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LETTER FROM THE EDITORS

Welcome to the *Academy of Information and Management Sciences Journal,* the official journal of the Academy of Information and Management Sciences. The Academy is affiliated with the Allied Academies, a non-profit association of scholars whose purpose is to encourage and support the advancement and exchange of knowledge throughout the world.

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CODIFYING ACADEMIC RESEARCH: SEMANTIC WEB DRIVEN INNOVATION

Ron G. Cheek, University of Louisiana Lafayette
Michelle B. Kunz, Morehead State University
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ABSTRACT

Academic researchers expend an enormous amount of time retrieving, assimilating, and analyzing material for their research projects. The US National Science Foundation (NSF) estimates that researchers spend more than half of their total research and development hours hunting for information. For academic researchers there is a tremendous amount of online digital research databases available at university libraries such as EBSCOhost and ABI/INFORM. These online digital databases offer access to a wide array of full text articles from top-tier, peer-reviewed journals. Each of these journal articles represents the tacit knowledge of their respective authors. The challenge for researchers is to read, comprehend, interpret, and codify these readings based on their individual domain of expertise.

The Semantic Web, its tools and technologies are able to take this tacit knowledge (unstructured), create explicit knowledge (structured) that can then be machine (computer) processed and codified for use by researchers. Ontologies are the key building blocks for the Semantic Web. They provide the structural frameworks for organizing information from digital resources and can be used to capture the body of knowledge from textual content. The tools available in the Semantic Web allow the codified knowledge to be used to analyze or query this structured data for trends, inferences, clusters of information, and knowledge discovery.

In this paper we propose the development of a Semantic Web enabled Content Management System, the Center For Knowledge Discovery (CFKD). The model is designed specifically for the non-technical academic research community. Ease of use by researchers is of paramount importance. The model is based on a Drupal Content Management System that allows access and use of the tools and technologies of the Semantic Web. A digital repository database of top-tier, peer-reviewed journal articles is created. The tacit knowledge in these articles are codified, and then made explicit. This codified knowledge is then available to the academic community for research, collaboration within and across disciplines, and throughout the global community for identifying trends, inferences, clusters of information and knowledge discovery.

INTRODUCTION

In this conceptual model we propose a systematic knowledge codification process for academic researchers. We develop a dataset from top-tier, peer-reviewed journal articles, using our model to codify the authors' tacit knowledge, make it explicit and available for use by researchers. Datta and Acar (2010) define knowledge codification "as a software and human agent-driven process by which organizations extract, transform, and store knowledge for codification and embodiment in organizational routines." From their perspective it allows the overall organization to share the tacit knowledge of the individual members of the organization. In our model we codify the tacit knowledge of individual authors (of journal articles), make them explicit, and then able to be used for the identification of trends, clusters of knowledge, and knowledge discovery. Our model does not merely aggregate data but tags it and makes it able to be processed by machines (computers).

Professors Malecki and Moriset (2008) in their book, chronicle the global impact of the administration and distribution of digital and technology information on universities. They see the world as operating in a digitally interconnected economic space where digital information continuously grows and changes at an exceptionally rapid pace. From their perspective one of the key benefits of participation in the digital economy is the acquisition of knowledge. Vincent-Lancrin (2006) explains that information and communication technology will be the driver of change in academic research. He states "Computers, digital data, and networks have indeed revolutionized the research environment (as much as society at large). Facilitated by the Internet, researchers have access to resources such as digital libraries and other knowledge repositories.

Industry experts estimate approximately eighty (80) percent of the data found on the Web is in text (unstructured) format. The problem with the Web is not too little information, but rather too much information. For researchers, the quality, reliability, and validity of information generally found on the Web can be questionable and may lack validity. For academic researchers there is a tremendous amount of digital data available on the World Wide Web (the Web). Most peer-reviewed academic journals are available digitally from university or college libraries.

Academic researchers expend an enormous amount of time retrieving, assimilating, and analyzing material for their research projects. The US National Science Foundation (NSF) estimates that researchers spend more than half of their total research and development hours hunting for information. For academic researchers there is a tremendous amount of online digital research databases available at university libraries such as EBSCOhost and ABI/INFORM. These online digital databases offer access to a wide array of full text articles from top-tier, peer-reviewed journals. Each of these journal articles represents the tacit knowledge of their respective authors. The challenge for researchers is to read, comprehend, interpret, and codify these readings based on their individual domain of expertise.

As the amount and availability of digital data continues to increase, academic researchers are challenged to find new, innovative ways to collaborate with researchers from other universities, government and private industries, and to address their research in the global economy. Academic research in the 21st century, driven by the Semantic Web 3.0 will dramatically change the way faculty approach these challenges. Tim Berners-Lee, the founder of the World Wide Web explains "the Web was designed as an information space, with the goal that it should be useful not only for human-communication, but also that machines would be able to participate and help. Leaving aside the artificial intelligence problem of training machines to behave like people, the Semantic Web approach instead develops languages for expressing information in a machine process-able form (Berners-Lee)." The Web is often viewed from the perspective of a dataset of collective intelligence. It becomes the challenge of academic researchers to sort through the "noise" of unstructured data (text). Our model addresses this challenge.

SEMANTIC WEB

Most people see the major impact of the Web being the overload of information we have to deal with on a daily basis. This overload of information is not a new phenomenon, but has actually being going on for years. Scientists for decades have been attempting to mine all this information for its knowledge value. During WWII many scientists were taken from their academic pursuits and thrown into America's war efforts. Dr. Vannevar Bush was Director of the Office of Scientific Research and Development and coordinated the war activities of these scientists. The war was nearing its end and Dr. Bush envisioned the tremendous possibilities available to future leaders if they were able capture the tacit knowledge of these scientists. The potential benefits of their tacit knowledge would be available to future leaders if they should ever be thrown into another war. If only he could find a way to utilize their remarkable store of knowledge it would be accessible to future generations. His greatest fear was that the truly significant advancements by these researchers would be lost to future generations (Bush, 1945).

The Web is a collection of distributed, interlinked web pages encoded primarily in Hyper Text Markup Language (HTML). The information found in HTML documents are primarily unstructured (text) data, readable by humans but unable to be processed by computers. To address this problem Tim Berners-Lee, inventor of the Web and director of the World Web Consortium (W3C) developed an extension to the Web called the Semantic Web. The goal of the Semantic Web is to encode (structure) information in web pages with content (meaning) and thereby allow it to be processed by machines (computers).

For academic researchers in the 21st century, the promise of the Semantic Web 3.0 (known as Web 3.0) may well provide the answer to these challenges. Tim Berners-Lee, the founder of the World Wide Web explains "the Web was designed as an information space, with the goal that it should be useful not only for human-communication, but also that machines would be able to participate and help. Leaving aside the artificial intelligence problem of training machines to behave like people, the Semantic Web approach instead develops languages for expressing information in a machine process-able form" (Berners-Lee). The Semantic Web offers pragmatic, achievable alternatives for academic research. Rather than chasing documents through online searches, Semantic Web allows the search for content within documents. This content is developed and articulated by the researcher and has the potential to narrow the search from thousands to just those truly relevant articles. The overreaching goal is for the Semantic Web is to machine process research in a way that closely resembles the human-person performing the task.

The Semantic Web "is the extension of the World Wide Web that enables people to share *content* beyond the boundaries of applications and websites." It is the "web of data" that enables machines (computers) to understand the semantics, or meaning, of information on the World Wide Web (Semantic Web). The World Wide Web Consortium (W3C) is an international community that develops standards to ensure the growth and standardization of the web. The Semantic Web represents a way of defining metadata (data providing information about one or more aspects of the data) for use and reuse in a digital environment. Ontologies define/classify the metadata making it able to be processed by machines (computers).

The Semantic Web takes the human-readable content (unstructured text) classifies it with ontologies and makes it machine-readable (structured data). The ontologies are basically vocabularies or dictionaries that describe the system of relationships based on the domain specific vocabularies. They provide a foundation for developing frameworks of information. Ontologies (vocabularies) are the most important part of the W3C standards for the Semantic Web. They are the key technology enabling the Semantic Web. Ontologies provide formal and explicit specifications of conceptualizations (i.e. knowledge representations). The development, maintenance, and sharing of ontologies has become increasingly important in the facilitation of information exchange. The CFKD provides a platform to enable this sharing and exchange.

The Semantic Web, its tools and technologies are able to take this tacit knowledge (unstructured), create explicit knowledge (structured) that can then be machine (computer) processed and codified for use by researchers.

ROLE OF ONTOLOGIES

Ontologies are the key building blocks for the Semantic Web. They provide the structural frameworks for organizing information from digital resources and can be used to capture the body of knowledge from textual content. The tools available in the Semantic Web can now be used to analyze or query this structured data for trends, inferences, clusters of information, and knowledge discovery.

