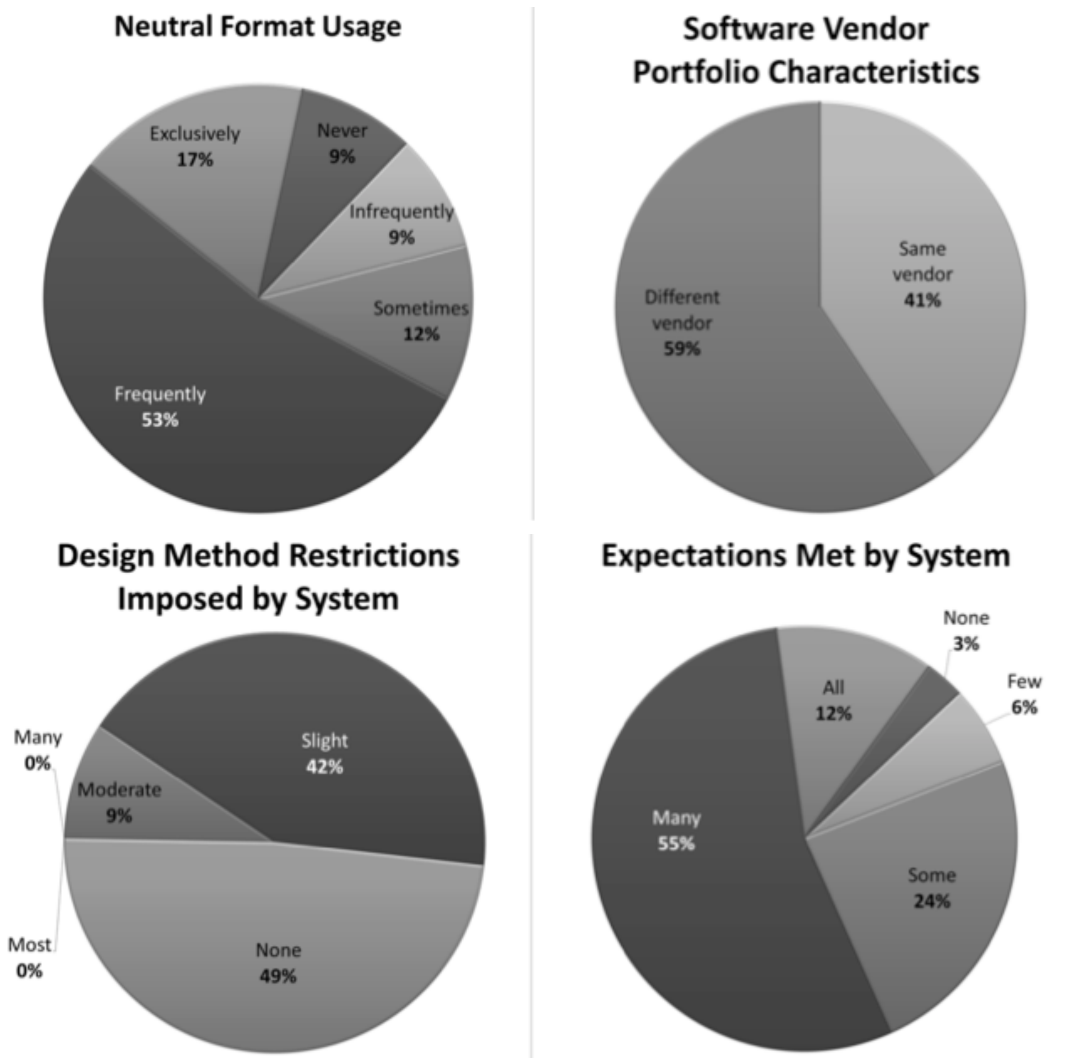
COMPARISONS OF COMPANIES WITH ENGINEERING DESIGN SYSTEMS

Several general findings were discovered from the data, as described in Figure 3. According to the survey respondents, they used neutral file formats frequently and tended to get their software from different vendors. Their design systems did not pose any major restrictions on their engineering processes, and their systems generally met their expectations. In many instances, the use of neutral files in data exchange and the use of multiple software tools (and the accompanying discontinuity of data usage) had a direct effect on the success of collaborative activities using digital product data.

Table 1. Comparison of Company Demographics to Presence of Design System

Variable 1	Variable 2	Chi-square
Industry	Presence of an engineering design system	.583
# of Employees		.098
# of Locations		.44
Digital format used		.071
OEM/Supplier/Both		.722

Figure 3. General Response Characteristics of Small and Medium Manufacturers



Though important conclusions can be reached based on basic metrics, there are also relationships between different variables, such as level of involvement in the system when compared with the perceived effect on the time it takes to find information to perform a task. Other relationships include the frequency of exchanging data with outside entities versus how the system has contributed to concurrent engineering, and the use of neutral file formats versus the organizational group that manages the design system. Table 2 represents the characteristics of companies that responded to the survey as having an engineering design system. It is a subset of the companies represented in Table 1. Based on the amount of responses returned and the number of variables examined, Table 2 includes those variables that formed a statistically significant relationship based on their chi-square values.

An interesting relationship was found between involvement level and attitudes toward how the system enables the finding of information. As seen in Table 2, It appears that users who rated themselves as "very involved" tend to feel that the system makes finding information slightly faster, whereas those who rated themselves as "extremely involved" feel the system makes finding information much faster.

Table 2. Characteristics of Those Companies with Design Systems

Variable 1	Variable 2	Chi-square
Digital Design Format	Industry	.060
Engineering Design Locations	# of Employees	.000
OEM, Supplier, or both	# of Employees	.118
OEM, Supplier, or both	Digital design format	.200
System maintenance group	Neutral file format usage	.013
System meets expectations	Involvement Level	.156
System meets expectations	Restrictions on design methods	.090
System meets expectations	Contribution to concurrent engineering	.004
System meets expectations	Data exchange frequency	.046
Contribution to concurrent engineering	Data exchange frequency	.052
Restrictions on design methods	Data exchange frequency	.000
Effect on informational retrieval time	Effect on design task time	.018
Effect on information retrieval time	Involvement Level	.025
Effect on information retrieval time	Data sharing beyond Engineering	.027
Workflow usage	Data sharing beyond Engineering	.136
Workflow usage	Data entry point during design	.065
System upgrades	Data entry point during design	.115

Another interesting correlation ($\chi^2 = .027$) that proved to be significant was the connection between whether an engineering design system shares data beyond just engineering, and how much effect the system has on finding information for a task. Respondents whose design system shares data tend to strongly feel the system makes finding information for their tasks faster, either slightly or much faster. This may due to the fact that the design tasks in an integrated design system must pull information from more sources, and thus a centralized location for data made finding information easier.

It also appears that respondents whose companies frequently exchange data with their customers and suppliers – more than a few times each week – tend to feel that their engineering design systems do not place many restrictions on their engineering design process ($\chi^2 = .000$). This could be because the data exchange capabilities of their design system save them time in other ways that affect how respondents feel about the restrictions the system puts on them, or there could be other reasons for this correlation.

Another correlation between variables was the one between the level of concurrent engineering these design systems tend to create, and how the systems met expectations ($\chi^2 = .004$). It appears that as systems tend to contribute more to concurrent engineering, respondents felt the systems met more and more of their expectations. That's partially to be expected considering that product lifecycle management as a concept is based on the idea of concurrent engineering and product focus rather than process focus.

DISCUSSION

Several compelling findings were gleaned from the data, such as that the primary usage of engineering design systems is the storage of manufacturing information for these small businesses, and they use neutral file formats frequently. They also tend to get their software from different vendors, but believe that their design systems do not pose any major restrictions on their engineering processes and their systems generally meet their expectations. There also seems to be interactions between different variables, such as level of involvement in the system when compared with the perceived effect on the time it takes to find information to perform a task. Others include the frequency of exchanging data with outside entities versus how the system has contributed to concurrent engineering, and the usage of neutral file formats versus the organizational group that manages the design system.

Two variables in particular stood out as having some effect on whether or not a company adopted a digital engineering design system: number of employees ($\chi^2 = .098$), and the type of digital formats used to define design ($\chi^2 = .071$). It makes sense that both of these variables are connected to the presence of a design system because typically a company that has adopted digital formats as a method to define design needs places to store, manage, and archive all this data over time. Software vendors that sell 2D and 3D design tools also often have file management tools of some sort that they may offer to companies for a lower price when bundled with the design tool itself. Also, companies that use 3D tools were more likely to have a system versus companies than used 2D tools. This is an interesting distinction, which can best be explained by the fact that 3D software vendors more often have a system that can be bundled with the 3D tool itself that was designed to be integrated together. The 2D tools may lack associative part management, which, for a company that does not necessarily need to maintain referential integrity between part files, could make a separate digital system for storing and managing 2D part files seem like a waste of resources.

Over 75% of respondents to the second part of the survey about engineering design systems reported that they were very or extremely involved in the system at their company. This is a generally good marker that the rest of the answers were relatively reliable, because it means that respondents were most likely generally knowledgeable about the systems used at their companies and their answers would be credible. Respondents also report that they used their systems primarily to store manufacturing information, and then as a general repository for data and product structure management and bills of materials. This indication, that the main use of engineering design systems is to store manufacturing information, is an interesting result given that the traditional PDM tool is built mostly for engineering design itself and typically must be modified or added to better support manufacturing information. It also shows that these small manufacturers are not in the "PLM" mindset, in that they were focused more on their processes than the product itself, which may be a good thing for them at the present time, but in the long term it may not be conducive with growth, given the advance of technology and competition.

The speed of tasks, particularly doing a design task and finding information, is usually the major benefit cited by companies who have adopted a robust PDM system (Philpotts, 1996). This benefit is also reflected in this study's sample of small manufacturers, where the majority of respondents reported that their system makes design tasks faster or has no effect, and finding information in particular is either slightly or much faster.

Because these small manufacturers have relationships with multiple suppliers and customers, they happen to exchange data with these outside entities on a relatively frequent basis: most companies exchange data at least a few times a week, if not daily. This shows that these smaller manufacturers are in constant contact with their suppliers and customers, which can help to avoid unplanned costs and miscommunication errors. However, even though they frequently exchange data with outside entities, only a few use their design systems to interface directly with the customer or supplier. This may be due to the lack of integration between systems, or in some cases, there is simply no need to have an automated process to exchange data between companies. All interviewees during the first part of the study cited high costs associated with integrating suppliers into their system, and likewise some survey respondents cited high costs to maintain fully integrated systems with their customers. However, these small businesses are still operating as islands of data with manual, more closely scrutinized exchanges of data with outside companies.

Although new research suggests that PDM implementation is most successful when it originates and is managed by the IT group in a larger corporation, most groups in the sample reported that their engineering design systems are managed by their engineering groups (Jackson, 2010). This may be because specific groups of employees dedicated to IT, especially in companies with fewer than 50 people, are difficult to find. However, this may also be a disadvantage because people who are not experts in system management and project management are in charge of such a business-critical system. It is important to mention here, too, that more than a few respondents reported that their design systems were written and maintained internally, implying that their companies do not buy specially designed system software to handle engineering data, but instead they write their own using Microsoft Access or other easily available software development tools. This is an interesting phenomenon that would probably not be seen outside the small business arena.

Contrary to popular belief, a small majority of respondents reported that their design system software, including 3D/2D design tools, was not written by the same software vendor. This may be due to the relatively slow process of adopting technology at small manufacturers and a lack of system planning due to a piecemeal implementation of different business systems (Lee, Bennett, & Oakes, 2000). It could also be because the engineering software industry has yet to produce a truly integrated, cohesive package of software that serves the needs of small and medium manufacturers without being too complicated or expensive.

How PDM systems change the business is one of the most important factors when trying to decipher how the use of these types of systems have affected the companies that have adopted them, which is part of the research question for this study. The last three questions in the survey dealt with how engineering design systems affected collaborative engineering, the use of clearly defined design processes, and whether or not the system met the expectations of the respondent. In a smaller company, each employee has a greater chance to interact with the engineering design system every day than might be seen in a larger corporation, and that level of familiarity may affect attitudes and impressions of the system itself. Most respondents felt that their design system had contributed to concurrent engineering, which is one of the main goals of PDM systems in general. But as an interviewee in the first part of the study pointed out, it is quite possible to use PDM systems in a manner that only further exacerbates the over-the-wall engineering problem. However, most respondents believed that their systems made a moderate or higher contribution to collaborative engineering, showing that these small manufacturers indeed use their systems as they were intended to be used.

CONCLUSIONS

Given the findings in this study, some conclusions can be made about common traits of small manufacturers who have implemented PDM-like systems. First, members of companies who have implemented PDM systems are generally happy with the way these systems have worked for them. They believed their design systems contributed to concurrent engineering, pose little or no restriction on their design method, and met most expectations for what they should be able to do. Locating information is significantly faster, and the system makes doing a design task faster as well, although to a lesser extent. Most of the small manufacturers in the sample exchanged data with outside suppliers and customers at least a few times per week, but this exchange is generally a manual process. The exchange does use neutral file formats extensively, that is, either neutral 3D or 2D file formats. Inside the business, companies share data from their engineering design system with manufacturing systems and purchasing systems, but most do not use workflows as a way to automate the flow of data within the design system. They tend to upgrade their software either every year or every 2-4 years, most likely depending on the nature of their licensing agreement with the commercial software provider, or whether they have created their own homegrown system for managing engineering data. Most companies enter data into their design systems as early as possible and use it throughout the design phase of their products.

In reviewing this study, the researcher came across an interesting revelation: small manufacturers are very enthusiastic about what they do. After the initial survey was sent out, the researcher received several emails from managers and owners of small businesses who were curious about the results of this study. They seemed genuinely interested in this topic because it is an issue they struggle with every day, but in some respects they felt disenfranchised because they rarely have the resources to commit to an extremely robust system. They write their own systems, they do much of their data management manually, and at times they seem to be out of the loop of the ever-advancing manufacturing industry and all its leading-edge technology. Alternatively, they feel that they are at the mercy of their larger original equipment manufacturer (OEM) customers to conform to what the customer requests, often a huge investment in system infrastructure that is burdensome to them. But, they are also the same suppliers and small OEMs that enable larger OEMs to focus their manufacturing efforts on other things. At the federal and academic levels, many programs are in place to help these small businesses thrive, because they truly are one of the driving forces in the U.S. economy. At the same time, there is an acute lack of academic research on these same businesses, including what they are currently doing, what they want to do in the future, and where they fit into the grander scheme of manufacturing economics. This study was mainly concerned with what SMEs are currently doing to manage data in an increasingly digital world where forces beyond their control have started to make them carry out their design and manufacturing in new ways. However, the real question is what this segment of the manufacturing industry will do in the future. How can small manufacturers be enabled to step into the world of PLM and PDM in a way that is cost effective for them but will encourage growth and change while using their unique advantages to help them get ahead? Finally, more research should be conducted that will illuminate more traits of small manufacturers and find better solutions to help address their unique needs.

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The Current State Of Wireless Information Technology In The Construction Industry In Ohio

By Alan Atalah and Aaron Seymour

ABSTRACT

Construction projects are increasingly getting complex and fragmented in nature, yet contractors persistently face shortened project durations and reduced budgets. Timely delivery of accurate and reliable information among all project participants is critical and important because information is the foundation upon which decisions are made and projects are estimated, planned, monitored, and controlled. Recent developments in technology promise to introduce efficiencies that were not previously available to the industry. This study seeks to identify the current state of wireless information technology through the analysis of quantitative data from a web-based survey that represents the views of the respondents on the usage and interest in wireless technology.

The study suggests that the level of interest in wireless technology is much higher than the level of use. Wireless technology enhanced the skills, productivity, and customer service of the participants, but did not improve their ability to negotiate projects and monitor project costs. The respondents believe that the return on investment is not a barrier; slow download speeds and durability are the largest barriers keeping people from using wireless technology.

Keywords: Mobile devices, Web-based project management,

INTRODUCTION

The Internet unquestionably represents one of the most important technological developments in recent history. It has revolutionized the way people communicate with one another, obtain information, and has created an unimaginable variety of commercial and leisure activities (Yoo, 2010). Communication technologies that intimidated many of us just a few years ago are now a part of our daily lives. The wide use of cell phone and the Internet in the early nineties, Hotmail in 1997, Skype in 2004, Twitter and Facebook in 2007 are just a few examples of the changes in the way we conduct our personal and professional lives (Marston, 2011). Technological change increases productivity and economic growth, and the focus should be on how new communication technologies affect business (Wallsten, 2010). Information is the cornerstone of any business process (Stewart & Mohamed, 2004). During the last two decades, a wide range of industries experienced significant productivity improvements because of the technological advancement in information technology, which has provided these industries with great advantages in speed of operation, in consistency of data generation, and in accessibility and exchange of information (Mohamed & Stewart, 2003). The majority of construction business processes rely heavily on traditional means of communication such as face-to-face meetings and the exchange of paper documents in the form of technical drawings, specifications, and site instructions (Deng, H. Li, Shen, & Love, 2001). Wasted time and cost in construction projects can, more often than not, be traced back to inadequate, late, or inconsistent handling of information (Mohamed & Stewart 2003). Construction projects often generate 1 to 2 million pages of documents throughout the course of a job. Without the proper means, retrieving pertinent information from these documents is a time-consuming process for anyone involved with a project (Zack, 2002).