Ontologies are important because they provide clarity and structure to text within a digital document. For example when a human reads a document and sees the term “apple tree,” they understand its meaning. A computer on the other hand when performing a key word search for Apple, the corporation will invariably include documents containing information on “apple trees.” Ontologies using URIs (Unique Resource Identifiers) understand that “apple” is a fruit and “Apple” is a corporation. Thus via the Semantic Web with content tagged with ontologies can now be searched for “content and meaning” rather than merely key word search.

For example tools within the Semantic Web will search the natural language text within articles, identify key words or topics. Once identified these key terms may then be defined to represent the tacit meaning of the author. In the CFKD our domain ontology will include the key concepts for the discipline of Management and can then be machine processed for knowledge discovery.

There are two types of ontologies: Upper ontologies (foundation) and Domain-specific. The Upper ontologies (vocabularies) are core glossaries that contain general terms, associated object descriptions commonly used in text. There are several standardized upper ontologies available for use, including Dublin Core, GFO, SUMO, and DOLCE (Ontology, 2011). Domain ontologies on the other hand provide concepts specific to the person or organization. An adoption of a domain ontology is a formalized approach to knowledge codification of a specific topic or area (Zhang, 2010). Every area of study has its unique set of concepts and vocabulary.

The domain ontology formalizes this vocabulary and allows it to be processed by computers. For example in our model we develop the Domain ontology to capture the tacit knowledge of academic researchers.

The key to the success of the CFKD will be the development of the domain specific ontology. A semantic wiki will be used as the primary instrument in the creation of our domain ontology. Semantic wikis offer the ability to capture, identify, and interpret relationships within digital documents. It will be used by participating domain experts (academic researchers) to formalize and make explicit their unique tacit knowledge. The semantic wiki will be a collaborative effort allowing creation and changes by the members of the CFKD. Membership in the CFKD will be restricted to the academic community and registration will require and email with an "edu" extension.

MODEL FOR CODIFYING ACADEMIC RESEARCH

The purpose of our model is to codify implicit knowledge in academic journal articles, make them explicit, and then able to be machine (computer) processed for trends, inferences, clusters of information, and knowledge discovery. The conceptual model we propose for the Codification of Academic Research is based on a Drupal Content Management System. A Content Management System (CMS) can be used to manage workflow in a collaborative environment. It can facilitate the sharing, editing, formatting, and analyzing data among the participants of the CMS. Drupal is an open source web-based CMS designed to allow the creation and management of content on its site requiring minimal technical knowledge and expertise. Drupal is maintained and developed by its community of users that number in the hundreds of thousands. It was chosen for its cutting-edge work with the Semantic Web.

A web-based digital repository database of top-tier, peer-reviewed, journal articles will be created and located at the Center for Knowledge Discovery (CFKD.org). As discussed earlier, participation will be limited to members of the academic community. A vocabulary for the CFKD will be built by combining existing semantic ontologies with the domain specific ontologies. The domain specific ontologies will be generated with a combination of semantic tools using the digital repository dataset and manually through the semantic wiki. The semantic wiki will allow members to revise, extend, and continually grow the domain's vocabulary.

Initially the CFKD will be funded by its site administrator, Dr. Ron G. Cheek. The site will be hosted by the Acquia, an open source software company providing products, services, and technical support for Drupal. This company was developed by Dries Buytaert, the founder of Drupal. As the site grows Acquia is scalable and offers an abundance of online user networks, video tutorials, and a support system geared to the non-technical user. All other software will be open source and the site will be maintained by its users. Initially the site will focus on the Management discipline. Once the site grows and gains acceptance it will be expanded to include other academic disciplines. This will be a truly self-sufficient, user driven site.

The key to success in the Semantic Web will not come from mathematicians, programmers, or technicians. Success will be defined by the innovative ways domain experts use the tools and technologies of the Semantic Web for building new, exciting research applications and discoveries. Our model facilitates the unique synergy that can evolve from cross-discipline, global academic researchers using the powers of the Semantic Web, and will bring academic research into the 21st century.

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A MODIFIED GENETIC ALGORITHM FOR THE FLOW-SHOP SCHEDULING PROBLEM

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ABSTRACT

Genetic Algorithm (GA) is a useful heuristic algorithm to solve a complex problem. This paper provides a modified generic algorithm to solve a flow-shop scheduling problem and shows that this approach gives a better solution at the cost of a longer running time.

INTRODUCTION

According to Chen, Vempati, & Aljaber (1993), the flowshop scheduling problem (FSP) is defined as "a scheduling problem which considers m different machines and n jobs; each of the jobs consists of m operations; and each of the operations requires a different machine; and all the jobs are processed in the same processing order." This problem's objective is to minimize a makespan; a makespan is completion time at which all jobs complete processing or equivalently as maximum completion time of jobs (Hejazi & Saghafian, 2005).

In the paper by Reeves and Yamada (1998), they state the FSP as follows, "If we have processing times p(i,j) for job i on machine j, and a job permutation $\{\pi_1, \pi_2, \ldots, \pi_n,\}$, where there are n jobs and m machines, then we calculate the completion times $C(\pi_i,j)$ as follows"

(1) $C(\pi_1, 1) = p(\pi_1, 1)$

(2) $C(\pi_i, 1) = C(\pi_{i-1},1) + p(\pi_i, 1)$ for I = 2, …, n

(3) $C(\pi_1, j) = C(\pi_1, j-1) + p(\pi_1, j)$ for j = 2, …, m

(4) $C(\pi_i, j) = \max\{C(\pi_{i-1}, j), C(\pi_i, j-1)\} + p(\pi_i, j)$[1] for I = 2, …, n; j = 2, …, m

Finally, they define the makespan as

(5) $C_{max}(\pi) = C(\pi_n, m)$

The FSP is then to find a permutation Π^* in the set of all permutations Π such that

(6) $C_{max}(\pi^*) \leq C_{max}(\pi) \ \forall \pi \in \Pi$

Genetic algorithms (GA) borrowed an idea from the process of evolution of organisms. According to Chinneck (2006), GA can be applied to any problem that has these two characteristics: (1) a solution can be expressed as a string, and (2) a value representing the worth of the string can be calculated.

There are three main operators in a GA: reproduction, crossover, and mutation (Chinneck, 2006).

(1) The reproduction is equivalent to the "survival of the fittest" contest. It determines not only which solutions survive, but how many copies of each of the survivors to make. The probability of survival of a solution is proportional to its solution value, known as its fitness. By generating a random number, a new intermediate population known as the mating pool will be reproduced.

(2) Crossover operation happens as follows:
   1. Randomly select two parent strings from the mating pool,
   2. Randomly select a crossover point in the solution string,
   3. Swap the end of the two parent string from the crossover point to the end of the string to create two new child strings.

(3) The mutation operator is used to randomly alter the values of some of the positions in some of the strings based on a parameter that determines the level of mutation.

Based on the above three operations, the following are the basic genetic algorithm process:

Step 0: Design the algorithms: choose the population size n and mutation rate; choose the operators and the stopping conditions.

Step 1: Randomly generate an initial population and calculate the fitness value for each string. Set the incumbent solution as the solution with the best of the fitness function in the initial population.

Step 2: Apply the reproduction operator to the current population to generate a mating pool population of size n.

Step 3: Apply the crossover operator to the strings in the mating pool to generate a tentative new population of size n.

Step 4: Apply the mutation operator to the tentative new population to create the final new population. Calculate the fitness values of the solution strings in the new population and update the incumbent solution if there is a better solution in this population.

Step 5: If the stopping conditions are met, then exit with the incumbent solution as the final solution. Otherwise go to step 2. One of the stopping conditions is to stop after a pre-specified number of populations have been created.

LITERATURE REVIEW

Implementation of genetic algorithms for a flow shop scheduling problem is seen in many papers. Authors of those papers used a different operator in each step which is explained in the previous section. Reeves (1994) compared the performance of SA (Simulated Annealing) and GA for FSPs ranging from 20 jobs and 5 machines to 500 jobs and 20 machines. Chen (1995) implemented GA with a different crossover operator (Partially Mapped Crossover) and Murata(1996) showed similar findings and also compared various crossover (10) and mutation (4) operators and showed that the two-point crossover (C2) and shift mutation operators are effective for FSP (Hejazi & Saghafian, 2005). At those times (1994 ~ 1996), because of limitation of computing power, they generated a limited number of generations. In the recent years, Etiler (2004) and Iyer (2004) implemented GA to the FSP with their own unique crossover operator, LOX (Linear Order Crossover) and LCS (Longest Common Subsequence). Iyer increased the number of generations up to 300.

STEP 1: INITIAL POPULATION

Reeves used the NEH algorithms to generate the initial population. Chen used the CDS algorithms to construct the initial population. Etiler used the (m-1) sequences produced by the CDS method and one sequence produced by using the Dannenbring method to generate an initial population (Etiler, Toklu, Atak, & Wilson, 2004). Iyer and Murata made a randomly generated job sequence as an initial population.

STEP 2: SELECTION (REPRODUCTION)

There are different criteria used as fitness values; the most popular one is makespan and total flow time (Etiler, Toklu, Atak, & Wilson, 2004). Fitness function can be calculated as

$$f(S_i(t)) = max\{C(S_i(t))\} - C(S_i(t))$$

where $S_i(t)$ is the ith string in tth generation and $C(S_i(t))$ is the makespan of $S_i(t)$. The probability of selection is

$$P(S_i(t)) = f(S_i(t)) / \Sigma f.$$

Iyer used reciprocal (*ri*) of the makespan of the strings in the population as a fitness function.

$$f_i = r_i / \Sigma r_j.$$

STEP 3: CROSSOVER

The above five papers tried to use a different crossover operator to outperform a result of previously published papers. Reeves used one-point crossover (C1), and Chen used a partially mapped crossover (PMX). Murata used 10 different crossover operators (one-point, two-point, position-based, etc) to compare outputs of each operator. Iyer used a longest common subsequence (LCS), and Etiler used a linear order crossover (LOX) operator. The following is a comparison of procedure of five major operators.

STEP 4: MUTATION

An exchange operator and a shift operator are two main mutation operators and some papers said the shift operator gave a better performance than the exchange operator. Chen did not use a mutation operator.

STEP 5: TERMINATION

Chen found that the solutions become stable after 20 generations, which was used as a terminal condition. Etiler used 30 generation as a terminal condition when the size of problems is relatively small. Iyer used 300 generation for his terminal condition.

SOLUTION APPROACH

The genetic algorithm to solve a FSP is implemented by Matlab 7.0. As a reference paper, Etiler (2004) is chosen. Initial population (60 sequences) is generated by a random number generator. Linear order crossover operators and exchange operators are used as crossover and mutation operators. Mutation probability is set to 0.05.

There are two main approaches for generating a new population in this paper: (1) fully updated population and (2) partially updated population. In the former there are 30 times generating a new child pair (two children per time) and make a new population based on the 30 pairs of new children (60 sequences per population). In the latter, there is only one time generating a new child pair, which is used for updating two sequences (parents or worst members) in the previous population. In the partially updated population, the author tried the following four methods to replace sequences chosen:

(1) Method 1: if makespans (Cmax) of child sequences are better than those of parents', replace parent sequences by child sequences,
(2) Method 2: if the makespans of child sequences are better than those of the worst two sequences in the population, replace them by child sequences,
(3) Method 3: Select parent sequences in the top 33% of population based on Cmax and use a Method 2 for replacement.
(4) Method 4: Select parent sequence in the top 33% population based on Cmax and use a Method 1 for replacement.

A fully updated population is a general way to make a new population. In this case, generated population could lead to a worse output than the previous population. A partially updated population as a new population updates only when the child performance is better than that of the chosen sequences in the previous population. Therefore, a completion time of new population is at least equal to that of the previous population. Method 1 compares the completion times of child's and parent's. Method 2 is a way to make a better population by removing the worst members if they are worse than the children's makespan (instead of updating parents' sequences). Method 3 is another way to improve population quality to make better children from the top 33% parents' string. Method 4 is a combined method of Method 1 and 3, selecting parents from the top 33% of the population and replacing them if children's Cmax is better. In the Method 4, it is a similar effect to reduce size of population 1/3 of the original population size. A 30 generation is used for a condition to stop. Table 1 summarizes the overall implementation approach, and table 2 summarizes the above four methods in the partially updated population approach.

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Table 1 Summary of Approach

Reference Paper	Initial Population	Crossover Operation	Mutation Operation	Termination
Etiler (2004)	Randomly Generated 60 Sequence	LOX	Exchange	30 generations

Table 2 Summary of Four Methods

	Parent's Strings Selection	Object for Replacement
Method 1	Randomly from whole population	Parent's strings
Method 2	Randomly from whole population	Worst two strings in the whole population
Method 3	Randomly from top 33% population	Worst two strings in the whole population
Method 4	Randomly from top 33% population	Parent's strings

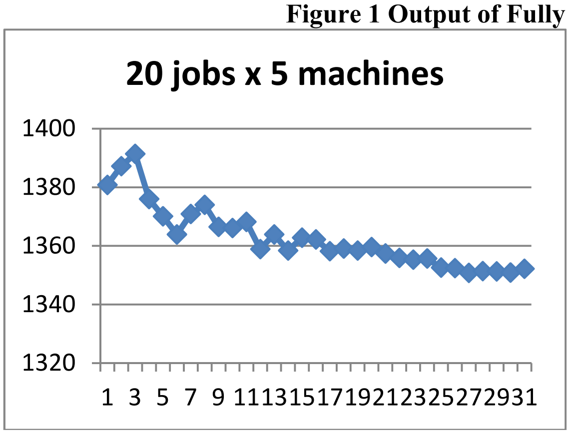
COMPUTATION RESULT

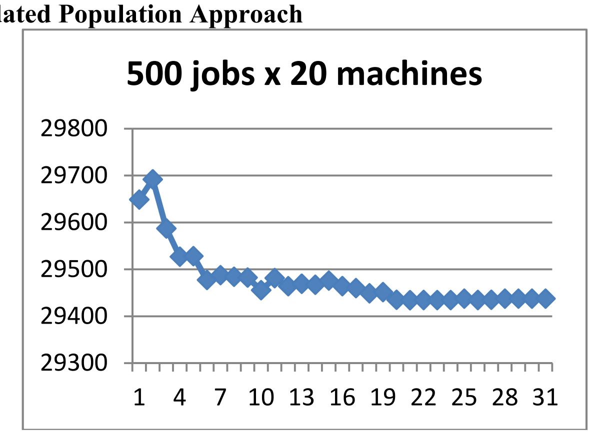
Table 3 shows a result of the above genetic algorithms for the flow shop scheduling problem. Because of the random number generating method as an initial population, 10 run times are needed to calculate an average minimum Cmax of the two assigned cases, (1) 20 jobs and 5 machines and (2) 500 jobs and 20 machines. Because Etiler did not use Tilard's data set, direct comparison with Etiler's result is impossible.

FULLY UPDATED POPULATION APPROACH

As I mentioned in the previous section, fully updated population approach does not guarantee a better performance than that of the previous population. Therefore, in the early generation there is a fluctuation of performance. In both cases, the pattern is very similar, and they become stable in the later generation. Figure 1 shows an evolution of average completion time of each generation of the two problems (20x5 and 500x20).

Figure 1 Output of Fully Updated Population Approach



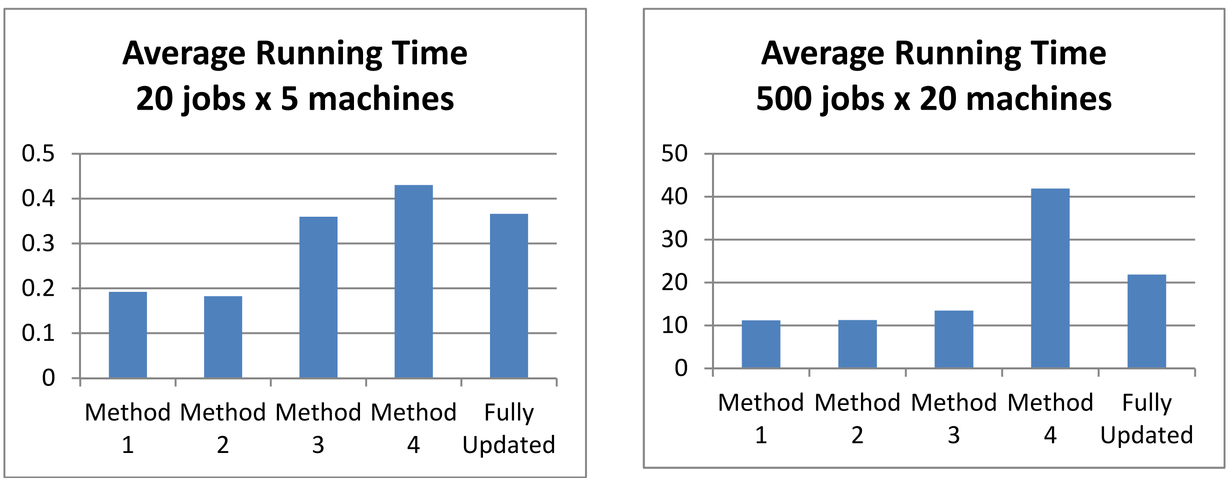


PARTIALLY UPDATED POPULATION APPROACH

Among the four methods of partially updated population approach, Method 4 provides the best output. However, there is a tradeoff between output quality and processing time. Average running time for Method 4 is the longest. Figure 2 shows comparison of average running times of the two cases (20 by 5 and 500 by 20).