The industry recognizes the need to increase the efficiency of its processes via exchanging massive volumes of information at high speed and at relatively low cost (Deng et al., 2001). Although construction companies seek new solutions to remain competitive in the marketplace, the use of information technology (IT) in construction has not progressed to the level that can be seen in other industries (Flanagan, Ingram, & Marsh, 1998). This is due to a number of historical, industrial, and market forces that have perpetuated the industry's culture and affected the adoption of IT in day-to-day business processes (Baldwin, Thorpe, & Carter, 1999).

Many developments toward the convergence of wireless communications and Internet-based technologies have emerged. Mobile collaboration using wireless networking can be very effective at minimizing the impact of the physical dispersion of project managers and site supervisors (Anumba, Aziz, Bouchlaghem, Carillo, & Ruikar, 2006). Research suggests that reductions in project delivery time of 20 to 50 % are possible when enabling technology improves communication between project participants (Wood & Alvarez, 2005).

Knowledge has been identified to be a significant organizational resource, which if used effectively can provide a competitive advantage. The fragmentation of the construction industry (CI) and ad hoc nature of construction projects provides a challenge for operational communication and information processes. Ultimately, the ineffective capture and reuse of valuable knowledge gathered during a construction project inadvertently contributes to project cost increases and time delays. Given the nature of construction projects, collaborative knowledge management seems to be the most appropriate solution to capture project-based knowledge. Information and communication technologies offer a number of solutions to implement collaborative knowledge management solutions. It is suggested that construction businesses must communicate and exchange information more effectively by adopting IT; the adoption of IT reduces project costs, which in turn provides competitive advantage (Love, Irani, Li, Cheng, & Tse, 2001).

Microsoft, Oracle, Sage, Meridian, Autodesk, HCSS and many others firms have developed web-based construction project management applications for the architecture engineering construction (AEC) industry to collaborate, integrate, communicate, and coordinate construction projects during the last decade. However, many construction organizations still face collaboration challenges, including how to bring extended project teams together across geographical locations, in online and offline environments, and across different technology systems and devices. By providing a rich Web-based user interface on a powerful Web services platform, Web-based project management (WPM) applications allow the project team to collaborate more efficiently and give users flexible choices in how they access critical project data.

Electronic document and project management solutions have increased in popularity as a result of these circumstances. Web-based project management (WPM) allows project participants to access relevant documents through the Internet from virtually any location that has Web access. However, the wired access points that are available through the clients' Internet service provider limit the benefits of WPM. The functionality of WPM and other information technology can be greatly improved by increasing the mobile ability of the Internet through the use of wireless information technology (WIT).

WIT consists of networking hardware and software that significantly increase the mobile access to the Internet by eliminating the need for wired access. This can be done either through a cell phone network with data capabilities or a wireless local area network (WLAN) on local modem or Wi-Fi hotspot. The future of digital communication is mobile; anything and everything will be mobile/wireless (Fleishman Hillard, 2009). A construction workforce that is outfitted with wireless technology could gain mobile access to various critical applications, such as construction management (CM) programs, schedules, cost accounting, and documentation management. Several software providers have adapted construction project management software to run on handheld computing devices, allowing the wireless transmission of data from nearly any location that has access to a wireless data network.

Recent price reductions and improvements in information technology and network speed have allowed many progressive contractors to adopt wireless communications and Internet-based technologies in an attempt to improve communication between the office, the job site, and the client (Anumbaet al., 2006). Small businesses today can get broadband Internet service from many communication companies, for example, Verizon Communications, Time Warner, Comcast, AT&T, and others, for $30 to $90, depending on the speed and the amount of data traffic. Verizon Communications, Time

Warner, Comcast, AT&T, and others offer businesses wireless data plans that cost less than $10/GB. These businesses can bundle Internet services with many other communication services for more savings (Verizon Communications, 2012) (AT&T, 2012). In addition, a wireless modem at the job-site office reliably and securely provides cost effective wireless data communication to the machines on the job site or in the office.

These prices are significantly less than what they were a few years back, and this trend is expected to continue into the future. As the competition among technology giants, such as Apple, Microsoft, Google, Samsung, and others heats up and production exceeds demand, the cost of their devices will be lowered and their capabilities will increase. The same competitive pressure among the retail giants, such as Wal-Mart, Best Buy, and Amazon will lower the cost of these devices (Arora, 2012; Smith, 2012; Zeitlin, 2012). The competitive pressure among communication giants, such as Time Warner, Comcast, AT&T, and Verizon will lower the cost of transferring data among these devices.

The recent release of the National Broadband Plan by the Federal Communications Commission (FCC) has focused the attention of industry leaders, academics, and ordinary citizens on having sufficient bandwidth available anytime and anyplace to support a growing array of broadband services. Broadband services include both wired and wireless access to the Internet and the delivery of high-definition, even 3-D, television (Hatfield, 2010). The FCC's National Broadband Plan recommends that 500 MHz of spectrum be made available for broadband within 10 years, of which 300 MHz should be made available for mobile use within 5 years (Hatfield, 2010).

Many research studies support the enhanced communication, faster decision making, and cost savings that result after initiating information technology solutions (Mohamed & Stewart, 2003). Successfully implementing wireless technology in the CI could streamline many operations of the building process by transcending physical distance when accessing or manipulating information. Significant productivity improvements and shortened project durations could be realized as a result (Menzel & Rebolj, 2004).

Most importantly, adopting WIT can greatly improve the service that is delivered to the owners of projects, as they ultimately receive the benefits. Improved customer service can be realized through customizable Web interfaces that are set up specifically for the project owner to review updated drawings, changes in the schedule, and other project data. The owners' demand for the technology is an important factor in the rate of adoption across the industry. If owners begin regularly requesting advanced technology, then the industry will follow (El-Diraby et al., 2004). Research should focus on the economic effects that digital communications have on specific industries, which are more likely to be identifiable and measurable (Wallsten, 2010); in our case, it is the construction industry.

The use of IT in construction has not progressed to the level seen in other industries (Mohamed & Stewart, 2003) likely because the decision-making process behind investing time and money into wireless communication technologies is poorly understood (Bernold, Lu, & Williams, 2006). After analyzing results of similar studies, one could infer that utilizing an efficient and convenient process of accessing data by means of mobile computing can oftentimes be overlooked.

AEC industry professionals may be reluctant to consider emerging technology as a way to improve the bottom line for several reasons. Construction companies with accounting or project management software already in place may be hesitant to make a large investment into new software with wireless capabilities that has not been proven to provide cost-saving benefits within their organization. Some may be dissuaded by the perceived barrier of entry that could exist due to additional training, software support, and hardware purchases. Others may be unwilling because of the apparent legal and security complications that could result from the lack of retaining hard copy documentation with signatures of change orders or approvals (Alshawi & Ingirige, 2003). However, contractors must realize that wireless communication technology has become extremely feasible with regard to both setup and cost, and a return on their investment can be achieved in relatively little time (Emborg & Olofsson, 2004). In addition, recent court rulings determined that an official document created, stored, or transmitted electronically can be submitted and verified as evidence in a trial (Zack, 2002).

The main objective of the study was to identify WIT utilization among the employers of the graduates of the CM program at Bowling Green State University (BGSU). The improvements in cost, security, reliability, availability, and capability of mobile communication technology are expected to increase the utilization level significantly in the near future.

As stated previously, the recent advancement in WIT in terms of reliability, speed, and affordability enabled many industries and businesses to achieve higher efficiency, cost savings, and profitability. However, the AEC industry has been slower than other industries in the utilization of these advancements (Mohamed & Stewart, 2003). Learning how the AEC industry uses wireless communication technologies, which ones use them, and the obstacles to using them, will benefit both the AEC industry and the WIT industry. The authors aim to help AEC companies by presenting key factors that should be considered prior to a successful investment and implementation. Software and hardware developers can benefit by gaining insight into the AEC users of WIT for continued product development and improvement.

RESEARCH DESIGN

The employed research instrument was an electronic survey to preselected professionals in the CI. The study population consisted of construction professionals that employed the students and graduates of the CM department in the College of Technology at BGSU. The participants worked for general contractors, subcontractors, and CM firms, and they reflect the construction industry in both Ohio and United States. The subjects were familiar with the CM department, and a good percentage of them were graduates of the department. The respondents' participation in the study was kept completely anonymous, and they were free to withdraw at any time. The results were then analyzed with both descriptive and inferential statistics.

DATA COLLECTION INSTRUMENT

The primary data collection instrument of this study was the voluntary Web-based survey, which is shown in Appendix A. The authors, who are active members of the construction industry, formulated the questionnaires after conducting an extensive review of literature and surveying the available technology in the marketplace and the technologies used in the construction industry. The Human Subjects Review Board (HSRB) at BGSU approved the survey prior to conducting the research. By beginning the survey, the subjects were giving consent to participate in the study, and they were permitted to skip questions or discontinue participation at any time. The electronic survey service anonymously recorded IP addresses to ensure eligible participation and to allow the tracking of unique access without placing a burden on the participant.

Motivating respondents was an important aspect of this study, and the researchers took several steps in order to maximize the response rate and ensure an adequate sample size. In an effort to keep the survey as brief as possible and aid in the final analysis of results, there were no open-ended questions. The invitation to fill in the survey indicated that the survey would take only 10-15 minutes. The questions were designed to be answered with a minimum amount of effort and time for the respondents. The questionnaire consisted of selected-response questions with many including Likert-type rating scales for answers that ranged from strongly disagree to strongly agree as well as numerical ranking scales that ranged from 1 (least) to 5 (most). The questionnaire was worded to be as brief as possible and sought to determine the participants' opinion of the current state of WIT for construction projects in which they had been involved. The survey included questions regarding demographics, industry type, and primary occupation within their construction company.

Four industry professionals were called upon to participate in a pilot test of the survey. The test sample was asked to identify any vague or unclear wording in the document and note suggestions and performance ratings in an evaluation form that was distributed with the test survey. The electronic Web survey was also assessed to ensure proper functionality among those who may not be completely familiar with navigating electronic surveys. At the conclusion of the pilot test, the researchers analyzed the evaluation to identify the necessary enhancement and eliminate any ambiguity from the final instrument.

A week after the launching of the survey, a follow-up reminder was sent to anyone who had not yet completed the survey. The total number of subjects who received the survey request was 298; 62 completed the survey, for a response rate of 20.8%. Anonymous Internet Protocol (IP) addresses were collected and analyzed along with the questionnaire results. It was determined that each response was unique.

FINDINGS AND ANALYSIS OF DATA

The results of the Web-based survey were compiled and exported into Microsoft Excel for formatting and charting purposes prior to using Statistical Analysis System (SAS) software to complete advanced statistical analyses. The Center for Business Analytics at BGSU was instrumental in running a series of inferential statistical analyses such as the chi-square test of independence and Fisher's exact test to investigate the relationships among the categorical variables. The confidence interval of 95% was selected, which is typical for this type of study (Devore, 2011).

Descriptive Statistical Analysis

General Contractors represented 62.9% of the respondents as shown in Table 1.

The subjects whose primary type of construction was Commercial/Industrial represented 56.5% of respondents as shown in Table 2.

Fifty-three of the 62 respondents spent the majority of their time in the office, representing the largest response rate at 85.5%. Those who spent more time in the field represented 14.5% as shown in Table 3.

Table 1. The Primary Business of the Subjects

	Response Count	Response Rate %
General Contracting	39	62.9%
Construction Management	6	9.7%
Subcontractor	6	9.7%
Other	11	17.4%
Total	62	100%

Table 2. Company's Primary Construction Focus

	Response Count	Response Rate %
Heavy/Civil	21	33.9%
Commercial/Industrial	35	56.5%
Residential/Multifamily	6	9.7%
Total	62	100%

Table 3. Majority of Time Spent in Field or Office

	Response Count	Response Rate %
Field	9	14.5%
Office	53	85.5%
Total	62	100%

Out of the 62 respondents, the majority (35) were between the ages of 36-55, which represented 56.5% of the sample population. Only 6 respondents were above the age of 56. Table 4 summarizes the response rate by age.

Table 5 presents the respondents' level of interest in tablet PCs (i.e., iPad, Galaxy, ToughBook, MS Surface, etc.) with mobile construction applications; Smartphones with mobile construction apps; cellular wireless network hardware for laptops (hotspots, wireless cards, etc.); Web-based project management software; GPS tracking software and hardware (location, speed, etc.); and RFID tags (radio frequency identification for tracking materials).

The participants were questioned on how often they accessed Web-based project management software from a wireless device. Of the 59 respondents, those who selected not at all represented the majority, with a 40.7% response rate as shown in Table 6. Thirty-four percent of the subjects used project management software from a wireless device frequently.

The next question, related to the type of business information/applications that the subjects used with a Smartphone or Tablet PC, showed that 94.7% of the respondents selected email; 49.1% and 40.4% of the respondents selected drawings and product information/specifications, respectively as shown in Figure 1. How-to information and videos represented the lowest response rate.

Respondents were questioned regarding how many hours they spent accessing construction-related content on a smartphone or tablet PC on a weekly basis. Table 7 shows that 42.4% indicated that they spent 1-4 hours per week working on construction-related content. Figure 2 shows the percentage of the respondents who used advanced wireless technologies

Table 4. Respondent's Age

	Response Count	Response Rate %
18-35	21	33.9%
36-55	35	56.5%
56+	6	9.7%
Total	62	100%

Table 5. Level of Interest in Wireless Devices

Level of interest in	Score
Tablet PCs with mobile construction apps (i.e., iPad, Galaxy, ToughBook, etc.)	4.03
Smartphones with mobile construction apps	4.15
Cellular wireless network hardware for laptops (hotspots, wireless cards, etc.)	4.31
Web-based Project Management software	3.90
GPS Tracking Software and Hardware (Location, Speed, etc.)	3.46
RFID Tags (Radio Frequency Identification for tracking materials)	2.88

Table 6. Frequency of Accessing Project Management Software from a Wireless device

	Response Count	Response Rate %
Extremely often (multiple times per day)	10	16.9%
Very often (multiple times per week)	10	16.9%
Moderately often (a few times per month)	10	16.9%
Slightly often	5	8.6%
Not at all	24	40.7%
Total	59	100%

such as Field BIM (Building Information Modeling), a handheld wireless scanner with RFID capabilities, digital signature capture, mobile asset management (tools and equipment tracking), wireless security/alarm monitoring, and material management with RFID.

Figure 1. Types of Business Information/Applications Accessed by Respondents (*n*=57).

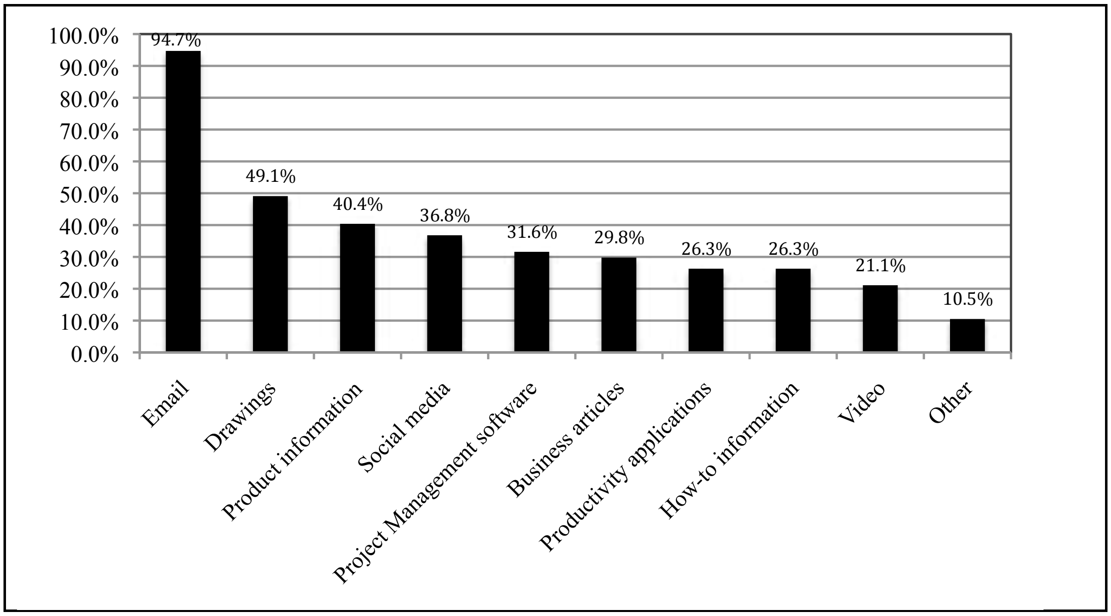
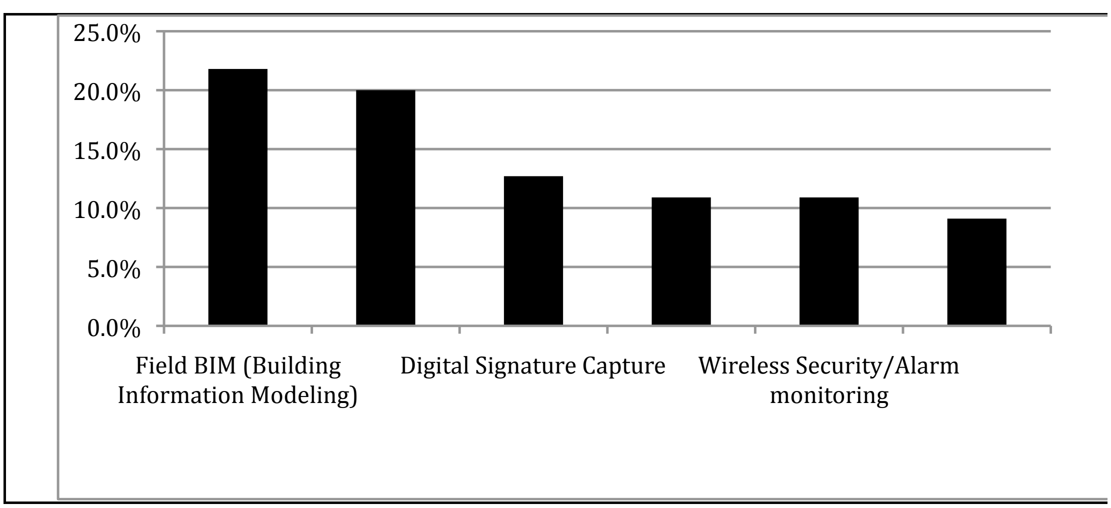


Table 7. Hours Per Week Spent on a Wireless Device

	Response Count	Response Rate %
None	11	18.6
1-4	25	42.4
5-9	14	23.7
10+	9	15.3
Total	59	100%

Figure 2. The Percentage of the Respondents Who Used Advanced Wireless Technologies



The next question sought to identify the respondents' opinion of the barriers to using wireless technology. Table 8 represents the average score on the Likert scale of their responses, which suggests that the return on investment and lack of a clean and stable environment are the main barriers, but they were not very high barriers. Please note that high cost, required training, steep learning curve, and the price of additional wireless service plans are subcomponents of the return on investment.