Table 3 Solution Output							
		20 jobs and 5 machines			500 jobs and 20 machines		
		Average Cmax (% Improvement)		Best Single Cmax (among 10 trials)	Average Cmax (% Improvement)		Best Single Cmax (among 10 trials)
Fully Updated		1352.2	2.07%	1301*	29437.4	0.71%	29237
Partially Updated	Method 1	1365.7	1.55%	1322	29536.2	0.40%	29401
	Method 2	1355.5	2.20%	1327	29514.7	0.39%	29322
	Method 3	1359.4	2.42%	1336	29487.4	0.61%	29329
	Method 4	1341.4*	2.62%	1315	29415.5*	0.66%	29192*
Well-Known Result				1278			26059

Figure 2 Average Running Time



CONCLUSION

Genetic algorithm is a good heuristic approach to find a near optimal solution within a limited amount of time. In this paper, the author applies a genetic algorithm of the Etiler's paper to a flow-shop scheduling problem with a processing time matrix built by Tilard. The output is not the same as well-known results, but this approach gives us a better solution as the number of generation increases.

The following is author's suggestion how to improve it.

(1) Initial population is a key to improve your output. Using a random number generation, there is no guarantee for a good initial population. Use NEH or CDS method to make your initial population.

(2) Change Crossover Operators: Change other operators such as LCS or C2 or combined operators with LCS and LOX.

(3) Change Mutation Operators: Shift operators are known as a better operator than an exchange operator.

(4) Increasing the number of generation from 30 to 300 (fully updated population) does not guarantee a better solution. In the case of 20 jobs x 5 machines, the average completion is 1346.5 which is a little better than that of 30 generations (1352.2). However, in the case of 500 jobs x 20 machines, the average completion time of 300 generations is 29467.7 which is worse than that of 30 generations (29237). The average running time of each case is around 1.4 seconds and 51 seconds.

(5) In the case of partially updated population, increasing the number of generation is not a feasible solution from the point of running time. As the number of generation goes higher, it might be more difficult to make a better solution to replace parents in the previous generation.

ENDNOTES

[1] *i*th job can start only on machine *j* if its job is completed on machine (*j-1*) and if machine *j* is free.

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SOFTWARE PIRACY AND INTELLECTUAL PROPERTY RIGHTS PROTECTION

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ABSTRACT

International software piracy, a major concern for intellectual property owners, is considered in the context of intellectual property rights laws, national cultural landscape, and economic environment. To evaluate the impact of legal and regulatory environments, the World Economic Forum surveyed business leaders on the level of intellectual property protection in their country. Regarding national culture, five (5) dimensions identified by Hofstede are considered. To evaluate the economic impacts, a country's gross domestic product (GDP) per capita at purchasing power parity is utilized. All three factors were found to be related to software piracy. Managerial and policy implications of this study are discussed.

Key words: Multiple Regression Analysis, Cultural Frameworks (Hofstede), Software industry, software piracy, intellectual property protection

INTRODUCTION

This study relates intellectual property rights protection, cultural factors, and wealth, to software piracy rates by country. Intellectual property protection is of major importance in modern economic affairs. A strong component of economic growth can be attributed to advances in intellectual property, particularly in the most advanced countries. Intellectual property comes in a variety of forms, and can be thought of as a type of knowledge good. Pharmaceuticals, for example, are much more than the specific chemical compounds. Pharmaceuticals are valuable due to the tremendous research and development work of determining which compounds are effective and safe, and under which conditions. Likewise products such as computer software and motion pictures are valuable for the knowledge work that went into developing these products.

The economic factors affecting knowledge goods can be somewhat different than traditional goods. Knowledge goods often share the properties of high fixed development costs coupled with low marginal production costs. For example average capitalized cost estimates per approved biopharmaceutical of over $1.2 billion (DiMasi & Grabowski, 2007). Developing new software products are similarly tremendously costly and time dependent. Microsoft employs approximately 35,000 people in research and development and spent $8.2 billion in 2008 (2008

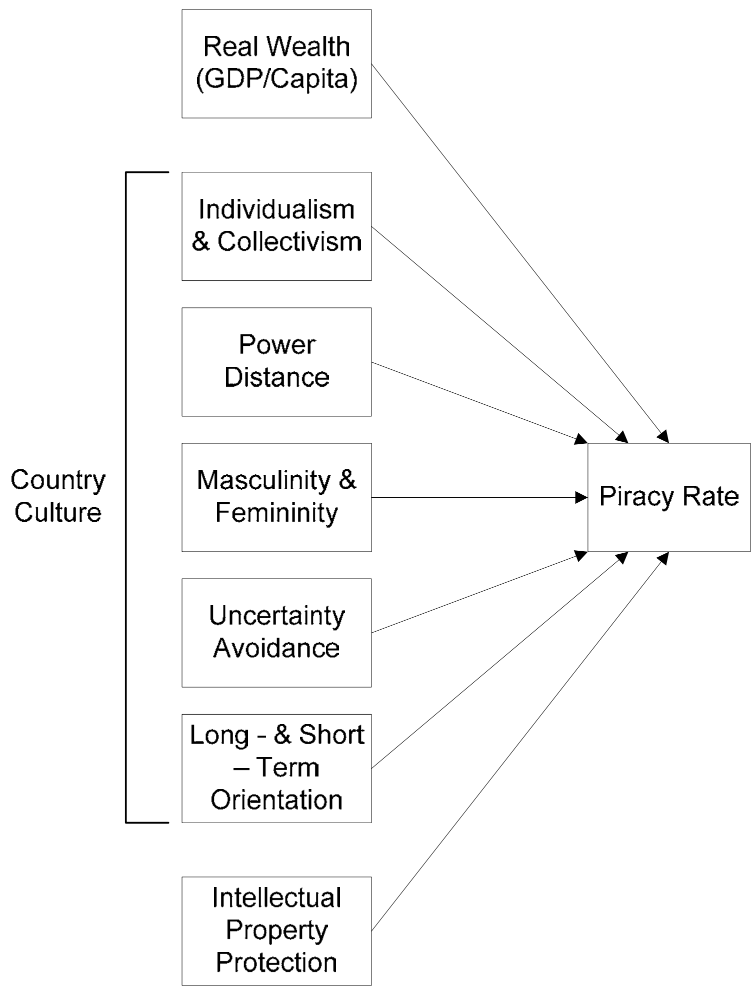
10-K statement). On the other hand, the incremental production costs of knowledge goods are often quite low. The incremental production cost of computer software is negligible with the advent of the Internet, since software products can be distributed over the Internet at little or no incremental cost. This creates a problem for the software developer: consumers can share products with each other free, leaving the developer without income. The same phenomenon occurs with other knowledge products. Bootleg versions of Hollywood films can be found, particularly in less developed countries. The Motion Picture Association of America (MPAA) estimates that the world-wide film industry in 2005 lost about $8.2 billion in revenue do to piracy (http://www.mpaa.org/piracy_WhoPiracyHurts.asp, 2/11/09). A political movement is taking place to legitimize compulsory licensing of pharmaceuticals. Compulsory licensing is when a country grants the rights to a local pharmaceutical company to produce a patented drug without permission of the patent holder. The argument advanced is that the value of the medicine to the population is more important than the rights of the patent holder to monopoly rights to this medicine. In summary, there are a variety of forces acting to limit the ability of developers to generate returns from investment in knowledge goods. The purpose of IP rights protection is to encourage new inventions by granting these monopoly rights; therefore the reduction of these rights in practice has the potential to curtail future advances in knowledge. Additionally, the reduction in profits due to the piracy of software and other knowledge goods may also preclude the investment into future research and development activities.

The purpose of this study is to advance the understanding of one particular aspect in IP rights protection, software piracy. This study expands on prior work in this area (Shin, Gopal, Sanders, & Whinston, 2004). Shin et al. (2004) proposed a model of software piracy that incorporated a country's wealth, as measured by gross domestic product per capita and the national culture dimension of collectivism as the factors in explaining the level of software piracy within the country. While this approach explained a high level of the variation in software piracy rates observed between countries (R^2 of 74% in the full model), the paper was able to generate only a limited range of suggestions regarding the appropriate actions organizations should undertake concerning the piracy.

Prior to the Shin *et al.* (2004) study, Ronkainen & Guerrero-Cusumano (2001) conducted a study that included both market factors and involvement factors. The market factors considered by Ronkainen & Guerrero-Cusumano included purchasing power parities, enforcement of laws and regulations governing the protection of intellectual property (approximated by the Corruption Perceptions Index) and the four cultural values (power distance, uncertainty avoidance, masculinity and individualism) from the work of Hofstede (1980, 1991). Additionally these authors included involvement factors that are related to the involvement of countries in intellectual property treaties, the level of trade dependence and the level of trade with advanced economies.

Our research adds to the understanding of software piracy by incorporating the intellectual property protection afforded by a country to the Shin *et al.* (2004) model, coupled with investigating all relevant cultural dimensions. Of particular interest is whether laws have any effect on software piracy behavior above and beyond the impact of wealth and culture as indicated by the Shin *et al.* (2004) and Ronkainen & Guerrero-Cusumano (2001) models. In addition to providing a replication of sorts for these two models, the impact of the national cultural value of long term orientation will also be considered. Long term orientation, also labeled Confucian Dynamism, is a fifth cultural value identified by Hofstede and Bond (1988). This national cultural variable along with the other independent variables will be discussed later in this paper.

Figure 1. Research Model



MOTIVATIONS FOR THIS RESEARCH

There are several motivations for this research. At the theoretical level, it proposes to examine the interaction among economic, national culture and intellectual property protections afforded by countries on behavior in the context of using information products.

There are implications for public policy as well. Of particular interest is whether, and how, to best implement an intellectual property protection regime. The World Trade Organization recently concluded a round of talks among most of the governments in the world on liberalizing trade. One of the key aspects of this round of negotiations has been the agreement to implement standards for intellectual property protection on a worldwide basis. This agreement, called TRIPs, or Trade Related Aspects of Intellectual Property, is beginning to impact developing countries (Chadha, 2009; Zuccherino, 2008). Intellectual property protection has become a contentious issue, in part due to cultural and political forces. The nature of the legal protections provided, and the enforcement regimes chosen, have the potential to have a substantial effect on businesses. Also, although this study will focus on software piracy, the conclusions may also be relevant to other areas of intellectual property protection.

The second practical consideration for this project is the impact on business processes. Shin *et al.* provided some recommendations on price discrimination with respect to responding to high piracy rates. But price discrimination is only one possible response to the problem of piracy. Other possible responses: education through advertising, legal actions, and market withdrawal are some alternative choices. These choices may depend on the particular country context, and relate to the variables chosen in this study. This paper will shed some light as to where these choices are relevant.

Third, IP protection extends beyond the issue of software piracy. Currently pharmaceutical manufacturers are facing tremendous pressure in trying to preserve their patent protections for various drugs. Many argue that patent protection, and the associated monopoly powers of the patent holders, harms poor and vulnerable people in less developed countries. There are many parallels in this argument to software piracy, so the conclusions of this research may also lend some insight into the pharmaceutical issues.

MODEL DEVELOPMENT

Our paper develops a model of software piracy rate in a country that is a function of the level of intellectual property protection within that county, the cultural endowment of the country, and the level of real income. The dependent variable for our study is the rate of software piracy in a country as reported by the Business Software Alliance (BSA http://www.bsa.org) in their Seventh Annual BSA and IDC Global Software Piracy Study, which is available for download at the BSA's website. This study had been conducted annually, with the objective of identifying the rates of software piracy within countries and regions. The study was conducted by IDC (http://www.idc.com/), a market research and forecasting firm that specializes in the information technology sector. Since this study is funded by the software industry, there is a potential that there is an incentive to overstate the level of software piracy. The software industry of course is interested in eliminating piracy since piracy costs the members' money, and higher reported software rates may encourage more vigorous IP activities by governments. There is however no apparent bias by country in the SIIA's approach, described below; therefore we argue that this measure is reasonable for the purposes of our study.

The BSA defines the software piracy rate as the total number of pirated units of software deployed in a country divided by the total software base in a country (both legitimate and pirated). The BSA tracks the following data to arrive at the piracy rate:

1. Determine how many packaged software units are deployed in each country during the study year. These measures are based on sales reports from both hardware and software vendors, as well as survey data on software loading and local analysts.
2. Determine the amount of software that was legally acquired during the year.
3. Subtract total software deployed from legally acquired software to get an estimate of the number of pirated units of software. This number is divided by total software deployed (both legitimate and pirated) to develop a piracy rate.

The IDC study examines the following categories of software:

The BSA and IDC Global Software Piracy Study covers piracy of all packaged software that runs on personal computers (PC), including desktops, laptops, and ultra-portables. This includes operating systems, systems software such as databases and security packages, business applications, and consumer applications such as games, personal finance, and reference software. The study does not include other types of software such as that which runs on servers or mainframes or software sold as a service.

We used the latest year reported by the BSA for this analysis: 2009. Data from 107 countries were used for this research. The average piracy rate reported in 2009 was 59% by country, which is relatively consistent with prior-year reports. The lowest reported piracy rate was in the U.S. at 20%, and the highest reported rate was in Yemen at 90%.

There are three independent variables in this study: intellectual property protection, national culture, and wealth. The following section will discuss these three variables.

INTELLECTUAL PROPERTY RIGHTS PROTECTION

The nature of the legal environment can have a dramatic impact on behavior, even such seemingly non-public behavior such as software piracy. Laws are shaped by culture and history, and therefore vary by country. Laws can act as a direct deterrent on behavior by establishing and enforcing sanctions. For example, people are much more likely to obey posted speed limits when there is a high likelihood that they will receive a traffic ticket. The law also acts to establish norms of behavior. The posted speed limit will tend to moderate the speeds driven even absent a likelihood of being ticketed. Therefore the intellectual property laws and their enforcement in a country are likely to affect behavior of software piracy.

This analysis will use indexes published by the World Economic Forum (Schwab, 2009) as a measure of the level of intellectual property protection within a country. The WEF publishes tables of country-level measures organized into groups that are referred to as "12 pillars of competitiveness." The Global Competitiveness Report publishes an index of comparative country statistics called the Global Competitiveness Index (GCI). The GCI is an index for measuring national competitiveness, which is defined as the set of institutions, policies, and factors that determine the level of productivity of a country. This index is composed of 12 "pillars," or interrelated factors, in three groups: basic requirements, efficiency enhancers, and innovation and sophistication factors. Factors scales are developed from published data and WEF survey methods. The GCI is the weighted-sum of these 12 factors.

The first of these pillars is titled Institutions and is defined as the "legal and administrative framework within which individuals and institutions interact to generate income and wealth in the economy." One measure in this set is Intellectual Property Protection (IPP). IPP is measured by a cross-country executive opinion survey. Of interest for this study is the measure 1.02 from the report, Intellectual Property Protection (IPP). IPP is measured by the WEF's Executive Opinion Survey. Surveys are administered in each country by partner institutions to the WEF such as business organizations and universities with the survey sampling frame is developed for each country to generate a representative group of respondents from the main economic sectors and from a range of business sizes. 12,297 responses were received, representing a 20% participation rate, with respondents from 134 countries. The IPP variable is measured on a 1 to 7 scale as follows:

> *Intellectual property protection and anti-counterfeiting measures in your country are (1 = weak and not enforced, 7 = strong and enforced).*

Average score by country ranged from a high of 6.3 (Switzerland) to a low of 1.9 (Bolivia). Survey administration and data treatment are described in Schwab (2009).

H1 Higher intellectual property rights protection will be associated with lower software piracy rates.

CULTURAL FACTORS

Cultural values can influence economic behavior. People behave rationally, on average, within the bounds allowed by the cultural context. Also, culture can explain to some extent the utility function that is at the heart of rational economics (Jeffrey, 2006). Utility functions are often exogenous to the economic model and taken as givens. However these utility functions are to some extent shaped by the cultural context. For the purpose of this study, all five (5) dimensions of national culture identified by Hofstede (1991, 1993, 2001; Hofstede & McCrae, 2004) will be employed.

Culture has been defined by Hofstede (1991) as "the collective programming of the mind which distinguishes the members of one group or category of people from those of another" (p. 5). At the national level, the level of analysis in this research, five values have been identified that distinguish different national cultures from each other. These five dimensions are power distance, individualism, uncertainty avoidance, masculinity and long term orientation (Franke, Hofstede, & Bond, 1991; Hofstede, 1980, 1994; Hofstede & Bond, 1988). The meaning of each of these values is explained in the following paragraphs.

Power distance is the degree of inequality among people in a population that is considered normal (Franke et al., 1991; Hofstede, 1980, 1994). That is to what extent do less powerful members of a society accept and expect that power will be distributed unequally (Hofstede & Bond, 1988). Nations with high power distance expect that there will be extreme inequalities while nations with a small power distance expect relative equality (Hofstede, 1993). However one of the purposes of this study is to determine the relationship between culture and law, and therefore the measure of power distance will be proposed. Hofstede (1991) described high power-distance cultures as those where inequality among people are both expected and desired, less powerful people were more dependent on the more powerful, and organizations tend to be more hierarchical (Hofsted, 1991, page 37.) The states in high power-distance countries therefore tend to be more hierarchical and authoritarian, as well as more arbitrary. This arbitrariness, when considered in the context of software piracy, should render attempts to reduce software piracy also arbitrary. As found by Ronkainen & Guerro-Cusumano (2001), we seek to replicate their findings.