Table 9 shows the average score for areas of improvement caused by using a smartphone or tablet PC on a scale of one to four; it indicates that the subjects strongly agreed that their use of smartphone or tablet PC improved productivity, customer responsiveness, and collaboration. However, improving their ability to meet tight deadlines, solve problems, make decisions, manage subcontractor/ labor, manage material, manage change orders, and monitor project cost got an average score between 2.60 and 3.00.

Table 10 shows the average score in response to the question related to level of interest in construction functions for which they will use mobile devices.

Table 8. Barriers to Using Wireless Technology

Answer Options	Average score
Little return on investment	3.66
Required training	3.23
Lack of a clean and stable environment	3.23
High cost	3.19
Steep learning curve	3.14
Price of additional wireless service plans	3.05
Lack of security	3.03
High risk of breaking (durability)	2.79
Slow download speed	2.60

Table 9. Areas of Improvement Caused by Smartphone or Tablet PC

My Smartphone or Tablet PC improves my	Average score
Productivity	3.45455
Customer responsiveness	3.32727
Collaboration	3.05455
Ability to meet tight deadlines	2.94444
Problem-solving skills	2.87273
Decision making process	2.81482
Subcontractor/labor management	2.78182
Material management	2.76364
Change order management	2.64815
Ability to monitor project cost	2.6
Ability to negotiate/win projects	2.50909

Table 10. Level of Interest in Constructions for Which They Will Use Mobile Devices

Answer Options	Average Score
Daily reports	3.931034
Safety checklists	3.844828
Quality checklists	3.724138
Punch lists	3.607143
Drawing review/annotation	3.578947
RFI submission	3.464286
Submittal Review and Approval	3.22807
Timesheet tracking	3.192982

Figure 3 shows the responses regarding their expectations of purchasing wireless software or hardware in 2012 relative to 2011. The graph suggests that the highest investment is going toward smartphones, tablet PCs, and construction-related mobile applications.

Figure 4 shows the construction applications for which the subjects used smartphones or tablet PCs; they mostly used them for email, document management, and daily reports

Figure 3. Expectation to Purchase More, Less or the Same Dollar Amount of the Following Items During 2012 Versus 2011

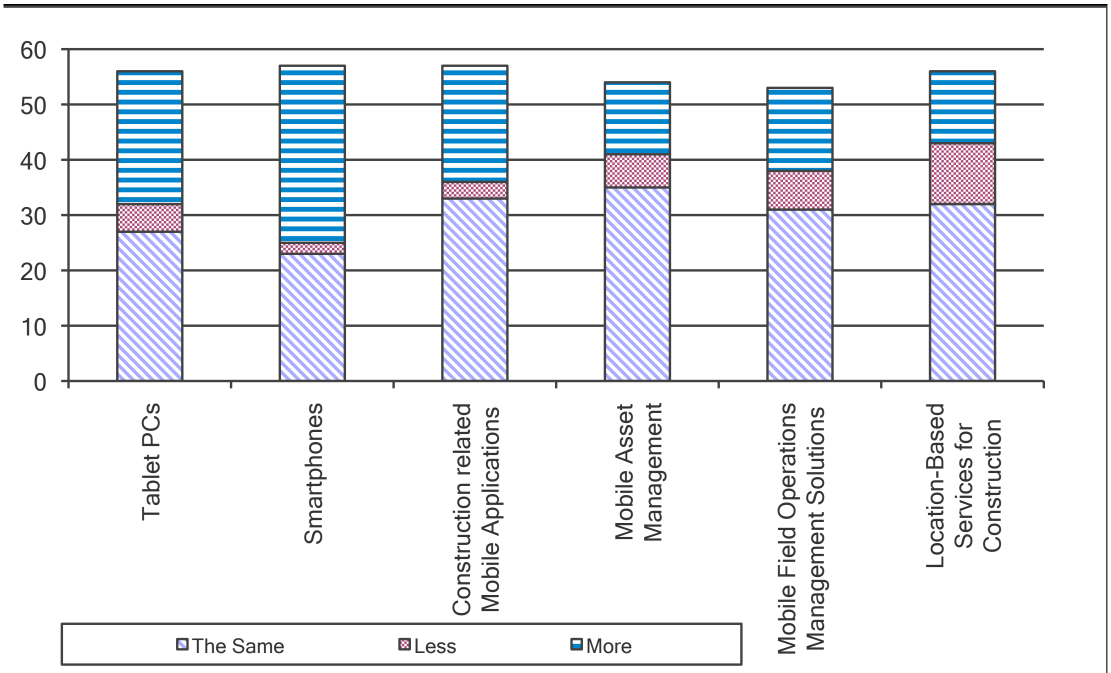
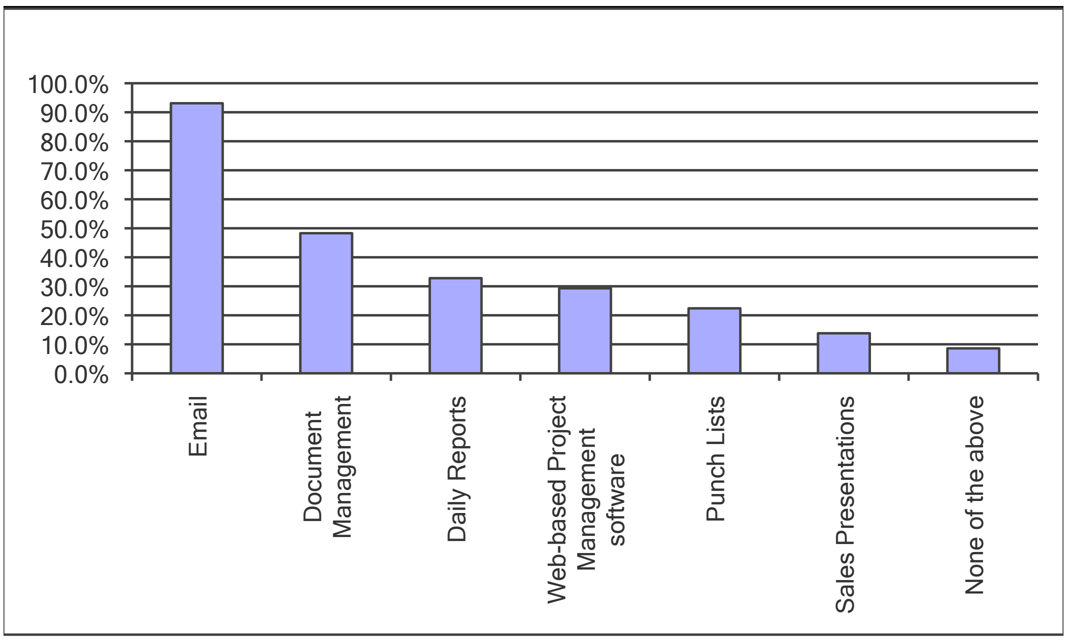


Figure 4. The Construction Applications for Which the Respondents Used a Smartphone or Tablet PC



CONCLUSION AND RECOMMENDATIONS

While interest levels among respondents were high, the results of the research study revealed several areas that should be improved before significant progress can be achieved. In summary, 72.1% of respondents indicated a high level of interest in tablet PCs, smartphones, and wireless hotspots; 59.3% of respondents indicated high interest in mobile applications that can complete daily reports, safety checklists, and quality checklists. The analysis suggests a discrepancy between the interest and usability of WPM software; 67.2% of respondents indicated a high interest in using WPM software on a wireless device, but 66.1% are only accessing project management information from wireless devices a few times per month or not at all. Wireless technology was found to enhance the skills, productivity, and customer service of the participants, but it did not improve the respondents' abilities to negotiate projects and monitor project costs.

The respondents shed some light on the barriers to wider implementation of wireless technology in the CI. Slow download speeds and durability in the rough construction environment were the largest barriers that kept people from using wireless technology. It is anticipated that the widespread use of 4G LTE and protective gear (such as ruggedized cases) will alleviate these barriers. The respondents indicated that a return on their investment in wireless technology was not a primary barrier. Interactive, online collaboration will someday be commonplace among project teams, and companies will need to create more flexible organizational roles.

The analysis of the results showed no significant difference in the level of interest among the participants whose primary business was heavy, commercial, or residential construction. However, individuals in the heavy/civil specialization reported a statistically significant higher use of mobile technology. There was not a statistically significant difference between the level of interest and use among the field and office subjects. As expected, the respondents in the age group of 18-35 used wireless technology more than the group of individuals over the age of 36; however, there was no significant difference between these groups when compared against their interest in wireless technologies. This suggests that technology interest and use is becoming less dependent upon age. As expected, the respondents who spent more time per week on their wireless device realized an improved synergistic effect on productivity and customer service skills than the group who spent less time on their wireless device.

Tablets will outsell laptops in 2013, with over 240 million units to be sold worldwide, as it is no longer the exclusive domain of Apple. Lenovo, Samsung, Toshiba, and many other leading firms introduced their own tablets. There are interesting battles brewing on whether the tablets will be powered by ARM, Intel, or AMD processors and whether the operating system will be Apple iOS, Google Android, or Microsoft Windows. These choices are good for buyers as the tablets become more optimized for specific uses such as retail point of sale (POS) or enterprise sales force tools (Ellett, 2013). Developers of WPM and other construction management software need to create a responsive design to make these programs accessible and user friendly on both tablets and PCs.

The following recommendations for future study are offered:

- This study should be repeated periodi cally to evaluate the impact of future developments in wireless technology on the CI.
- Some open-ended questions should be incorporated into a questionnaire to gain a better understanding of the motiva tions behind the answers.
- The CM departments at BGSU and other universities should adjust, if needed, the construction curriculum to prepare the students better for the future digital construction world.
- Additional survey research should be conducted on a bigger sample of re spondents that include representative of different types of construction, geo graphical locations, sales volumes, field professionals, and so forth.

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Appendix A
Survey – Current State of Wireless Technology

1. Please indicate your company's primary business?

o General Contracting	o Construction Management	o Architectural/Engineering	o Subcontractor

2. Please indicate your company's primary construction focus? (please check one)

o Heavy/Civil	o Commercial/Industrial	o Residential/Multifamily

3. Is the majority of your time spent in the field or in the office?

o Field	o Office

4. How old are you?

o 18-35	o 36-55	o 56+

5. How much interest do you have in using the following wireless technologies using a scale of 1 (least) to 5(most)? If no interest or previously unaware of the product, please check "N/A." If you already own a product, please mark "Own."

	1(least)	2	3	4	5	N/A	Own
• Tablet PCs with mobile construction apps (iPad, Galaxy, ToughBook, etc.)							
• Smartphones with mobile construction apps							
• Cellular wireless network hardware (hotspots, wireless cards, etc.)							
• Web-based Project Management software							
• GPS Tracking Software and Hardware (Location, Movement, Speed, etc.)							
• RFID tags (Radio Frequency Identification for tracking materials							

6. How often do you access web-based project management software from a wireless device?

o Extremely often (Multiple Times per day)	o Very Often (Multiple Times per week)
o Moderately Often (A few times per month)	o Slightly Often
o Not at all	o

7. What type of Business information/applications are you accessing with a Smartphone or Tablet PC? (please check all that apply)

o Email	o Web-based Project Management software
o Productivity applications	o Drawings
o Product information/specifications	o How-to information
o Video	o Business articles
o Social media (Business Purposes Only)	o Other________________________________

8. **How many hours/week do you spend accessing construction content on a smartphone or Tablet PC?**

o None	o 1-4	o 5-9	o 10+

9. Please indicate the severity of barriers to using Wireless Technology on a scale of 1 (is a significant barrier to use) to 5 (not a barrier at all) for each of the following:

	1(barrier)	2	3	4	5(not a barrier)
• High cost					
• High risk of breaking (durability)					
• Slow download speed					
• Steep learning curve					
• Lack of security					
• Required training					
• Little return on investment					

	1(barrier)	2	3	4	5(not a barrier)
• Lack of a clean and stable environment					
• Price of additional wireless service plans					

10. My Smartphone or Tablet PC improves my

	Strongly Agree	Agree	Disagree	Strongly Disagree
• Productivity				
• Problem-Solving skills				
• Material management				
• Subcontractor/Labor Management				
• Decision-making process				
• Ability to meet tight deadlines				
• Collaboration				
• Customer Responsiveness				
• Ability to Negotiate/Win Projects				
• Ability to Monitor project cost				
• Change Order Management				

11. During 2012, do you expect to purchase/receive more, less or the same dollar amount of the following items? (versus the same period in 2011):

	More	Less	The Same
• Tablet PCs			
• Smartphones			
• Construction related Mobile Applications			
• Mobile Asset Management			
• Mobile Field Operations Management Solutions			
• Location-Based Services for Construction			

12. On a scale of 1 (least) to 5 (most), how much interest would you have in using the following mobile apps?

	1(least)	2	3	4	5(most)
• Timesheet tracking					
• Punch Lists					
• RFI submission					
• Submittal Review and Approval					
• Daily Reports					
• Quality Checklists					
• Safety Checklists					
• Drawing Review/Annotation					

13. I have used a smartphone or Tablet PC for the following: (please check all that apply)

o Sales Presentations	o Document Management
o Email	o Web-based Project Management software
o Punch Lists	o Daily Reports
o None of the above	o

14. I have used the following advanced wireless technology (please check all that apply)

o Mobile Asset Management (tools and equipment tracking)	o Material Management with RFID
o Handheld wireless scanner with RFID capabilities	o Field BIM (Building Information Modeling)
o Wireless Security/Alarm monitoring	o Digital Signature Capture
o None of the above	o

Addressing Safety and Liability in STEM Education: A Review of Important Legal Issues and Case Law[1]

By Tyler S. Love

ABSTRACT

Labs of today are less safe, students are inadequately instructed in safety, and faculty members do not have adequate experience to lead students safely (Haynie, 2008). Technology education, career and technical education (CTE), industrial education, engineering education, and science education laboratories are potentially dangerous places, which is why faculty members working in these areas must not only be concerned with student and faculty safety, but also protection against their own liability (Gathercoal & Stern, 1987; Frantz, Friedenberg, Gregson, & Walter, 1996; Hall & Marsh, 2003; Toglia, 2009). Injuries resulting from school laboratory activities are a harsh reality due to the hands-on design-based learning that is the cornerstone of science, technology, engineering, and mathematics (STEM) education. Despite potential injuries, STEM educators cannot fear liability and sacrifice the advantages of laboratory experiences that foster inquiry-based science and are essential to student learning (Zirkel & Barnes, 2011).

Studying and following developing case law can serve as a viable means for institutions, administrators, and faculty members potentially to prevent an accident and to avoid being found liable. STEM education teacher preparation programs must adequately prepare pre-service and in-service teachers and administrators through coursework, professional development, and developing case law. Being proactive about potential litigation will save time, money, and other costly measures that are important considering today's tight budgets and trying to prevent losses (Janosik, 2005). This article examines current legal cases regarding classroom and laboratory safety issues for grades P-16 STEM education programs. In addition, strategies for managing these risks and reducing liability will be discussed.

Keywords: STEM education, liability, case law, safety, technology education

BACKGROUND

Integrative science, technology, engineering, and mathematics (STEM) education is defined as, "the application of technological/engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education concurrently with content and practices of technology/engineering education. Integrative STEM education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels" (Wells & Ernst, 2012, para. 2). Therefore, in this article technology, engineering, and design education (TED) will encompass technology education, CTE, and industrial education to represent the T in STEM due to their considerable amount of (intentionally) integrative instruction (Herschbach, 2011), their curricular alignment with STEM initiatives (Asunda, 2011), and their high risk of liability (Frantz et al., 1996). This article examines current legal cases regarding classroom and laboratory safety issues for grades P-16 STEM education programs. In addition, strategies for managing these risks and reducing liability will be discussed.

The Utah Department of Health (2007) reported that on average, 160 students are injured and 86 school days are missed because of school shop (laboratory) injuries every school year in the state of Utah alone. The most common piece of equipment involved in school laboratory injuries was the band saw, which accounted for 13% of the reported injuries (Utah Department of Health, 2007). Also, laboratory safety extends beyond the school building to workplaces where students apply their educational experiences. Storm (1993) drew many parallels between safety in school laboratory settings and industry, specifically financial and productivity losses resulting from an accident. The National Institute for Occupational Safety and Health (Bergeson et al., 2002) reported that every year 6,000 Americans die from workplace injuries, 6 million people suffer from nonfatal workplace injuries, and injuries alone cost the U.S. economy more than $110 million. An incident could occur at any institution or school; thus, it is a best practice to remain proactive about legal issues (Janosik, 2005) related to STEM education.

Current TED laboratories use smaller scale equipment that is less powerful and intimidating than machines used during the industrial arts era (Haynie, 2009). Despite not being as powerful or intimidating, faculty members (all educators) and students may not be properly trained in their safe operation, resulting in injuries and lawsuits. Haynie (2008) believes that "The labs of today are less safe, the students of today are inadequately instructed in safety, and the teachers of today simply do not have adequate experience with equipment to lead students safely" (p. 97). This risk poses a threat to students, faculty members, administrators, institutions, and school districts. To avoid being found liable, administrators and faculty members in STEM education teacher preparation programs should stay informed regarding the latest lawsuits occurring in STEM education classrooms at the P-16 grade levels.

LITERATURE REVIEW

The common misconception of administrators and faculty members is that these type of accidents (e.g., eye injuries, lacerations, amputations, and other permanent injuries resulting from STEM education classroom and laboratory activities) will not happen to them or occur at their school (Pennsylvania Department of Education [PDE], 2012). The reality is that these accidents occur at all types of schools more often than administrators and faculty would like to believe. In 2007 Barrios, Jones, and Gallagher conducted a study analyzing 455 cases from 1996-2002 in which P-12 schools or school districts were sued for an injury sustained on school property. They found that on average, cases took nearly four years from incident to trial or settlement. Approximately two thirds of the cases resulted in schools paying an award because of a verdict directed for the plaintiff or a settlement. The mean award was $562,915, although Barrios et al. (2007) admitted that the award amounts were highly skewed.

Barrios et al. (2007) cautioned that the percentages of injuries and settlements retrieved by their legal research database are likely to be smaller than the published numbers because many cases are settled before being filed with a court. Despite settlements being underrepresented, they still account for the most common outcome representing the decision in 40% of the cases. Laboratory or shop injuries were the second least common activity to cause an injury lawsuit, only accounting for 7.6% of the cases. Although this number seems small, it still accounts for permanent injuries and consumption of time and money for the school, which was reported in the mean award amount. The majority, almost 80%, of the injuries occurred to students. About 58% of the time the injury resulted from the negligence to properly supervise. Barrios et al. (2007) reported that amputation resulted in the least amount of cases, but had a mean award of about $1 million. Tendon, cartilage, or ligament damage occurred 5.9% of the time, with a mean reward of about $300,000, and lacerations occurred 10.6% of time, resulting in a mean award of about $230,000. Although this data summarizes injuries within P-12 schools, it shows the significance to proactively prepare pre-service and in-service teachers to be properly trained in safety and liability issues. Despite the permanent damage to the student, it will cost the defendant hundreds of thousands of dollars, sometimes millions. Administrators and faculty members can save countless hours, headaches, and dollars by understanding the law and researching case law to implement precautionary safety measures.

The current educational reform movement has been calling for the integration of STEM education (National Commission of Excellence in Education [NCEE], 1983; American Association for the Advancement of Science [AAAS], 1989; AAAS, 1993; AAAS, 2011; International Technology Association [ITEA/ITEEA], 2000/2002/2007; National Research Council [NRC], 2012). A related question is, who is adequately trained to teach this content in a safe and integrative manner (Wells, 2008)? Most recently, A Framework For K-12 Science Education: Practices, Crosscutting Concepts, And Core Ideas (NRC, 2012) explicitly calls for integrating engineering concepts within the science curriculum. Although hand

and power tools are routinely used by TED teachers to implement engineering concepts in the curriculum, science educators need more instruction in hazard recognition and safety training (Roy, 2012) to successfully implement design-based engineering content using these tools.

TED educators play a vital role in delivering integrative instruction (ITEA/ITEEA, 2000/2002/2007), and Sanders (2012) suggested that they should play a prominent role in delivering integrative STEM literacy. Because most educators are not adequately prepared to teach STEM education simultaneously, collaboration among STEM education instructors is the most promising approach for implementing integrative practices (Wells, 2008).

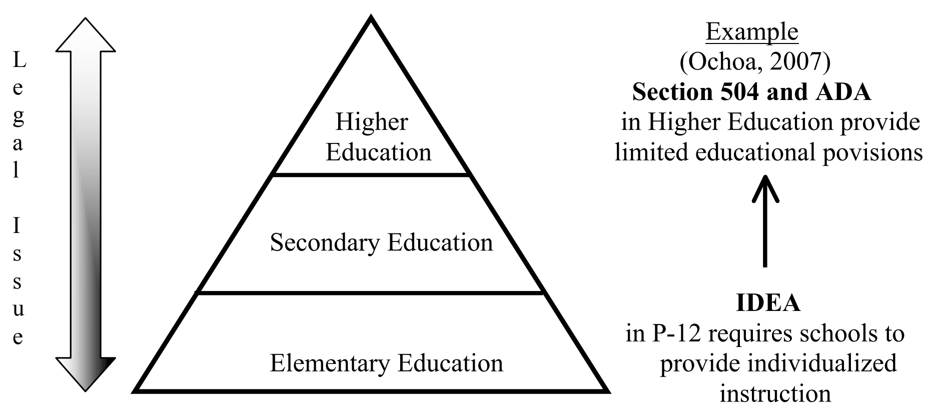
Minors and Adults on College Campuses

Paying attention to changes in the law and following case law resulting from employee and institutional liability is critical in anticipating and planning for potential issues. Employees in higher education may also benefit from following litigation at the P-12 level. Litigation beginning at one educational level may emerge or evolve into legal issues at another educational level. Figure 1 displays the way legal issues can start at one level of the educational continuum and work up to higher education or down to secondary and elementary education (Janosik, 2005).

Janosik (2005) cautioned higher education employees to interpret P-12 case law with great care. Judges will draw differences between P-12 children who are normally minors and are required to participate in schooling until the age of 16 and college students who are legal adults if 18 years or older. Students who are legal adults are usually deemed able to think for themselves and can exercise free choice (Janosik, 2005). The lines become blurred when a college freshman is 17 years old (still a minor) despite the majority of students at an institution being legal adults. A different legal process and care of duty may be applied toward minors.

At the P-12 1evel, faculty members assume some of the rights and duties of the parents, also known as in loco parentis (Kigin, 1983). However in higher education, and sometimes in secondary education, in loco parentis is not applicable because of the age and maturity of the students (Hall & Marsh, 2003). Paying attention to the case law for both minors and adults may prove beneficial. Knowing the law for students with disabilities will also be helpful, because

Figure 1. Safety and Liability in STEM Education



Anticipating legal issues in Education. Legal issues on the left can move up or down the educational continuum in the triangle. The example on the right shows future implications to provide more provisions for students with disabilities, which is slowly emerging from P-12 into higher education. Adapted from personal communication with S.M. Janosik, September 13, 2012.

these students may require a care of duty regardless of age and special accommodation. Legal rulings at the higher education level may differ from those at the P-12 level; however, important information can be drawn from examining rulings at both levels.

Tort Liability

Injuries to students in a STEM education classroom are classified as tort liability, also referred to as tort law. Kaplin and Lee (2007) define tort law as follows:

> A civil wrong, other than a breach of contract, for which courts will allow a remedy. A tort claim generally involves allegations that the institution, or its agents, owed a duty to one or more individuals to behave according to a defined standard of care that the duty was breached, and that the breach of that duty caused injury to the individual(s) (p. 87).

Although tort liability has a broad range, negligence is the most common claim brought against institutions and faculty members for injuries sustained in a STEM education classroom (Toglia, 2009). In addition, Ferguson, Ford, and Bumgarner (2010) claimed that common tort cases involving higher education institutions are instructor negligence in laboratory settings. Negligence occurs when an employee or institution breaches the duty to protect students from foreseeable harm, if an employee or institution fails to act on a situation, or if an employee or institution's actions contributed to the plaintiff's injury (Owen, 2007). An institution is generally liable for tortious acts committed by employees acting within the scope of their job responsibilities. For example, if a student, an employee, or an invitee (an individual that an institution entitles or permits to be on its property) is injured as a result of a careless or wrongful act of an employee, the institution may be liable (Kaplin & Lee, 2007).

When students or other invitees are injured resulting from on-campus instructional activities, they may file negligence claims against either the institution or the employee. Individual employees may be liable if they committed the tortious act, directed it, or participated in its commission. Both the employee and institution may be liable if an employee commits a tort while representing the institution and is acting within the scope of the authority delegated by the institution. However, an employee may be personally liable and the institution not liable if the employee committed a tort while acting outside scope of delegated authority (Kaplin & Lee, 2007).

Strict liability is another type of tort that can be brought against either an institution or its employees. Strict liability is defined as, "the legal responsibility for damages, or injury, even if the person found strictly liable was not at fault or negligent" (Batten, 2010, p. 403). This means that the defendant (institution or employee) could be found not responsible, but asked to pay the plaintiff to make up for the loss in the incident.

The Shotgun Theory of Litigation

In a tort lawsuit, the plaintiff's attorney will frequently use "shotgun litigation." In this case, the plaintiff will file suit against "anyone even remotely connected to an incident to ultimately find a 'deep pocket' defendant liable or to force a settlement from that deep pocket even when there is no liability" (Phillips, 1986, p. 699). This could involve bringing suit against the institution, administrators, employees, third-party companies (e.g., machine manufacturer), and possibly other students. The judge will determine who can be put on trial. The motive for plaintiffs to sue anyone involved is to find someone who is liable and will owe money to the plaintiff. Administrators or employees at an institution may find their names in a lawsuit even if they were not directly involved. It is important for administrators and employees to be aware of what is going on at their institution so they do not end up being found liable for an incident that they could have prevented.

Immunity is Not Always an Option

Immunity means that the institution or employee cannot be sued according to state statutes. Many employees are misled into believing that they are shielded from lawsuits due to governmental or sovereign immunity. Immunity is narrowly defined and has numerous exceptions (Toglia, 2009). Even in the case where governmental immunity is granted to an institution, students may still sue individual employees for their negligence (Schimmel, Fischer, & Stelleman, 2008).

For example, under section 8541 of the Pennsylvania Judicial Code (1980), local government agencies (such as schools) are generally immune from tort liability; however, this is not absolute. Section 8542 of the Pennsylvania Judicial Code (1980) states that an injured party may recover in tort from a local agency if there is negligence in several areas. One of those areas is real property, which refers to the buildings or fixtures on the government agency's property. Fixtures can sometimes refer to equipment in a STEM education laboratory as is shown in the cases described later in this article. Real property negligence is not applicable where there is no defect or condition of the agency's real property that causes an injury. This interpretation of governmental immunity will also be seen in many of the cases presented later in this article.

Immunity laws are different in every state, so it is important for employees and institutions either to thoroughly understand the laws in their area (Roy, 2009) or to seek legal counsel to make sure they are in compliance with the laws. Ignorance is not a defense against a tort liability suit. Because governmental immunity is not always applicable, employees and institutions must educate themselves and others on how to avoid being negligent and found liable. One way to avoid being found liable is to review case laws and make the proper adjustments at one's institution.

CASE LAW

Lawsuits relating to STEM education programs and facilities can be found in the newspaper, scholarly journals, and in academic legal research databases, as shown in Table 1. It is seemingly impossible for an individual to research every case related to STEM education, so Janosik (2005) suggested nine methods to stay abreast of important legal cases (Table 2).

Examining STEM Education Case Law

One of the fundamental cases in science education liability is Usher v. Upper Saint Clair School District (1985). In this case an instructor dropped a chemical beaker that splashed flaming fluid on a student's face. The student (Usher) alleged that the instructor was negligent in failing to take adequate measures to control the area surrounding the experiment. The court ruled that the instructor failed to control the students, not the area of the experiment; therefore, immunity was granted to the instructor and the school.

Eleven years later an accident at Georgia Tech occurred (Niles v. Board of Regents, 1996) when a doctoral student sustained injuries resulting from mixing chemicals inside a metal canister that exploded. The student graduated summa cum laude with an undergraduate degree in chemistry and spent hundreds of hours in the lab prior to this incident. The student sued Georgia Tech and the Board of Regents, but the

Table 1. Sources for Finding STEM Education Case Law

Source	Example(s)
In The News	Local and national newspapers, professional association newsletters, radio, local and national television news stations.
Scholarly Journals	*The Chronicle of Higher Education* *Science Teacher* (published by NSTA) *The Technology and Engineering Teacher* (published by the ITEEA) *Journal of School Health* *NASPA Journal* Other journals not listed
Academic Legal Research Databases	FindLaw (a free resource) – (Thomson Reuters, 2013a) LexisNexis – (Reed Elsevier Inc., 2013) Westlaw – (Thomson Reuters, 2013b)

Table 2. Staying Abreast of Important Legal Cases

Method	Action
Seek Expert Advice	Use expertise of others at your institution (e.g., attorneys, risk managers)
Subscribe to Periodicals	Invest in high-quality periodicals that address contemporary strategic issues.
Identify Topics	Create a manageable list of hot topics.
Involve Staff	Delegate responsibilities to include staff.
Search the Internet	Use the internet to search effectively.
Monitor Agendas	Follow the activities of federal, state, and local officials to identify shifts in agendas.
Follow Groups	Track the activities of special interest groups.
Network with Others	Build personal networks with informative people.
Share New Findings	Disperse new legal developments in a brief and effective manner.

court ruled in favor of the Board of Regents. They claimed that neither the university nor the professor were required to warn the student about mixing chemicals since he had a degree in chemistry, and there was no evidence that a lab safety course would have prevented the accident.

Fast-forward another 13 years to another case (Heuser ex rel. Jacobs v. Community Insurance Corporation, 2009) in which an eighth grade student sustained a cut while using a scalpel to dissect a flower in science class. His parents sued the school for negligence because he was the third student that day to sustain a cut from a scalpel in that class. The court ruled in favor of the student, finding that no precautionary measure was taken in response to the open and obvious danger of the scalpels. The instructor had the option to pick one precautionary measure over another but instead chose to do nothing, resulting in the school district being found liable.

A more recent case (Grammens v. Dollar, 2010) involved another eighth grade student in a science class who suffered an eye injury while launching a two-liter soda bottle with water and air pressure. When the bottle lifted off the launch pad and the student removed the pin that held the bottle in place, the pin struck the student in the eye. The student's father sued the instructor, the school principal, and the school superintendent, alleging the injury was the result of a violation of the county board of education's eye protection policy. The trial court granted immunity to all of the defendants because the negligence claims were discretionary and protected from personal liability under official immunity. The Court of Appeals agreed that the superintendent and principal qualified for immunity; however, it ruled the instructor should not be granted immunity because the eye protection policy was mandatory, not discretionary. On appeal, The Supreme Court of Georgia ruled that because the term "explosive materials" did not appear in the county's eye protection policy, it was the instructor's discretion to use safety glasses for the bottle rocket activity and the instructor was granted immunity from personal liability. The school district was encouraged to rewrite their safety glasses policy with greater detail.

There have been many cases involving TED education due to the nature of the high-risk equipment used in the profession. One case (Fontenot v. State ex rel. Department of Education, 1994) involved the student's father suing the State of Louisiana Department of Education, Pelican Mutual Insurance Company, Horace Mann Insurance Company, the instructor, and the school board for a table saw accident that injured his 14-year-old son who had special needs. The instructor had demonstrated the use of the table saw and observed students individually to ensure that they had mastered skills in its use. The student (Fontenot) was adjusting the guide fence when someone distracted him by calling his name, causing his hand to slip into the still-turning blade. The instructor had not left his immediate teaching area or abandoned his supervisory duty. The instructor and his insurer settled with the Fontenots. Fontenot's father also brought suit against the school for placing his son in a class that was not appropriate for his son's disability, but the court ruled his son was appropriately placed.

In 2002, Cureton v. Philadelphia School District, involved a 13-year-old student (Cureton) who permanently disfigured his right index finger while cleaning a scroll saw. The instructor informed students to keep the machines clean, and Cureton was granted permission to clean the saw. After cleaning the saw, Cureton reached across the saw and turned it on, which resulted in his untucked shirttails getting caught in the saw's pulleys. The pulleys amputated a portion of his finger, which was surgically repaired at a local hospital despite the student suffering permanent deformation and scarring. Cureton's mother originally filed a product liability suit, which she later changed to negligence claims against the school district. The court ruled that the scroll saw was real property and not personal property since the saw was in place since 1987, permanently hardwired through the building, bolted to the floor, and was never removed from the shop. The court used the ruling from Usher v. Upper St. Clair School District (1985) to determine if the negligence was the result of the real property (the saw) or was simply a cleaning accident that went awry. The court found the school district liable since the instructor neglected to turn the main power off when there was foreseeable danger. The instructor gave permission and responsibility to the student to clean the saw, and on prior occasions the teacher turned the power off, but not on this occasion. The school district argued that Cureton was able to comprehend danger and should have known better, but failed to present evidence showing that he was negligent because other classmates did or would do the same thing when cleaning the machine. Cureton was awarded $35,000.