H2 High power-distance countries will have more software piracy than low power distance countries.

The second dimension identified by Hofstede (1980, 1991, 1993, 1994) is labeled individualism. The opposite of individualism is collectivism. This dimension distinguishes between the preferences of people to act as individuals as opposed to members of a group. In a society with high levels of individualism, members are concerned with their own interests and the interests of their immediate family only. At the opposite end of this spectrum, for members of a collectivist society, strong loyalty is established with the group, usually extended families, that they are a member of. Strong distinctions are made between the in-group (the group they are a member of) and the out-group (everyone else). Cultures that are highly individualistic identify with "I" and highly collectivist cultures are identified by "we". Individualism is the construct that describes to what extent people think in terms of group versus thinking in terms of individuals. Gopal & Sanders (1998) posited that software piracy was a group activity, and therefore more likely in collectivist cultures. These findings were confirmed empirically by Shin *et al*. (2004) and Ronkainen & Guerro-Cusumano (2001) among others. We seek to replicate their findings.

H3 Highly collectivistic countries will have higher levels of software piracy than highly individualistic countries.

The next dimension established by Hofstede (1980, 1991, 1993, 1994) is uncertainty avoidance. This cultural value contends with the degree to which members of a group prefer structured to unstructured situations. Structured situations are those in which there are clear rules (either written or unwritten) to be followed so that the appropriate behavior is exhibited. A country that has high or strong uncertainty avoidance is rigid and people tend to exhibit nervous energy. On the other hand, countries with low or weak uncertainty avoidance are more flexible and its people tend to me more easy-going. In this light it can be expected that countries with high levels of uncertainty avoidance would have rules in place so that people would know how to appropriately act with respect to items such as software piracy. However this cultural value does not provide any guidance with respect to the direction of this effect. In other words, rules could exist that indicate that software piracy is either all right or not. To indicate and justify directionally, the results of Ronkainen & Guerro-Cusumano (2001) were utilized. They found that, contrary to their hypothesis, the higher the uncertainty avoidance, the higher the piracy rate. Employing these findings, we seek to replicate the following.

H4 Countries that exhibit high uncertainty avoidance will have more software piracy than countries with low uncertainty avoidance.

Masculinity is the fourth dimension identified by Hofstede (1980, 1991, 1993, 1994). This dimension is the degree to which values such as assertiveness, performance, success and competition that are typically associated with men prevail over such values as quality of life, maintaining warm personal relationships, service, care for the weak and solidarity that are typically associated with women. The roles of men and women in all societies are different but when these differences are large, the culture is said to be masculine and “tough” to its people. On the other hand if the differences between men and women are small, a more feminine culture is evident and society is “tender” to its people. A masculine culture is known as a performance society while a feminine culture is a welfare society.

We next seek to replicate the effects of masculinity on software piracy. Highly masculine cultures are associated with performance and competition. There is more concern for the acquisition of wealth and material goods as opposed to the welfare and care of others. Therefore the following hypothesis is tested in support of previous work by Ronkainen & Guerro-Cusumano (2001).

H5 Countries that exhibit high levels of masculinity will have lower levels of software piracy than countries with low levels of masculinity (i.e. are feminine).

The fifth dimension of national culture, long term orientation, was identified by Michael Harris Bond when a questionnaire created by his Chinese colleagues, the Chinese Value Survey, was used to measure national culture. By design the Chinese Value Survey had an eastern bias. The interesting result was that three (3) of the four (4) dimensions identified by Hofstede (1980, 1991) (power distance, individualism & masculinity) were highly correlated to three (3) of the four (4) dimensions identified by the Chinese Value Survey. There was no factor associated with uncertainty avoidance. However, there was a fourth dimension originally identified as Confucian dynamism and later renamed long-term orientation (Hofstede 1991). Cultures with a long term orientation have values associated with the future such as thrift and perseverance while cultures with a short term orientation have values oriented toward the past and present (e.g. respect for tradition and fulfilling social obligations (Hofstede 1993, 1994).

This last dimension of national culture, long term orientation, has not yet been considered in the context of software piracy. Hofestede (2001) defined Long Term Orientation as “the fostering of virtues oriented towards future rewards, in particular, perseverance and thrift. Its opposite pole, Short Term Orinetation, stands for the fostering of virtues related to the past and present, in particular, respect for tradition, preservation of ‘face’ and fulfilling social obligations” (p. 359). This dimension is unique from the other four dimensions in that “this dimension does not oppose East to West; it splits the world along new lines.” (p. 355). Countries with high LTO are East Asian Countries (e.g. China, Hong Kong, Taiwan, Japan and South Korea). At the lower end of the scale are European and other Western countries. However, other non-Western countries in Africa and Asia (e.g. Zimbabwe, Philippines, Nigeria, Pakistan) are at the very bottom of this scale.

Countries with a low Long Term Orientation have societal norms such as ‘immediate gratification of needs is expected’ and ‘quick results are expected’. On the other hand, high Long Term Orientation countries exhibit ‘deferred gratification of needs’ as being acceptable (Hofestede, 2001). Children in high Long Term Orientation cultures learn ‘not to expect immediate gratification of their desires’ while children in a low Long Term Orientation culture experience immediate need gratification and are sensitive to social trends in consumption (Hofestede, 2001). Software piracy is an activity that satisfies immediate needs. Therefore based on the above it is expected that countries with a low Long Term Orientation would exhibit higher levels of software piracy in order to satisfy immediate needs or desires. In order to test this hypothesis the following will be investigated.

H6 Countries that exhibit high levels of long term orientation will have lower levels of software piracy than countries that exhibit low levels of long term orientation.

The five dimensions of culture as discussed above are generally accepted to provide appropriate measures of a country's national culture. Implications of these national culture values and its impact on software piracy will be discussed in the next section.

ECONOMIC FACTORS

There are both direct and indirect economic factors that have the potential to influence the rate of software piracy in a country. The most obvious direct factor is a nation's wealth. The ability of consumers to pay for software increases as they become more affluent. This affluence can be tied in most cases to increases in the overall wealth of the economy, and is usually expressed in gross domestic product per capita. Of course an increase in average wealth does not mean that the distribution of wealth is even, simply that there is more aggregate wealth in the society. Gopal & Sanders (1998) established a theoretical model that linked piracy to economic and ethical factors. Empirical testing revealed a strong relationship between a country's GDP/capita and software piracy due in part to reduced opportunity costs of piracy in wealthier countries, and in part due to the large presence of software publishers in the wealthier countries.

There are also indirect economic factors affecting software piracy. Gopal & Sanders (1989) also considered the size of a country's software industry as a factor in explaining piracy rates. Their paper theorized that countries would have an incentive to protect intellectual property only to the extent that the domestic economy produced that intellectual property. Countries that do not produce software therefore will not have an incentive to establish and enforce copyright laws to limit software piracy. Gopal & Sanders (1989) did establish that software piracy was negatively related to the size of the domestic software industry; however their conclusions were based on a small sample size, primarily the more developed economies (with the exceptions of China and Korea.) This is perhaps natural, in that the software industry is not substantial outside of the most developed economies, however their approach did not consider legal factors that could influence software piracy outside of the context of more developed economies. Also, their approach considered the legal factors indirectly; they did not directly measure the type and nature of the legal regime. In addition to the work of Gopal and Sanders, many other works also concur with the economic finding the countries with higher GDP/capita (or other measures of economic wealth) have lower rates of software piracy ((Andres, 2006; Bagchi, Kirs, & Cerveny, 2006; Bezmen & Depken, 2006; Marron & Steel, 2000; Moores, 2008; Ronkainen & Guerrero-Cusumano, 2001).

H7 Software piracy is negatively associated with increasing wealth.

METHODS

In this section we discuss the analysis methods employed in this research. The main research questions are to quantify the impact of cultural and intellectual property protection variables affect the level of software piracy in a country. OLS regression is used to estimate parameters of interest. This section is organized as follows: first is a discussion of measures employed, followed by description of the regression analyses performed using R 2.11.1.

Missing information is a common problem in empirical research. Our database consisted of information on 105 countries. Full information on all variables of interest in this study was available for only 29 countries. This fact makes listwise deletion of cases with missing data particularly problematic. To overcome this problem, multiple imputation (MI) techniques were used to simulate missing response data (Graham & Schafer, 1999). Total missing items in the response database were 26%. MI is a simulation-based technique that replaces missing data with a random variable drawn from a multivariate normal distribution that is conditional on the rest of the data matrix. Analysis is repeated multiple times, five for this research, and the analysis is pooled to estimate statistical parameters.