Three years later in Wells v. Harrisburg Area School District (2005) an 11th grade student experienced a kick back on a table saw that hit him in the stomach, causing him to lose his balance and place his hand over the blade. He lost his ring finger, the tips of his thumb and small finger, and sustained serious injury to his middle finger of his left hand. The student was told that the guard could not be used when performing this type of cut, however expert testimony showed that another guard could have been purchased and used during a groove cut for that particular saw. The instructor and district engaged in negligent care by allowing novice students to use a table saw that lacked an adequate safety device. Therefore the court ruled that the school district created a dangerous condition of the real property (table saw) that caused the student's injuries. The student was awarded $240,000.

Just one year later in another Pennsylvania case, LoFurno v. Garnet Valley School District (2006) a 15-year-old 9th grade student caught his fingers on both hands between the belt and table while operating a vertical belt sander. The student (LoFurno) allegedly suffered permanent damage to his right and left index fingers. His parents sued the school claiming that the belt sander was a fixture (real property) with no safety guards or warnings on the sander, and also negligence for not properly supervising and instructing its employees on the proper use of dangerous equipment. The court ruled the sander as real property, but on appeal the decision was reversed. The appellant court granted the school district immunity, ruling that the sander was not realty because it was not bolted down, it could be plugged into any outlet in the room, and the dust collection hose was removable.

Learning from Case Law

Many of the cases presented involved middle and high school students whose parent or guardian brought suit against the school because these people were financially responsible for the medical bills of that child. Contributory negligence was used as a defense in Niles v. Board of Regents (1996) because the court looked at the student's age and experience in the chemistry lab to decide that he was negligent for performing a task he should not have performed. This defense may not have been valid if the student were a minor or had little experience in the chemistry lab. The variety of tools and processes that brought about these lawsuits shows the vast range of safety preparation and knowledge that STEM educators must possess. Roy (2011) emphasized the importance of educating pre-service and in-service teachers about how to safely use and teach about the tools in the lab.

These cases illustrate that no case is clear-cut. A great deal depends on the evidence presented and precautions taken by the institution and the faculty member. Many of the defendants in the Pennsylvania cases were granted immunity when a piece of equipment was deemed personal property or realty under state law. In Cureton v. Philadelphia School District (2002) the court ruled the scroll saw was real property, but in LoFurno v. Garnet Valley School District (2006) the school's belt sander was not deemed real property. The arguments the defendants in Garnet Valley School District case used to establish their belt sander as personal property were different than the arguments used in the Cureton case. The significance of the LoFurno case is it now allows school attorneys an opportunity to cite it when trying to obtain immunity by proving a machine is not real property. This creates more opportunities for school districts in the same jurisdiction to be granted immunity in future cases.

Understanding case law as verdicts emerge allows faculty members and institutions to make the proper adjustments to their facilities and teaching practices. The Wells case serves as a reminder for faculty members and institutions to check and make sure the proper safety guards are in place and working. The Fontenot v. State ex rel. Department of Education (1994) case should make faculty members more aware of what types of students they are letting use dangerous machinery that requires advanced skills. Grammens v. Dollar (2010) encourages institutions or school districts to check the wording of their safety policies.

Regardless of the tools used in the classroom, sometimes what faculty members do or do not do can determine if they and/or the school is at fault. In Cureton v. Philadelphia School District (2002) although the student had his shirt untucked and voluntarily reached across the saw to turn the power on, the faculty member was at fault for allowing the student to clean the machine and not turning off the main power supply as he had done numerous times before. In Heuser ex rel. Jacobs v. Community Insurance Corporation (2009) the faculty member took no precautions to address the continual danger of the scalpels (e.g., use scissors, have the instructor perform cuts) so the school district was found liable.

As new cases are decided, faculty members and institutions need to adapt their pedagogy and policies to address the changes in the law. More recently, Western Carolina University reviewed case law and used a risk assessment model to document and gain insight into developing a safety program for their engineering technology laboratories (Ferguson et al., 2010). Using recent case law to be proactive about potential hazards may take time and money to implement, but is quicker, cheaper, and less stressful than the litigation process resulting from an accident. Dealing with a legal issue after a summons has been served is not cost effective (Janosik, 2005). Being proactive about potential litigation will save time (personal and instructional), money, and reputations (Storm, 1993).

Case law pertaining to negligence resulting in injury of students in higher education environments is limited; however, the courts have established precedence in areas that offer insight for faculty members and administrators to develop laboratory safety guidelines and procedures (Ferguson et al., 2010). As new cases emerge, faculty members, administrators, and institutions should pay attention to the outcome of the cases. New rulings in tort liability cases may open up doors to increased liability for faculty members and institutions. College administrators need to be alert for important changes in the law. Focusing only on case law and emerging issues is only one portion of the education enterprise, which provides a limited view of legal issues that may be developing (Janosik, 2005). Most important, legal cases should serve as a learning tool for STEM educators. Faculty members and institutions cannot predict or prevent every accident, but they can implement proper systems to try to avoid being held liable if a similar incident happens at their institution.

TORT LIABILITY

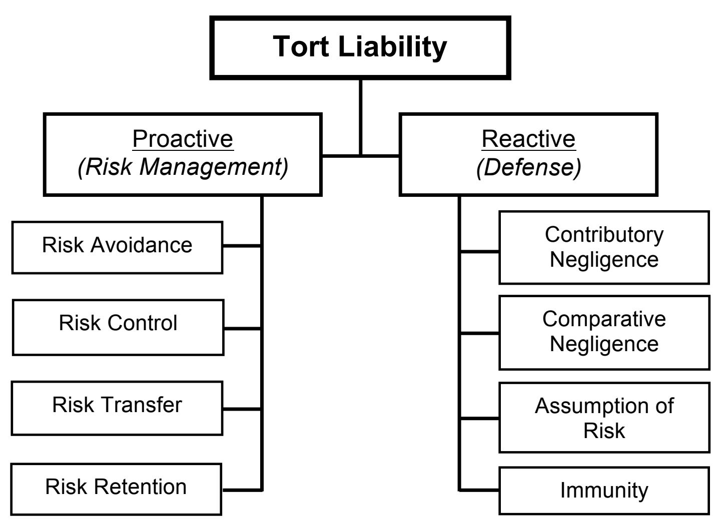
Best Practices to Avoid Tort Liability

According to Kaplan and Lee (2007) risk management can help stabilize the institution's financial condition over time and improve the morale and performance of faculty by alleviating their concerns about personal liability. Kaplin and Lee (2007) suggested four major methods of risk management to avoid legal liability: (a) risk avoidance, (b) risk control, (c) risk transfer, and (d) risk retention (Figure 2). Risk avoidance is the best method to reduce liability because the activity is avoided or eliminated due to foreseeable liability concerns (Toglia, 2009). Sometimes a risk cannot be avoided; therefore, other methods such as risk control can be implemented. Risk control is when restrictions are created to reduce the frequency or severity of exposure to liability.

Risk transfer could involve methods such as purchasing liability insurance and the use of waivers (Kaplan & Lee, 2007). Unfortunately institution and union insurances may not be enough, and sometimes these exclude hazardous activities undertaken by STEM education employees. An individual liability insurance policy, such as the one offered through the ITEEA is added protection in the event that litigation is brought against an individual. Another option is for STEM education employees to purchase a "business pursuits" endorsement or attach a rider to their homeowners insurance, which acts as professional liability coverage (Toglia, 2009). Individual liability insurance policies are usually fairly inexpensive, especially if they are ever needed to cover legal fees associated with a lawsuit. Institutions and faculty members should check with their school to ensure what type of liability insurance they have and what it covers prior to the event of an accident. Risk transfer could also involve hiring a private company to maintain the equipment in a laboratory. However, transfer of risk is not a universal defense for all institutions facing litigation (Toglia, 2009).

The last method to avoid liability is risk retention because the insurance cost is too high, the expected losses are minimal, or the probability of risk is extremely small. Institutions and employees must decide the probability and cost of a potential lawsuit before they approve the activity and take any precautions. In the event that a lawsuit is brought against an institution or employee, there are certain defenses that can prevent them from being found liable.

Figure 2. Addressing Tort Liability in STEM Education



Defenses Against Tort Liability

The four defenses against tort lawsuits are (a) contributory negligence, (b) comparative negligence, (c) assumption of risk, and (d) immunity (Figure 2). Contributory negligence results when the student's own negligent action contributed to his or her injury. Most experts believe this defense is of little value when a minor is involved (Toglia, 2009). Comparative negligence allows juries to find the degree to which each party is negligent, authorizing recovery based on the degree of fault (Gathercoal & Stern, 1987). For example, a court can determine what percentage the defendant was liable and ask that person to pay for a percentage of the damages. Assumption of risk is when a participant engages in an activity that involves a risk and is deemed to have assumed the risks inherent in the activity (Hall & Marsh, 2003). The assumption of risk is dependent upon the age, maturity, experience, and familiarity with the risk, despite any signed waiver. Assumption of risk is usually not a viable defense in a negligence claim if an employee fell below the standard of care (Gathercoal & Stern, 1987).

The last defense is immunity, which was previously discussed. It is important to note that immunity varies from state to state (Kaplin & Lee, 2007), therefore employees and institutions must know immunity laws specific to their state. Despite the defenses described previously, employees should always act within their job description and good faith to avoid being liable for an accident. The best defense against a tort is anticipating legal issues by reviewing case law and keeping current on any changes in the law (Janosik, 2005).

FUTURE IMPLICATIONS

Presenting recent case law to pre-service teachers, in-service teachers, and other employees may be a challenge. Simply passing along the information may not assure that the appropriate attention and reflection is given to the cases. Using a case study pedagogical approach can provide employees the chance to put their selves in the classroom situation, discuss the outcomes, and identify things they would have done differently before the final verdict is revealed. This case study pedagogical approach is often implemented in medicine and law schools. In law, new decisions, new cases, and new laws are built upon old decisions (Herreid, 1997). Harvard Law School (2012) uses a case study approach to educate their students. They found that the case study teaching method engages readers in active learning by putting them in the shoes of real people solving real problems. They also found that it is an appropriate teaching method for undergraduate and graduate education, as well as professional development workshops and courses. It elicits dynamic interaction in a real problem-solving scenario.

Most articles have been written recommending safe practices for science and TED faculty members to avoid liability in the event of an accident. Gunter (2007), Haynie (2009), DeLuca & Haynie (2007), Roy (2009), and Toglia (2009) all provide an extensive list of recommendations to create a safe learning environment in the laboratory. The number one recommendation that Haynie (2009) stressed is to have all persons wear safety glasses in the laboratory at all times. Togolia (2009) emphasized implementing safety throughout the curriculum and modeling safe practices, which is also mirrored in Haynie's article stating that safety is a process that is continually reinforced, not an event. Roy (2009) described safety actions for students and safety actions for teachers. He stressed the importance of lab safety training, a student and parent lab safety acknowledgment form, safety tests, MSDS sheets, keeping record of safety lesson plans, keeping record of student attendance during safety lessons, putting safety issues on department meeting agendas, displaying safety signs around the lab, and recording equipment inspections. All of these strategies, if recorded properly, create a paper trail that could be used in a court of law to prove the faculty member and school took numerous precautions to promote a safe learning environment. These articles should be referenced for professional development and safety training of pre-service and in-service teachers.

Ferguson et al. (2010) provided a set of safety recommendations for higher education faculty slightly different than Gunter (2007), Haynie (2009), DeLuca & Haynie (2007), Roy (2011), and Toglia's (2009) recommendations geared toward P-12 teachers. Among the many recommendations, Ferguson et al. (2010)

recommended working with the institution's attorneys to establish a safety plan and conduct workshops to learn the law. Another recommendation they make is to never accept an assignment teaching in a laboratory in which one is not professionally prepared to teach. With the shortage of qualified STEM teachers to fill positions, this recommendation may be one that is often breached. Despite the differences in P-12 and higher education, all of the articles provide valid recommendations that should be followed at all levels. Although employees and institutions cannot prevent being sued, they can take the proper precautions to prove that they did everything they could to avoid foreseeable danger.

CONCLUSION

Since institutions and faculty members cannot predict when they will be sued, it is critical to stay current on developing issues via case law. Bridging the gap between P-12 and higher education is essential to planning for potential legal issues coming down the pipeline (Janosik, 2005). Safety and liability will continue to be an issue for STEM educators. The hands-on design-based learning nature of these courses will carry increased liability compared to many other content areas. This design-based learning methodology that defines STEM education must remain the crux of its pedagogical practices.

Keeping a hands-on design-based learning pedagogy will require STEM education teacher preparation faculty to better prepare pre-service teachers and enhance in-service teachers' knowledge of safety and liability. Instructing pre-service and in-service STEM educators and administrators how to follow developing case law can save time, money, and injuries that result from accidents (Janosik, 2005). STEM educators of all disciplines must be adequately trained to safely implement the types of curriculums that national organizations and councils are requiring STEM educators to use. Safety training has been an essential part of the technology education curriculum for years. TED education must share its expertise in this area with the other STEM education disciplines to assure collaboration among educators who can safely deliver an authentic context for problem solving and transfer of knowledge that makes STEM education unique (Wells, 2010).

STEM educators cannot fear liability and sacrifice the advantages of laboratory experiences that foster inquiry-based science and are essential to student learning (Zirkel & Barnes, 2011). As Ferguson et al. (2010) suggested, "Tort law is changing constantly; it would be wise for professors to stay abreast of the law by periodically reading law review articles in scholarly journals" (p. 8). Through proper preparation and professional development, faculty and institutions can use case law to stay informed of the newest litigation and adapt their practices accordingly. Modern technology is constantly developing improved devices (Storm, 1993) with new safety considerations to learn. Without losing the laboratory learning experiences integral to STEM education, teachers in these fields must adapt to meet the safety requirements of future technologies and train professionals to keep student safety the center of focus.

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[1]*Disclaimer: This article is not intended to replace advice from competent legal counsel. It merely presents cases that recently occurred in STEM education classrooms and shows how institutions and individuals can be proactive in avoiding liability.*

A Review of the Impact of ISO 9000 and ISO 14000 Certifications

By Eli Kofi Aba and M. Affan Badar

Abstract

This paper presents some of the most important findings of studies of the impact of ISO 9000 and ISO 14000 certifications on organizations, based on a literature review. The article discusses potential synergistic advantages that can be derived from an integrated quality-environment system and qualitative benefits using ISO 9000 and 14000 certifications. This article also discusses some of the limitations of the current literature and how these can be addressed in the future research.

Keywords: ISO 9000, ISO 14000, quality systems, environmental systems

Introduction

Global competitiveness, an attribute of today's economic scenario, has compelled companies to invest more and more resources into enhancing their management efficiency. This economic and market globalization has given rise to an increasingly important role of standards. Guasch, Racine, Sánchez, and Diop (2007) and the National Research Council (NRC) (1995) explained the positive economic effects of standards: ability to exploit network externalities, increase productive and innovative efficiency, decrease imperfect information, diffuse information, reduce cost, promote competition, increase compatibility, promote process management, and foster public welfare. These benefits are not mutually exclusive (NRC, 1995). Guasch et al. (2007) stated the contradictory negative economic effects of standards: imposition of constraints on innovation and the decrease of market competition. However, Guasch et al. (2007) concluded that the positive effects of standards outweighed the negative effects.

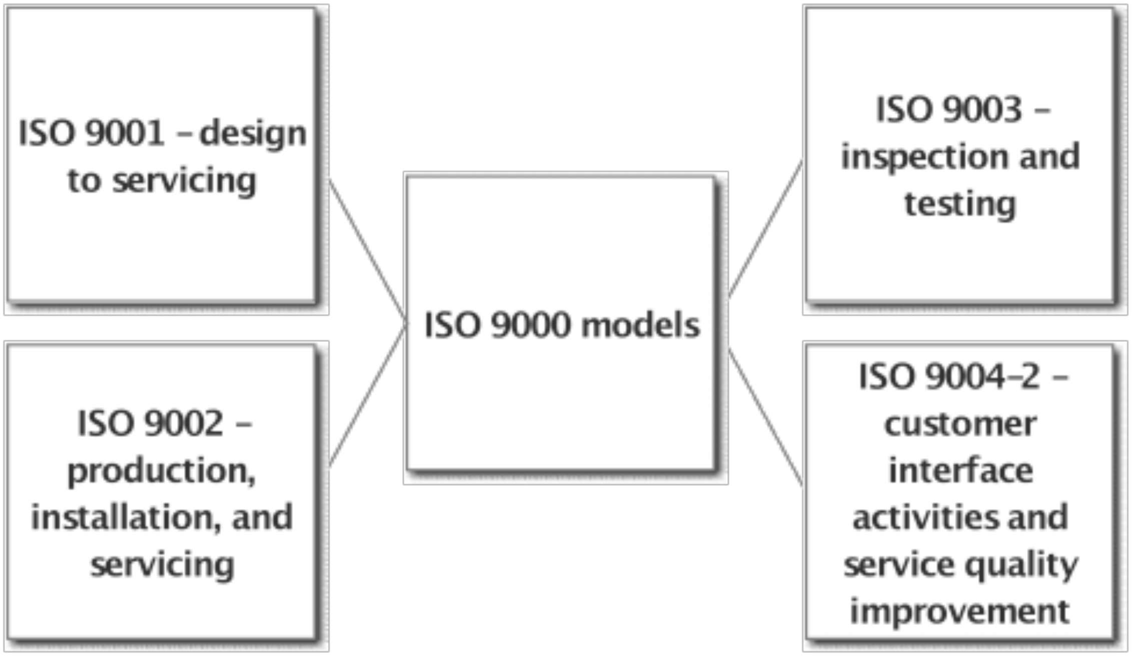
Approximately 60 programs and awards reward firms for improving quality globally (Wilson, Walsh, & Needy, 2003). The most famous ones are the Malcolm Baldrige National Quality Award, Six Sigma, ISO 14000 programs, and ISO 9000 programs (Troy, 1992). Most employers in the United States would want to know if the financial advantages associated with ISO 9000 and ISO 14000 registrations outweigh the costs associated with obtaining these certifications. ISO 9000 and ISO 14000 are not standards in themselves; they are descriptors for series of standards as described in the next sections. The main standards are ISO 9001 and ISO 14001, which set out the requirements for achieving efficient quality management and environmental management systems, respectively (Morris, 2004). In this article, ISO 9000 and ISO 14000 refer interchangeably to ISO 9001 and ISO 14001, respectively.