The WEF measure of intellectual property rights protection (WEF_IPP2009) was compared to another published measure of property rights protection in order to increase confidence in construct validity of this measure. The Heritage Foundation publishes a report titled the 2010 Index of Economic Freedom in conjunction with the Wall Street Journal (Miller et al., 2010). This report contains a section analyzing property rights by country based on a 0 to 100 point scale, with 100 representing the highest level of property rights protection. This scale purports to assess the degree to which there are clear and enforced laws within a country to allow individuals to accumulate private property, as well as the level of corruption within the country's judicial system. For example, the definition for a score of 100 is as follows:

> *100—Private property is guaranteed by the government. The court system enforces contracts efficiently and quickly. The justice system punishes those who unlawfully confiscate private property. There is no corruption or expropriation.*

Further details of the study and data sources are reported Miller et al. (2010). WEF_IPP2009 is 84% correlated with the Property Rights measure in the Heritage Foundation study. It's important to note that the Heritage measure defines property more broadly than intellectual property such as software, yet the high correlation between these two separate measures improves our confidence that WEF_IPP2009 taps into the construct of interest for our study.

Next we examine OLS regression models to estimate parameters of interest. At each step we examine scatter plots and studentized residual values to determine appropriate model specification and to check for outliers.

As shown in **Error! Reference source not found.**, there is a strong negative association between IPP as measured by the WEF survey and the rate of piracy in a country. The relationship is linear in shape with no significant outliers based on examining studentized residuals. The adjusted R^2 value for this relationship is 70%. H1 is therefore strongly supported with increasing intellectual property protection negatively related to software piracy rates in a country ($\beta = -0.85$, $p < .001$).

Next we examine the series of cultural hypotheses. Countries that were scored high on the power distance dimension had higher piracy rates ($\beta = .49$, $p < .001$), shown in **Error! Reference source not found.**. There were no significant outliers and the relationship pattern is linear, lending support to hypotheses 2. As hypothesized in H3, there is an inverse relationship between a country's level of individualism and software piracy ($\beta = -.63$, $p < .001$), with countries that rate high on the individualism scale having low piracy rates (**Error! Reference source not found.**). However, there appears to be no association between the three other dimensions of culture; uncertainty avoidance, masculinity, and long term orientation, and software piracy rates (please see **Error! Reference source not found.** through **Error! Reference source not found.**). Support for H4, H5 and H6 was not found.

Figure 2. Piracy Rate and IPP

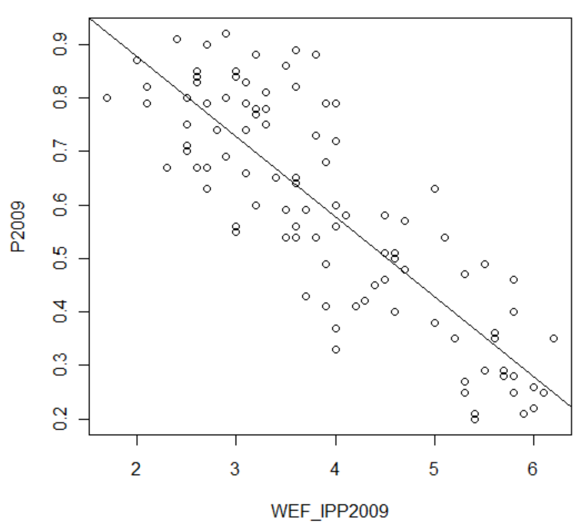


Figure 3. Piracy Rate and Power Distance

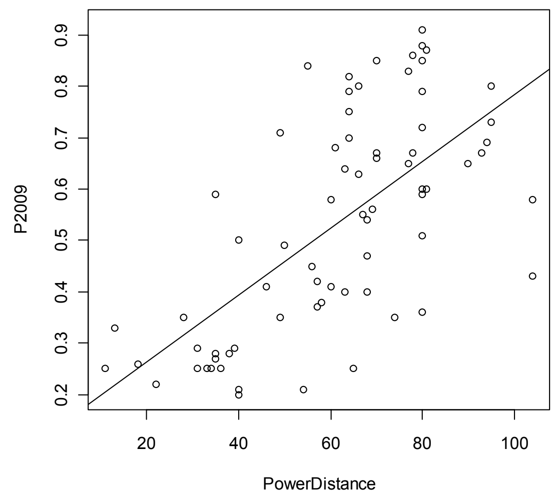


Figure 4. Piracy Rate and Individualism

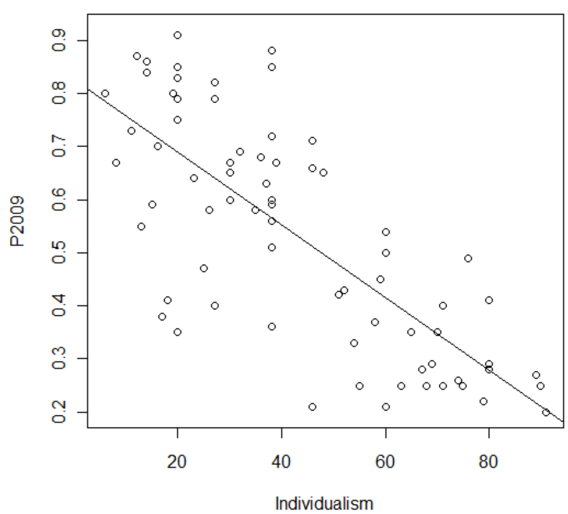


Figure 5. Piracy Rate and Masculinity

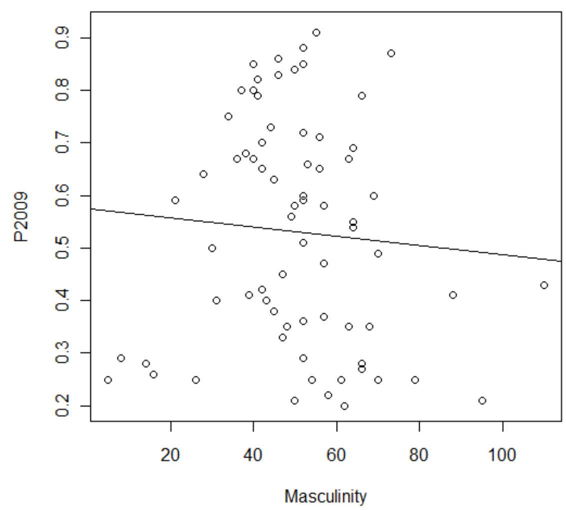


Figure 6. Piracy Rate and Uncertainty Avoidance

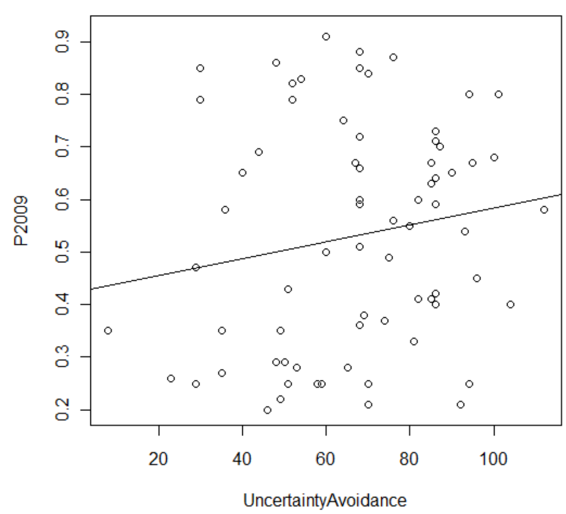
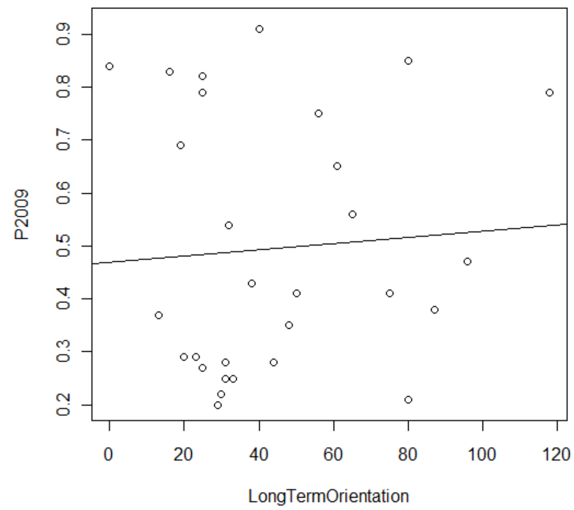


Figure 7. Piracy Rate and Long-term Orientation



GDP per capita at Purchasing Power Parity (PPP) was chosen to measure the construct of relative wealth for this study. Comparable country-level statistics are reported in The World Factbook published annually by the U.S. Central Intelligence Agency. GDP measures the value of all final goods and services within a country during the year. This value is converted to U.S. dollars and adjusted to U.S. cost levels to compare common purchasing powers across countries. This adjustment is common among economic studies to compare living conditions and resource use between countries. Dividing GDP by the population level approximates average wealth within the country. Some smaller countries may not fully participate in the World Banks PPP project. PPP adjustments to these countries may be based on small samples that are less comparable, increasing the variance of this measure relative to advanced countries.