ISO 9000

The International Organization of Standardization (ISO) was formed in Geneva, Switzerland, in 1946 to develop international, industrial, and quality standards as a model for quality assurance standards in design, development, production, installation, and service. ISO 9000 is a series of quality management standards published by the ISO in 1987 after a process of consensus handled by ISO Technical Committee 176; these are codified, verifiable, and easily adaptable (Wilson et al., 2003). ISO 9000 standards are so adaptable that updates and changes have been made roughly every three years since their adoption. According to Pantouvakis and Dimas (2010), ISO 9000 helps companies establish quality assurance systems. Kartha (2004) stressed that these standards are generic and not only limited to products or services, but they also apply to all processes and can be employed by manufacturing and service organizations.

Figure 1 shows the four ISO 9000 models for quality systems. The ISO 9001 model depicts all activities from researching, designing, building, shipping, installing, and servicing. The ISO 9002 model guarantees production, installation, and servicing. The ISO 9003 model is restricted to inspection and testing. The ISO 9004 or 9004-2 model deals with customer interface activities and service quality improvement (Todorov, 1996).

Figure 1. The Four Models for Quality Management System (Todorov, 1996)



ISO 9000 helps firms with internal improvements and strategic benefits that accompany the quality tool. Wilson et al. (2003) pointed out that the internal improvements comprise all business activities that are associated with a product and should be carried out in a three-part continuous cycle of planning, control, and documentation. ISO (2011) states a company that obtains ISO 9000 fulfills a customer's quality requirements and applicable regulatory requirements, while targeting enhanced customer satisfaction and achievement of continual improvement of its performance.

ISO 14000

ISO 14000 is a descriptor for a series of environmental management standards that was developed based on the success of the international quality standard ISO 9000 and in response to the global concern about the environment (Delmas & Montiel, 2008; Morris, 2004). According to Sayre (1996), ISO 14000 is derived somewhat from British Standard 7750, which includes the specification for environmental management systems and is considered globally a foundation for sound environmental performance. Furthermore, the 1994 American National Standard, ANSI/ASQC E4 might enhance the understanding of the components of ISO 14000. ISO (2011) pointed out that a company that obtains ISO 14000 certification minimizes the harmful effects that occur from its activities to the environment and accomplishes continual improvement of its environmental performance.

ISO 9000 and ISO 14000 are similar in their processes, but they target different elements of a company (quality versus the environmental impact of operations). Delmas and Montiel (2008) showed that ISO 14000, to some extent, complements the quality management system by establishing a similar system for the management of the environmental impact; however, these standards also address slightly different audiences. ISO 9000 aims to improve quality and facilitate business objectives. ISO 14000 targets the improvement of environmental performance and the facilitation of relationships with not only market actors, but also nonmarket actors, such as regulatory agencies and nongovernmental organizations (NGOs). The success of the implementation of ISO 9000 promotes the adoption of ISO 14000.

Impact of ISO 9000

McAdam and McKeown (1999) mentioned that the main benefit of ISO 9000 is that it gives rise to an effective quality system that assists in the elimination of errors, which eventually saves money on rework and scrap. They also claimed that ISO 9000 offers marketing benefits because ISO 9000 certification indicates an internationally recognized level of quality. According to Lloyd's Register Quality Assurance Ltd. (LRQA, 1995), the following reasons are why companies implement ISO 9000: pressure from large customers; reduce first time failure; reduce the costs of customer claims; get things right the first time; improve service to the customers and increase competitiveness; and maintain contracts with existing customers. Chow-Chua, Goh, and Boon Wan (2003) indicated that the two most common benefits of the ISO 9000 certification are increase in productivity and access to overseas markets.

Most companies place great emphasis on ISO certifications as a marketing tool. Burgess (1993) highlighted that certification tends to lead to improved marketing. However, Burgess also explained that most companies, irrespective of location, see improved efficiency as a major benefit. Porter and Rayner (1991) also made the same conclusions, that benefits from certification are associated with marketing factors. Additionally, Porter and Rayner (1991) mentioned the correlation between the benefits companies derive from certification and the reasons for their pursuing certification. Other studies indicate that benefits of ISO 9000 can far outweigh the costs of registering, but ISO 9000 should not be seen as a "quick fix, but as a long-term investment which requires commitment and continued effort" (McAdam & McKeown, 1999, p. 232).

Quinn (1992) stressed that considerable effort is made both in terms of money and valuable management resources to reach the level necessary for the achievement of ISO 9000 quality standards. However, Quinn stated that quality rewards itself many times over "in repeat orders from satisfied customers, in new customers . . . reduced waste . . . and in greater employee job satisfaction" (McAdam & McKeown, 1999, p. 232).

ISO 9000-associated papers focus mainly on the qualitative benefits associated with certification, such as increases in communication and an understanding of how the firm works. Regarding the quantitative benefits, there is little published documentation. Corbett, Montes, Kirsch, and Alvarez-Gil (2002) quantitatively showed that ISO certification does result in improved financial performance against competitors. Porter and Rayner (1991) found that the cost of obtaining ISO 9000 can usually be recovered within three years through reductions in quality costs. However, Corbett et al. (2002) indicated that certification does not lead to significant internal financial improvements. Wilson et al. (2003) concluded that the economic success reported by companies after obtaining ISO 9000 certification may be exaggerated, because this success cannot be guaranteed. Witcher (1994) claimed ISO 9000 helps with the promotion of the accountability of the processes but does not impact all the business activities that indicate the capability of the organization to satisfy customer requirements. Taylor (1995) mentioned that most companies lack measurement of the financial impact of ISO 9000 and Chow-Chua et al. (2003) pointed out that very few studies actually measure financial performance.

Several studies (Corbett, Montes-Sancho, & Kirsch, 2005; Easton & Jarrell, 1998; Hendricks, & Singhal, 1997) showed an improvement in the financial results of certified companies, while some researchers (Powell, 1995; Samson & Terziovski, 1999; Staw & Epstein 2000; Terziovski, Samson, & Dow, 1997) did not find better business performance after certification. Other researchers (Feng, Terzioski, & Samson, 2008; Heras, Casadesus, & Dick, 2002; Martinez-Costa & Martinez-Lorente, 2008) indicated the negative effect that ISO 9000 certification had on company benefits and profits. Casadesus and Gimenez (2000) mentioned customers' low levels of satisfaction with the implementation of the standards. It should be noted that the above studies collected evidence over a short period of time (three years) after the company obtained certification. Martinez-Costa and Martinez-Lorente's (2008) findings indicated companies obtained considerably less earnings and returns on assets (ROAs) during the three years after obtaining registration. From these findings, these authors also emphasized that the short-term results for a company's financial performance are not as impressive as the long-term results. These companies also had a noticeable increase in operational costs over the same period, but sales and personnel expenses were intact.

Overall, according to McAdam and McKeown (1999), the impact of ISO 9000 has been very positive—over 50% (or four times as many companies) believed it saves money rather than costs money, although small ISO-certified companies are less likely to state that ISO 9000 saves money and 75% of the service sector said that ISO 9000 costs money. Quazi and Padibjo (1998) stated that certified companies saw an improvement in their quality and an increase in their sales and market share. Haversjo (2000) indicated that an increase in sales correlates with an increase in the rate of return for certified companies, as opposed to noncertified companies. On a review of the financial and scale efficiency of 18 European port authorities, some certified and some not, Pantouvakis and Dimas (2010) revealed that ISO certified ports are financially more efficient than their noncertified competitors.

Impact of ISO 14000

According to Sayre (1996), ISO 14000 advocates "sustainable development for each and every nation and sustainable development for each and every person" (p. 1). This means a firm that is committed to ISO 14000 ensures activities, products, and services are good for humans and the world. Moreover, ISO 14000 fosters principles and practices that are germane to the competitive advantage of sound environmental performance: resource allocation, responsibility and accountability, and continuous performance evaluation for improvement.

The implementation of effective ISO 14000 standards by a firm can offer these benefits: protecting human health and the environment from the potential impacts of its activities, products, and services; helping with the maintenance and improvement of the quality of the environment; meeting customers' environmental expectations; maintaining good public and community relations; satisfying investor criteria and improving access to capital; providing insurance at a reasonable cost; gaining an enhanced image and market share; fulfilling vendor certification criteria; improving cost control; limiting liabilities; providing resource conservation; supplying effective technology development and transfer; and giving confidence to interested parties and shareholders that policies, objectives, and targets are conformed to: stress is on prevention first, then regular occurrence of reasonable care and regulatory compliance, and finally, a system design that includes continual improvement (Sayre, 1996). According to Johnson (1997), ISO 14000 builds a single global management system that allows for effective management of environmental responsibilities. It also reduces liability, controls costs, documents a firm's commitment to government, and finally fosters a firm's concern for the public. ISO 14000 has the potential to lead to competitive advantages for businesses in areas such as enhancing raw material and strengthening supply management, in order to justify and make the administration of legally binding environmental laws safer, as well as to improve corporate image (Renzi & Cappelli, 2000).

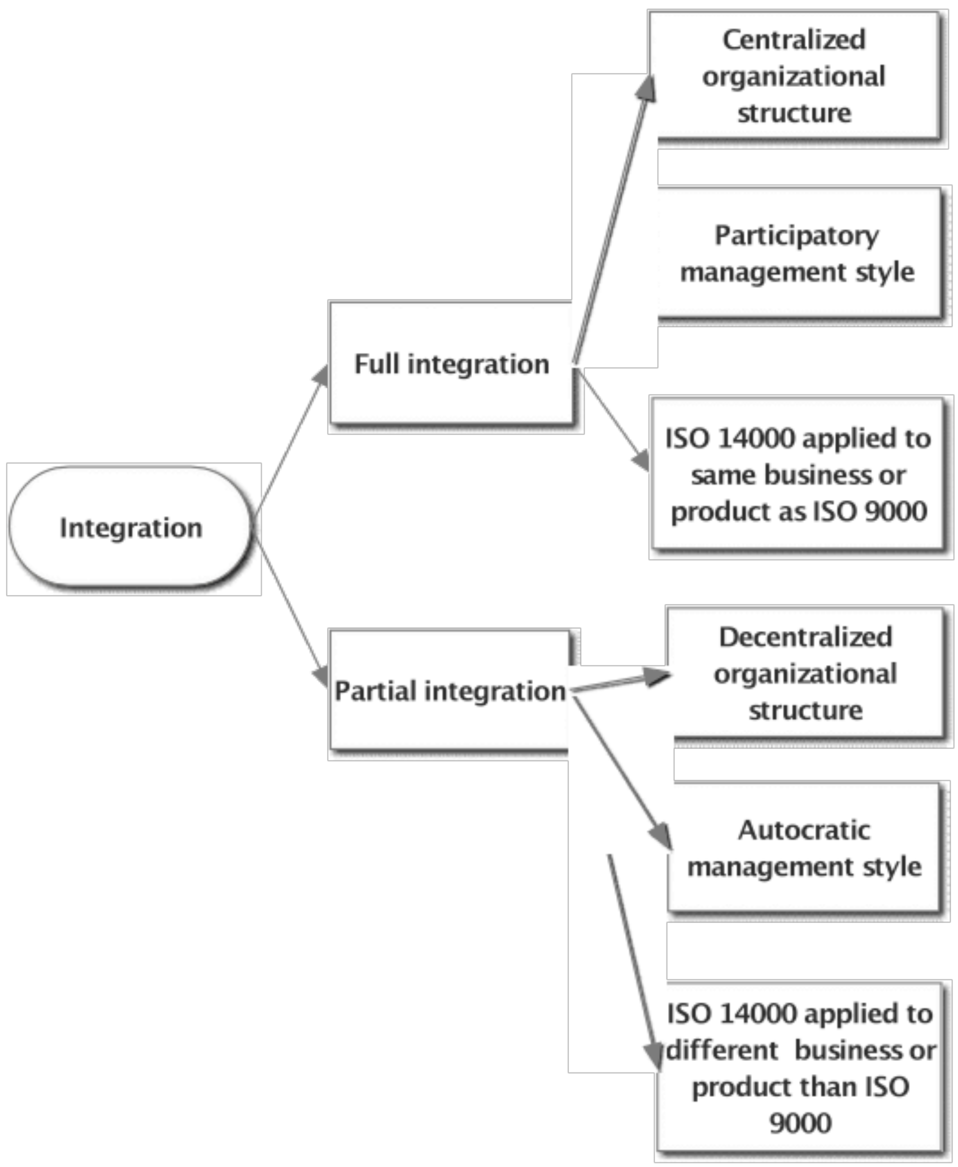
Integration of ISO 9000 and ISO 14000

The formation of one cohesive management system comes from two stand-alone systems: quality management systems (ISO 9000) and environmental management systems (ISO 14000). The integration of ISO 9000 and ISO 14000 is dependent on two assumptions. First, firms integrating the two stand-alone systems must have in place a mature quality management system and will employ ISO 14000 to expand it. Second, the quality management system in place conforms to ISO 9001, ISO 9002, or QS-9000 (Block & Marash, 1999). There are two ways of integrating ISO 9000 and ISO 14000. First, full integration leads to a single system that accommodates all of the requirements imposed by ISO 14000 and ISO 9000. The advantage this brings is one system manual in addition to one set of procedures, one audit that looks at the combined requirements, and one management review (Block & Marash, 1999). Second, partial integration involves keeping separate ISO 9000 and ISO 14000 internal audit processes, registration audits, and surveillance audits. By doing this, two system manuals are created: one for ISO 9000 and one for ISO 14000. Under the appropriate circumstances, an ISO 14000 system employs procedures from the ISO 9000 system. Such procedures may be modified to conform to ISO 14000 requirements; however, this must be done to ensure that the ISO 9000 system is not compromised. A noteworthy outcome of the partial integration is two sets of documentation, much of which may be unnecessary (Block & Marash, 1999).

Figure 2 displays the factors that influence either full integration or partial integration. Three factors that are parts of the corporate culture to consider are organizational structure, management style, and scope of system. These factors help in making the decision either to fully or partially integrate ISO 9000 and ISO 14000.

Integration of quality management and environmental management systems is advantageous in many ways. First, it brings together quality assurance and the environmental staff. This helps the staff to know more about each system. For example, the integration helps the quality management staff to be more knowledgeable about their firm's environmental impacts and legal obligations, while those of the quality environmental staff would be aware of established procedures associated to document control, records, and similar activities. Some researchers (Corbett & Cutler, 2000; Gupta

Figure 2. Flow Chart of Factors Impacting Full Versus Partial Integration (Block & Marash, 1999)



& Sharma, 1996; Kitazawa & Sarkis, 2000; Klassen, 2000) have argued that environmental managers should be integrated with quality managers in companies so they can take advantage of their possible synergies.

According to Block and Marash (1999), advantages of stand-alone ISO 9000 standards are twofold. First, these standards offer both a framework for firms that want to implement effective quality management systems and requirements against which companies can evaluate the quality management systems of their suppliers. Second, suppliers employed these standards to fulfill quality management requirements imposed by their customers. Stand-alone ISO 14000 improves a firm's environmental performance through prevention of pollution problems. Other related benefits include cost savings and improved relations with state environmental agencies (Block & Marash, 1999).

Integration of ISO 14000 into an existing ISO 9000 has significant advantages. First, the employment of existing ISO 9000 procedures to fulfill ISO 14000 requirements ensures consistency and eliminates redundancy because both standards require almost the same number of procedures. Second, using existing ISO 9000 procedures also helps to create significant cost savings in developing and implementing ISO 14000 (Block & Marash, 1999). Third, introducing ISO 14000 is seen as a normal way of doing business, so that ISO 14000 is no longer seen as the primary responsibility of the environmental department. Operationally, a fully integrated system produces an umbrella of programs that accommodates all facets of business, ranging from product quality and customer service to maintaining operations in a safe and environmentally acceptable way. Renzi and Cappelli (2000) pointed out that the following advantages are derived from integrated quality-environment system: "cost reduction, because it improves data and personnel management; homogeneity in management methodologies; and a decrease in the bulk of company papers and the creation of common forms that can be more easily used by several operators" (p. 2).

Limitations of the Current Literature

In the literature reviewed for this article, authors have discussed the advantages of both ISO 9000 and ISO 14000. However, these studies are limited to qualitative research that occurred during a short time frame.

Arbuckle's (2004) results showed a statistically significant change in total assets and return on assets for a period of two years after selected companies were certified in ISO 9000. However, Arbuckle's control groups were limited, because the researcher did not compare with non-ISO-certified companies to determine if the changes in total assets or return on assets were the result of only ISO certifications or other political and economic factors. Based on Martinez-Costa and Martinez-Lorente's (2008) findings, short-term results for a company's financial performance are not as impressive as the long-term ones; therefore, these findings imply that a longer time frame is needed to prove that Arbuckle's results would hold. However, Wayhan, Kirche, and Khumawala (2002) indicated that ISO 9000 certification has a very limited impact on financial performance, as measured by return on assets; however, this effect dissipates quickly over time. Renzi and Cappelli (2000) pointed out the advantages, which are derived from an integrated quality-environment system, make a company very competitive. There is a need for more quantitative research with a longer time frame on the financial benefits of the integration of ISO 9000 and ISO 14000.

Conclusion

ISO 9000 and ISO 14000 programs have shown well-established net advantages that were described under their impacts in this article. Additional benefits can be derived from their integration. However, most of the current studies are limited to qualitative findings and a short time frame. Therefore, more quantitative studies with longer time frames are needed to substantiate the benefits of both stand-alone certifications and the integration of the two certifications. Also, ISO certified companies must be compared with noncertified companies to determine if the benefits in financial performance indicators are the result of only ISO certifications or other political and economic factors. In the future, the authors plan to conduct research to address these issues.

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Reducing the Bullwhip Effect in the Supply Chain: A Study of Different Ordering Strategies

By M. Affan Badar, Shyamsundarreddy Sammidi, and Leslie Gardner

Abstract

Profitability of a company can be affected by the costs associated with backlogs and large inventories due to the bullwhip effect in the supply chain. This work aims to find an ordering strategy that is practical and can minimize the bullwhip effect. Five strategies with different levels of information about inventory and components along the supply line have been compared with the just in time (JIT) pull strategy and the usage of point of sale (POS) data. This work uses the beer game spreadsheet simulation developed by Adams, Flatto, and Gardner (2008). The simulation shows material and information flow in a four-echelon supply chain. Expressions for cost incurred and profit obtained by each player (manufacturer, distributor, wholesaler, and retailer) have been developed. Graphs for cost and profit with time are plotted. The strategy using POS data is found to be the best, and the pull strategy to be the next best. However, both require discipline. This study shows that putting information about the inventory levels and components of the supply line into an ordering strategy can also minimize the bullwhip effect.

Keywords: Supply chain, bullwhip effect, ordering strategy, beer game, inventory

Introduction

A supply chain integrates, coordinates, and controls the movement of goods and materials from a supplier to a customer to the final consumer, which therefore involves activities like buying, making, moving, and selling (Emmett, 2005). Fast- rising supply chain risks are poorly understood and managed by most companies, according to the World Economic Forum (Ladbury, 2008). Profit is the main goal of any commercial organization. To obtain profit one should reduce the costs incurred by manufacturing the product economically and reduce the supply chain costs. Supply chain costs involve inventory costs, which have a considerable share in determining the cost of the product. As the economy changes, as competition becomes more global, it is no longer company versus company, but it is supply chain versus supply chain (Henkoff, 1994).

Customer order plays a vital role in the supply chain; it actually triggers all the supply chain activities. Supply chain activities begin with a customer order and end when a satisfied customer has paid for the purchase (Chopra & Meindl, 2004). It should be noted that information flows in the supply chain are also as important as material flows. The whole supply chain process is kept moving by information flow from retailer to wholesaler, wholesaler to distributor, and distributor to manufacturer. Effective supply chain management maintains satisfied customers, growth in company market share, constant revenue growth, capability to fund continuous innovation, and capital investment for more value.

According to Simchi-Levi, Kaminsky and Simchi-Levi (2007) effective supply chain management reduces the costs incurred and thus increases the profit. It is very important to analyze demand and order in such a way that it reduces the costs incurred. Lead time is a critical component in making inventory decisions. Information delays are also one of the main components of total lead time, so electronic data interchange may reduce the delays and offer benefits through reduction in both the size and variability of orders placed (Torres & Moran, 2006).

Despite the undoubted benefits of the lean manufacturing and supply chain revolutions, supply chain instability still continues (often described as bullwhip effect), which harms firms, consumers, and the economy through excessive inventories and poor customer service (Torres & Moran, 2006). The bullwhip effect refers to the phenomenon where demand variability amplifies as one moves upstream in a supply chain, from consumption to supply points (from retailer to manufacturer) (Lee, Padmanabhan, & Whang, 1997a). It is an important demand and supply coordination problem that affects numerous organizations, and it is a major phenomenon in the beer game model (Kumar, Chandra, & Seppanen, 2007). Because of the bullwhip effect, the variability increases at each level of a supply chain as one move from customer sales to production (Chen, Drezner, Ryan, & Simchi-Levi, 2000). Lee et al. (1997a) lists demand signal processing, order batching, price fluctuations, and shortage gaming as the causes for bullwhip effect. Bhattacharya and Bandyopadhyay (2011) presented a good review of the causes of bullwhip effect. According to Chen (1999) a simple forecast formula, such as exponential smoothing or a simple moving average method can lead to bullwhip behavior in certain supply chain settings.

This work is focused toward supply chain costs by minimizing the bullwhip effect. A variety of remedies for the bullwhip effect have been proposed. For the beer game, Sterman (1989) modeled the ordering behavior of players in terms of an anchoring and adjustment heuristic. He used simulation to calculate the parameters that give the minimum total costs for the game. The beer game was developed by Sloan's System Dynamics Group in the early 1960s at MIT. It has been played all over the world by thousands of people ranging from high school students to chief executive officers and government officials (Sterman, 1992). Although this model is useful for simulation studies and development of theory, it probably has limited application for "real world" practitioners looking for effective decision rules. Industry experts and analysts have cited two recent innovations: the Internet and radio frequency identification (RFID), which t can improve supply chain performance by dampening the bull-whip effect (Lee, Padmanabhan, & Whang, 2004).

One of the most popular remedies is complete visibility of POS order data throughout the supply chain. However, Croson and Donohue (2003) conducted an experiment to evaluate whether humans actually use POS data in the beer game when such data was available. Interestingly they found that humans were still inclined to over order, although not as much as when POS data was not available. Thus, disciplined human behavior is required as well as visible information. Another potential remedy is the pull system of JIT manufacturing. Reducing variability in all aspects of a manufacturing system is one of the principles of JIT and lean manufacturing for eliminating waste and cost. JIT utilizes a pull system in which material is produced only when requested and moved to where it is needed. JIT partnerships throughout a supply chain occur when suppliers and purchasers work together to remove waste, drive down costs, and extend JIT to the supply chain (Heizer & Render, 2001). This can involve information sharing of forecasts as in point of sale (POS) strategies or can involve extending the pull system to the supply chain.

This study uses simulations developed in Microsoft Excel by Adams et al. (2008) to assess the impact of using simple adjustment heuristics based on information about inventory levels (inventory less backlog), orders in mail delays, materials in shipping delays, and the immediately upstream supplier's backlog to remedy the demand forecast updating the cause of the bullwhip effect in a four-echelon supply chain as represented by the beer game. The objective is to determine if providing all information about inventory levels and components along the supply line into an ordering strategy is superior to the JIT pull strategy and the use of POS data. Equations for cost and profit obtained by each player in the supply chain (manufacturer, distributor, wholesaler, and retailer) have been determined. The study assumes that the manufacturer satisfies the distributor's order and replenishes from limitless supply of raw material, while the distributor supplies the products to wholesaler, who in turn satisfies the demand of the retailer. The customer orders are placed with the retailer.

Background

Lee et al. (2004) mentioned that Forrester was the first person who documented the phenomenon of bullwhip effect, but the term was not coined by him. As per O'Donnell, Maguire, McIvor and Humphreys (2006), Forrester studied the dynamic behavior of simple linear supply chains and presented a practical demonstration of how various types of business policy create disturbance, and he stated that random meaningless sales fluctuations could be converted by the system into annual or seasonal production cycles.

The term "bullwhip effect" was coined by Procter & Gamble when researchers studied the demand fluctuations for Pampers. If there is no proper channel of information passage between the players in a supply chain (retailers, wholesalers, distributors and manufacturers), this leads to inefficiency like excessive inventories, quality problems, higher raw material costs, overtime expenses, and shipping costs (Lee et al. 1997a, b; Chen et al. 2000). According to Cao and Siau (1999) a change in demand is amplified as it passes between members in the supply chain.

Classic management techniques are widely employed to reduce the bullwhip effect in supply chains. In the JIT system, materials are moved when required, and the suppliers and purchasers work together to eliminate waste reducing the cost of production (Heizer & Render, 2001). Croson and Donohue (2003) examined the impact that POS data sharing had on ordering decisions in a multi-echelon supply chain. In a web-based simulation for supply chain management employing electronic data interchange similar to POS data, Machuca and Barajas (2004) found significant reductions in the bullwhip effect and supply chain inventory costs. Vendor- managed inventory (VMI) is another excellent method for reducing the bullwhip effect, and it has been employed by many international companies, such as Procter & Gamble and Wal-Mart, but the problem associated with this method is the sharing of information between retailer and factory (Lee et al. 1997a, b).

Warburton, Hodgson and Kim (2004) developed equations to compute the order and demand to nullify the bullwhip effect using a generalized order-up-to (OUT) policy. Control theory is another popular approach to reduce the bullwhip effect. Lin, Wong, Jang, Shieh, and Chu (2004) applied z-transforms to reduce the bullwhip effect, whereas Dejonckheere, Disney, Lambrecht, and Towill (2003) examined the bullwhip effect by using transfer function analysis. Many other researchers used computational intelligence techniques such as fuzzy logic, artificial neural networks, and genetic algorithms to reduce the bullwhip effect (O'Donnell et al. 2006). Carlsson and Fuller (2001) employed fuzzy logic. Goldberg (1989), Vonk, Jain, and Johnson (1997) and Moore and DeMaagd (2005) used genetic algorithms. Sarode and Khodke (2009) developed a multi-attribute decision-making technique: analytic hierarchy process (AHP).

A correct measurement is an essential start to investigating problems caused by demand amplification and to assess which measures can be taken to reduce this amplification. Fransoo and Wouters (2000) explained three issues in measuring the bullwhip effect: first, the sequence of aggregation of demand data, second filtering out the various causes of the bullwhip effect, and last the inconsistency in demand. Operational researchers also have worked on finding ways to reduce the bullwhip effect. For instance, Adelson (1966) studied simple supply chain systems, but the methodology required complex mathematics for solving the problem (Towill, Zhou, & Disney, 2007).

Simulation also has been used in supply chain management to study the bullwhip effect. The beer game is a hands-on simulation that demonstrates material and information flows in a supply chain. As mentioned previously, it was developed by the Systems Dynamic Group of Sloan school of Management at the Massachusetts Institute of Technology. Using the beer game, Sterman (1989) demonstrated that the players systematically misinterpret feedback and nonlinearities, and underestimate the delays between action and response, which leads to bad decision making and causes problems in the behavior of the supply chain (Torres & Moran, 2006). Jacobs' (2000) Internet version of the beer game is brief in description and is limited solely to its characteristics and how that game is played. Machuca and Barajas' (2004) web-based simulation using an electronic data interchange resulted in significant reductions in the bullwhip effect and supply chain inventory costs. Moyaux and McBurney (2006) used some kinds of speculators in agent-based simulations and concluded that these speculators can decrease the price fluctuations caused by the bullwhip effect. However, these speculators are not cost efficient and price bubbles may occur, particularly if too many speculators are used.

In their study, Kaminsky and Simchi-Levi (1998) showed the bullwhip effect, and they explained the effect of passing from a decentralized structure to a centralized structure and also observed the effects of shortening the lead time. Steckel, Gupta, and Banerji (2004) examined how changes in order and delivery cycles, shared POS data, and patterns of consumer demand affected the dynamics in a channel and thereby the severity of the bullwhip effect.

Cangelose and Dill (1965) considered the problem of the bullwhip effect from an organizational learning perspective. Jung, Ahn, Ahn, and Rhee (1999) analyzed the impacts of buyers' order batching had on the supplier demand correlation and capacity utilization in a simple branching supply chain involving two buyers whose demands are correlated; they found that increase in the size of the order lot mitigates the correlation of purchase orders. Cachon & Lariviere (1999) investigated the performance of balanced ordering policies in a supply chain model with multiple retailers and summarized that the bullwhip effect would depend on the order cycle and batch size. They recommended balanced ordering with small batch size and a long order interval to reduce the suppliers' demand variance.

This section has summarized a review of literature on the bullwhip effect. Researchers have employed JIT and POS data, mathematical techniques, algorithms, simulation, and balancing of order and delivery cycles in order to reduce the bullwhip effect.

The Beer Game

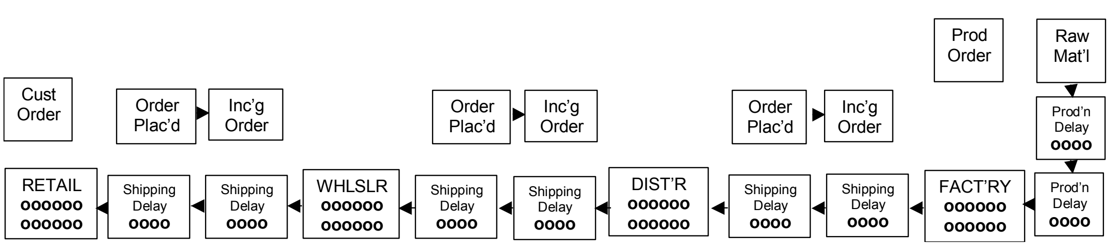
The beer game is played as a board game with four players: a retailer, a wholesaler, a distributor, and a factory (Adams et al., 2008). Customer orders are placed with the retailer who fills them to the extent possible. The retailer then orders from the wholesaler to replenish his/her stock. Similarly the wholesaler fills retailer orders and replenishes from the distributor who in turn fills wholesaler orders and replenishes from the factory. The factory fills distributor orders and replenishes from a limitless supply of raw material. All players keep records of backlogs, or unfilled orders, and attempt to fill them as soon as possible. Shipping delays of two weeks (or periods) separate each player, as do information delays of two periods. Initially, all four players have twelve units of inventory, and four units of inventory are on each square representing a shipping delay. Similarly, all of the orders in the information pipeline at the start of the game are for four units. The game board is shown in Figure 1.

The objective of the game is to fill all customer orders without carrying excessive inventories or having excessive backlogs. The players must fill backlogs eventually. For the first several periods of the game, the customer orders are at four units each period. At some point, the customer orders jump to eight units and remain at that level for the rest of the game. The only stochastic part of the beer game is the human behavior in placing orders but human behavior rarely fails to produce the bullwhip effect. The game runs for 50 periods or until the players become frustrated with excessive backlogs and inventories and the point about the bullwhip effect has been made.

Methodology

The objective of this work is to find whether using information about inventory levels and components of the supply line into an ordering strategy is superior to the JIT pull strategy and the use of POS data at all levels

Figure 1: The Initial Setup for the Board Game Version of the Beer Game (taken from Adams et al. 2008)



of supply chain. To explore this, cost incurred and profit obtained by each member in a four-echelon supply chain (manufacturer, distributor, wholesaler, and retailer) are computed. For finding the costs incurred and profit obtained, data from spreadsheet beer game simulation developed by Adams et al. (2008) is used. After calculating costs and profit for each player of the supply chain, graphs are plotted between cost versus week (period) and profit versus week for seven different ordering strategies. These graphs have also been plotted for different lead times by Sammidi (2008); however, this paper uses the lead time of two periods.

Sterman (1989) developed an expression for ordering behavior in the beer game in terms of adjustment heuristic that is,

$$IO_t = \hat{L}_t + AS_t + ASL_t$$

Where:

- IO_t - Order rate in time period t,
- $\hat{L}_t$ - Expected demand in period t,
- AS_t - Difference between the desired stock and actual stock in period t, and
- ASL_t - Difference between the desired and actual supply line in time period t.

The anchoring heuristic $\hat{L}_t$ is often determined using exponential smoothing as follows:

$$\hat{L}_t = \theta L_{t-1} + (1-\theta)\hat{L}_{t-1}$$

Where L_{t-1} is the demand for the previous period, $\hat{L}_{t-1}$ is the forecast value of demand for previous period, θ is a parameter varying between 0 and 1.

The adjustment for stock AS_t is the difference between the desired stock S^* and the actual stock S_t multiplied by a parameter α_S ($0 \le \alpha_S \le 1$) specifying the fraction of the difference ordered each period.

$$AS_t = \alpha_s(S^* - S_t)$$

The adjustment for supply line is the difference between desired supply line SL^* and the actual supply line multiplied by a parameter α_{SL} specifying the fraction of the difference ordered each period.

$$ASL_t = \alpha_{SL}(SL^*_t - SL_t)$$

The supply line consists of orders in mail delays, the immediately upstream supplier's backlog, and the material in shipping delays (Adams et al., 2008). We can have for orders: $0 \le \alpha_{SLO} \le 1$; for material: $0 \le \alpha_{SLM} \le 1$; and for upstream backlog $0 \le \alpha_{SLB} \le 1$.

The cost incurred by each member is calculated by finding the various costs involved. The cost includes the price of the product, ordering cost, holding costs or inventory cost, and the backlog cost. The backlog cost is the cost, which the supplier must pay as a penalty if he/she cannot deliver the product within the time actually agreed upon. The backlog cost per item is computed by assuming it to be double the cost of the inventory per item (Nienhaus, Zeigenbein, & Schoensleben, 2006). Thus,

Total cost = (Cost per item*number of items ordered) + Ordering cost + Inventory cost (2*Inventory cost per item*number of backlog items)

The ordering cost per order and inventory cost per item are assumed to be $100 and $0.5, respectively for each member in the four-echelon supply chain. Hence,

Total cost = Price per item*number of items ordered + 100 + 0.5*number of items in Inventory + 2*0.5* number of backlog items.

The value of price per item increases from manufacturer to retailer. The price per item for the manufacturer is assumed to be $10, and then it is increased by 2.5 times $10 when it comes to the distributor and then 2.5 times the price of the distributor for the wholesaler and then again 2.5 times the price of the wholesaler for the retailer. Thus, the price per item for distributor is $25, for wholesaler it is $62.5 and for the retailer it is $156.25. The number of items ordered, the number of items in inventory, and the backlogs values have been taken from the simulation developed by Adams et al. (2008). After finding the total cost incurred for each member, the revenue of each member of the supply chain is calculated. The revenue for the manufacturer is the price that the distributor pays for the product;

Table 1. Anchoring and Adjustment Cases (Adams et al. 2008)

Case	$\hat{L}_t$	AS_t	ASL_t
1	θ =1, (Pull)	α_S =1, (12–(inv–bklg))	None
2	Pull	12 – (inv – bklg)	α_{SLO} =1, α_{SLM} =0, α_{SLB} =0, (Less orders)
3	Pull	12 – (inv – bklg)	α_{SLO} =0, α_{SLM} =1, α_{SLB} =0, (Less material)
4	Pull	12 – (inv – bklg)	α_{SLO} =1, α_{SLM} =1, α_{SLB} =0, (Less material and orders)
5	Pull	12 – (inv – bklg)	α_{SLO} =1, α_{SLM} =1, α_{SLB} =1, (Less material, orders, and upstream supplier's backlog)
6	Pull	α_S =0, None	None
7	POS	Not applicable	Not applicable

the revenue for the distributor is the price that the wholesaler pays for the product; and the revenue for the wholesaler is the price that the retailer pays for the product.

Profit of each member is calculated by deducting their cost incurred from their revenue obtained, and graphs are developed for seven different cases. Sammidi (2008) contains the detailed work. The seven cases are shown in Table 1.

Among the seven cases mentioned, the first five cases demonstrate the reduction in bullwhip effect as more and more information is interpreted into the supply line. The first case uses an anchoring heuristic of ordering what was ordered, which is equivalent to the pull system, but with a stock adjustment of the full difference between the ideal stock of 12 and the inventory level, that is, 12 – (inventory – backlog). This case displays the largest bullwhip effect as shown in Figures 2-3 of all cases studied. Cases 2 – 5 use the same anchoring and stock adjustment heuristics of Case 1, but they have supply line adjustment heuristics that compensate for more and more of the supply line (orders in mail delays, material in shipping delays, and immediate upstream supplier's backlog). As more and more of the supply line is compensated, the bullwhip effect diminishes in Cases 2 – 4 until it is completely eliminated in Case 5, when the entire supply line consisting of the sum of the orders in mail delays, the immediate upstream supplier's backlog, and the material in shipping delays is accounted for.

This paper shows graphs in Figures 2 – 6 for cost and profit versus period (week) for four cases with lead time of two periods. Because profit is revenue minus cost, the profit graph takes into consideration the effect on cost. Hence, there is no need to display the cost versus week graph for each of the cases. Cost and profit for Case 1 are displayed in Figures 2 and 3. Case 1 illustrates the maximum bullwhip effect when no supply chain line information is provided. Case 5 (Figure 4), Case 6 (Figure 5), and Case 7 (Figure 6) show that the bullwhip effect is eliminated. In Case 5, adjustments for supply chain in terms of order delay, material in shipping delay, and upstream backlog have been taken into account. Case 6 is pull strategy, which does not adjust for either stock or supply line. It does not show any bullwhip but produces a steady-state error. This error is better than the bullwhip effect. Also the steady error of Case 6 is slightly better than that of Case 5. In Case 7 there is complete exchange of data between the members of the supply chain, which eliminates the bullwhip effect. However, Case 6 and Case 7 both require discipline and at times are not easy for companies to follow.

Figure 2. Case 1: Cost for Maximum Bullwhip Effect without Supply Line Information

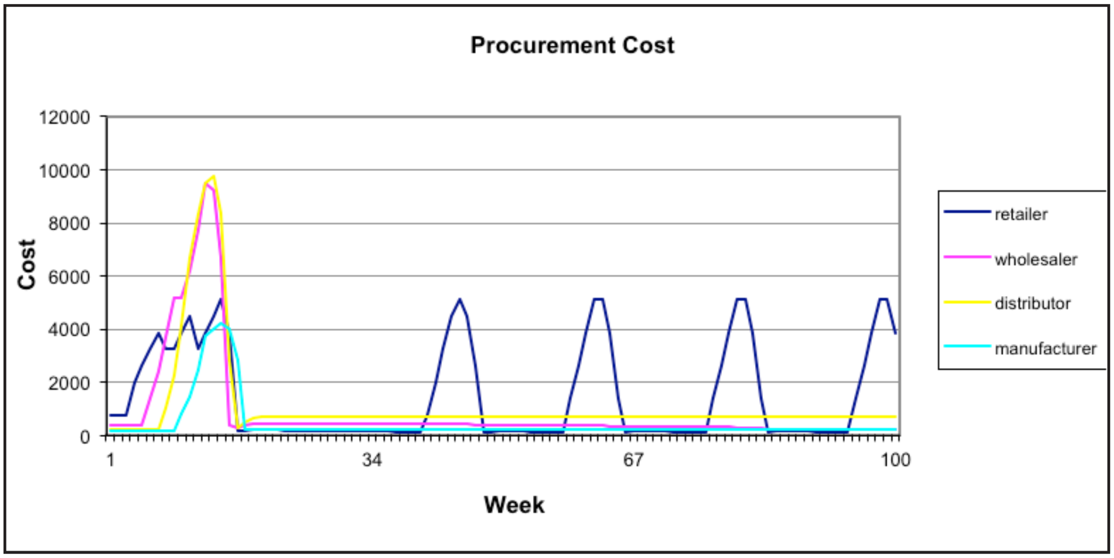


Figure 3. Case 1: Profit for Maximum Bullwhip Effect without Supply Line Information

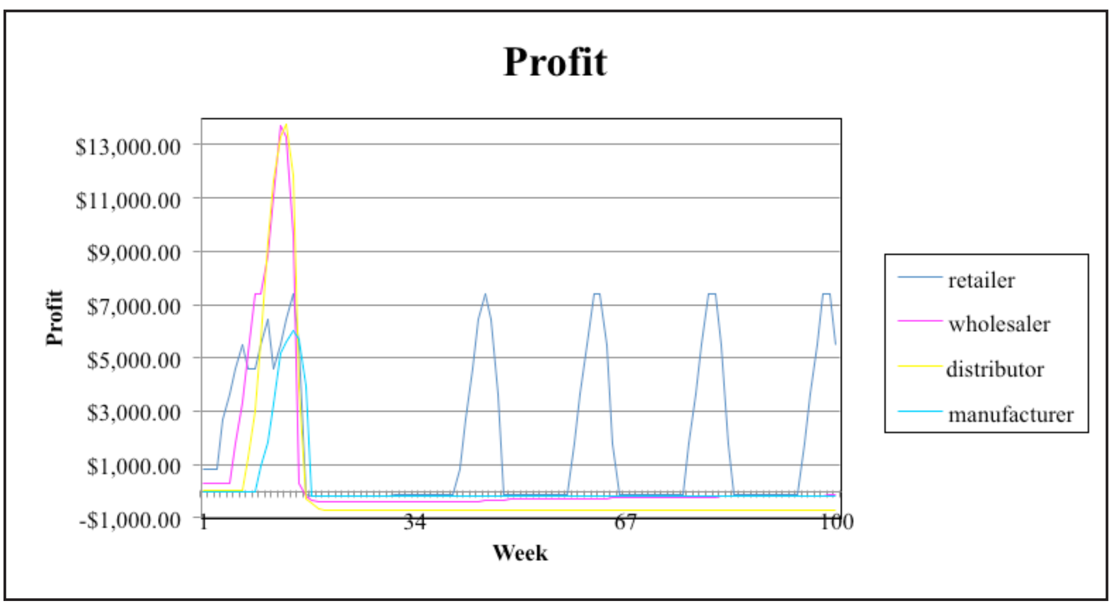


Figure 4. Case 5: Elimination of Bullwhip Effect on Profit by Compensation for Material, Orders, and Upstream Supplier's Backlog in the Supply Line

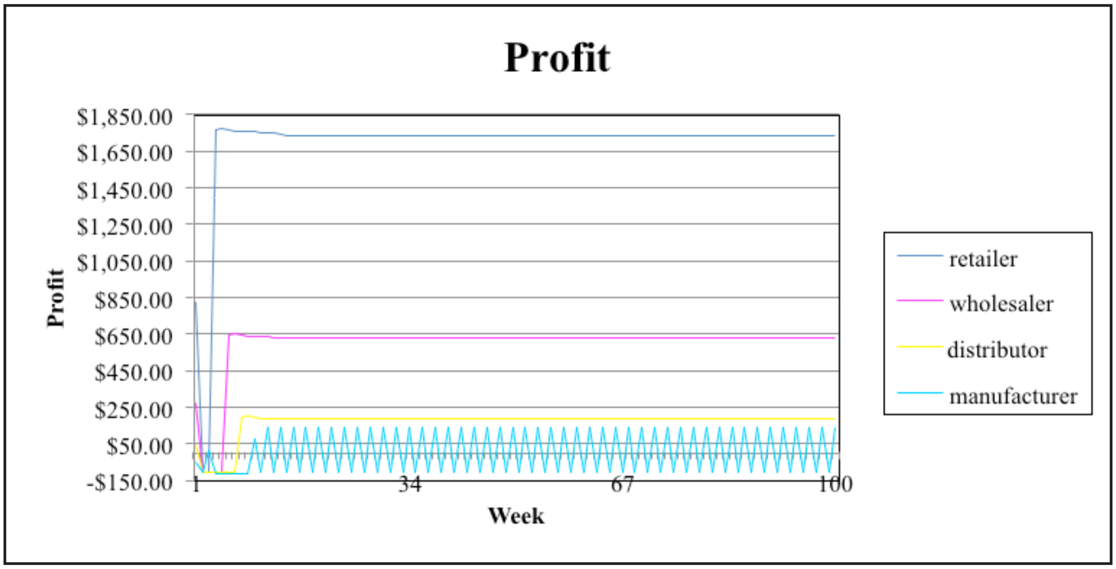


Figure 5. Case 6: Elimination of Bullwhip Effect on Profit by Pull Strategy

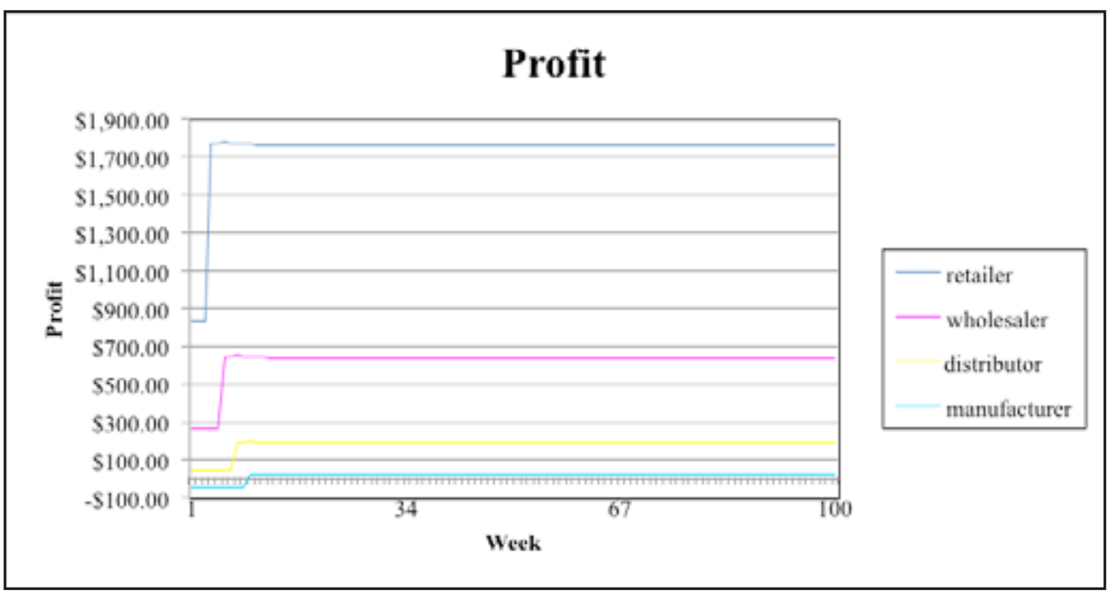
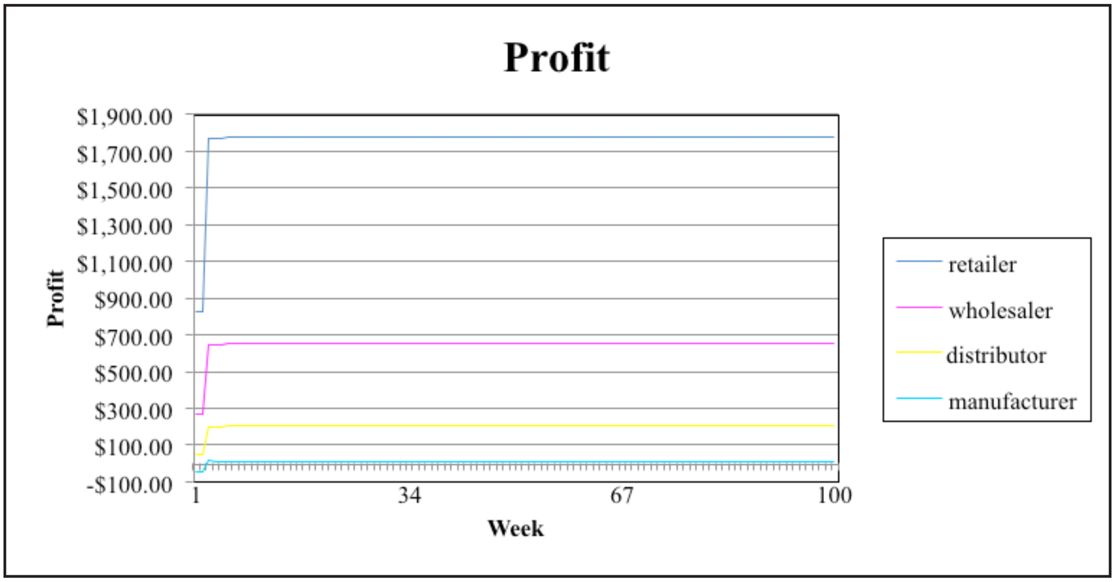


Figure 6. Case 7: POS Eliminates Bullwhip Effect and Backlog



Conclusion

This study is an extension of the work done by Adams et al. (2008), and it uses the beer game spread sheet simulation developed by them. The beer game (Sterman, 1992), shows information and material flow in a four-echelon supply chain. An attempt has been made in the current work to find an ordering strategy that is easy to employ and can minimize the bullwhip effect. Five strategies (Case 1 through Case 5) with different levels of information about inventory and components along the supply line have been compared with the JIT pull strategy (Case 6) and the usage of POS data (Case 7). The cost incurred and profit obtained by each player (manufacturer, distributor, wholesaler, and retailer) of the supply chain for the seven ordering strategies have been determined. Graphs for cost and profit versus time have been plotted.

From the graphs it is evident that as more and more information is provided for the inventory and components along the supply line from Case 1 through Case 5, the bullwhip effect is reduced. Case 1 uses an anchoring heuristic of ordering what was ordered and a stock adjustment to compensate for the difference between the ideal stock and the inventory level. This case shows the largest bullwhip effect. Cases 2 – 5 use the same anchoring and stock adjustment heuristics of Case 1, but have supply line adjustment heuristics that compensate for more and more of the supply line. As more and more of the supply line is compensated, the bullwhip effect diminishes in Cases 2 – 4 until it is completely eliminated in Case 5, when the entire supply line consisting of the sum of the orders in mail delays, the immediate upstream supplier's backlog, and the material in shipping delays is accounted for.

Case 6 is a pull strategy, which does not adjust for either stock or supply line. It does not show any bullwhip, but it produces a steady-state error. This error is better than the bullwhip effect. Also the steady error of Case 6 is slightly better than that of Case 5. In Case 7 there is complete exchange of data between the members of the supply chain, which eliminates the bullwhip effect. Thus, Case 7 where POS data is used is the best strategy that eliminates the bullwhip effect and Case 6 (pull strategy) is the next best. However, Case 6 and Case 7 both require discipline and at times are not easy for companies to follow. POS has an additional issue because of the reluctance between each member of the supply chain to share information. In such circumstances, Case 5 is a reasonable strategy with better applicability.

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