Incomes versus piracy rates were plotted in Figure 8 to examine the nature of this relationship. Two countries, Kuwait and Qatar, appear inconsistent with other countries with higher piracy rates than might be expected with the high level of piracy relative real income. This may be due to the concentrated nature of wealth in these oil-producing countries. The relationship also appears to be curvilinear; hence the variable GDP2009 was log-transformed for further analysis. Student residual values were examined to determine outliers. Only Yemen (-3.6, 103df, $p < .001$) exceeded critical value, please see **Error! Reference source not found.**. H7 is strongly supported with increasing wealth negatively related to software piracy rates in a country ($\beta = -0.81$, $p < .001$). The R^2 value for this relationship is 65%.

Figure 8. Piracy Rate and Real Wealth

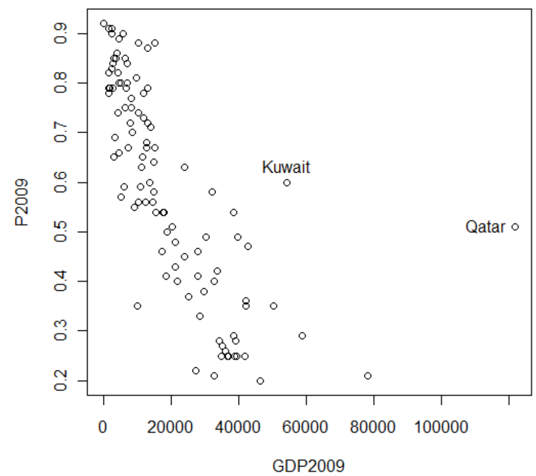
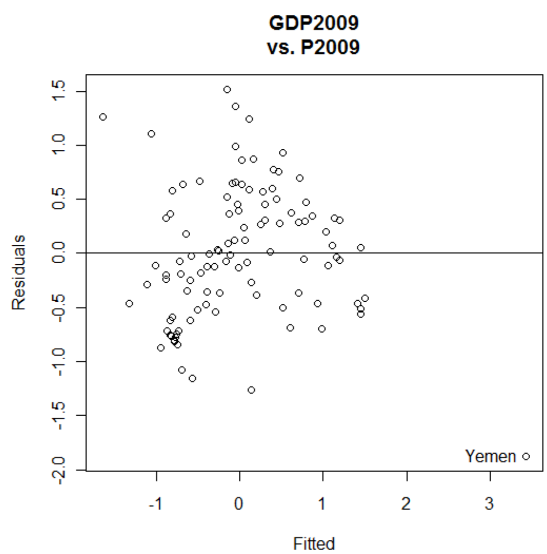


Figure 9. Model 7 Fit



It's interesting to note that IPP and GDP per capita are 90% correlated. Potential explanations for correlated predictors include missing common predictors or various other structural relationships between variables (Rosenthal & Rosnow, 1991). The WEF report discusses the nature and meaning of this correlation (Schwab, 2009). To examine these relations in more depth, hierarchical regression models on a reduced data set are compared using ANOVA tests. The order of comparison is: first GDP, then all five cultural dimensions, followed by WEF_IPP2009.

For the first test, we compare model 7(Wealth) to model 8 (Culture & Wealth). Please see Table 1. In this case, adding all cultural dimensions to the model is a significant improvement ($p < .003$), increase explained variation from 65% to 78%. This suggests that culture is important in addition to the contribution of wealth considerations in examining country piracy rates. The second comparison adds WEF_IPP2009 (model 9) to the previous model (model 8). Again there is a significant improvement ($p < .001$), which suggests that intellectual property protection significantly associated with reduced software piracy holding both wealth and culture constant. Because of the high level of multicolinearity, explained variation increases only modestly to 85%. All hypothesis tests are summarized in **Error! Reference source not found.**.

Table 1: Regression Results

	H1	H2	H3	H5	H4	H6	H7	R^2
Model 1 H1	-0.85***							0.70
Model 2 H2		0.49***						0.23
Model 3 H3			-0.63***					0.40
Model 4 H4				-0.12				0.02
Model 5 H5					0.05			0.00
Model 6 H6						-0.01		0.01
Model 7 H7							-0.81***	0.65
Model 8		0.21*	-0.17	-0.10	0.09	.02	-0.67***	0.78
Model 9	-0.50***	-0.14	-0.10	-0.13	-0.07	0.00	-0.35**	0.85

Figure 10. Model 9 Fit

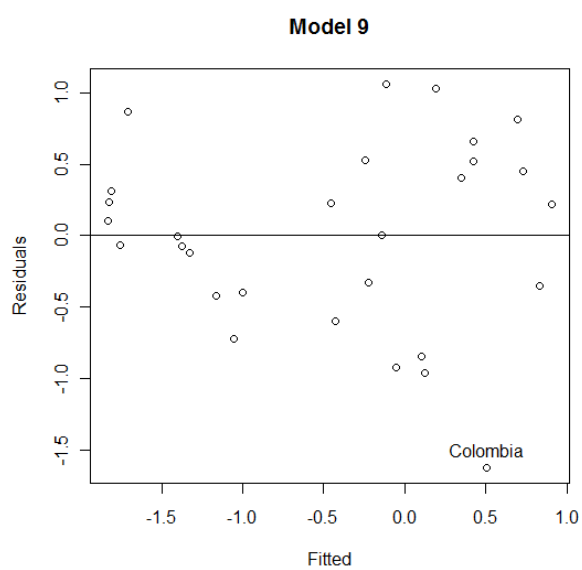


Table 2: Summary of Hypothesis Tests	
Hypothesis	*Findings*
H1: Higher intellectual property rights protection will be associated with lower software piracy rates.	Supported
H2: High power-distance countries will have more software piracy than low power distance countries.	Supported
H3: Highly collectivistic countries will have higher levels of software piracy than highly individualistic countries.	Not Supported
H4: Countries that exhibit high uncertainty avoidance will have more software piracy than countries with low uncertainty avoidance.	Not Supported
H5: Countries that exhibit high levels of masculinity will have lower levels of software piracy than countries with low levels of masculinity (i.e. are feminine).	Not Supported
H6: Countries that exhibit high levels of long term orientation will have lower levels of software piracy than countries that exhibit low levels of long term orientation.	Not Supported
H7: Software piracy is negatively associated with increasing wealth.	Supported

DISCUSSION AND CONCLUSIONS

Our main research objective was to quantify the impact of intellectual property protection measures on software piracy rates at the country level. Holding constant wealth and culture, we show that IPP can have a significant downward pressure on piracy rate. By quantifying this relationship our research can be a used as an input to cost/benefit analysis used by international business and governmental bodies interested in reducing software piracy rates. Since cultural values are slow to change, institutional reform efforts that fail to take into account culture are likely to be disappointing.

One of the interesting aspects of this study was the highly correlated nature of all of the variables in question. The IP enforcement dimension was highly, and negatively, correlated to power distance in cultures, and positively related to wealth. This supports the concept that laws are related to culture, and that rule of law is associated with wealth. It is therefore less likely for efforts to improve legal methods to reduce piracy to have effect absent strong growth initiatives. Perhaps in this case a better approach for the software industry is to focus on low marginal pricing of software products. There may also be some benefit to advertising approaches that encourage people to pay these reasonable prices. High power-distance cultures tend to respect status and face, therefore the marketing approach should try to tap into these feelings. Perhaps enlisting high-status local individuals in marketing efforts would be particularly useful in such cases.

Wealth was also highly negatively correlated to power distance. Since culture is hypothesized to be a relatively constant phenomenon, this does not bode well for development in the poorer countries that score high on this dimension. In looking for outliers, countries with high power distance and high income, two countries stood out: Kuwait and United Arab Emirates. Both countries have high dependence on oil for wealth generation, and therefore are not a model for other countries to emulate. Other high power-distance cultures with high income are Singapore, France, and Hong Kong. That means that in some cases countries have overcome any barriers that high power distance may impose, however these countries appear to be the exception. Software piracy levels in China are particularly important due the large market size and strong growth rate. The Chinese political culture has been identified as a source for IP appropriation with less defined concepts of ownership for intangible property since invention is based on past knowledge that the province of the community. While China agreed to adopt IP protections based on a bilateral trade agreement with the U.S. in 1979, it is clear that these protections are not vigorously applied (Zimmerman & Chaudhry, 2009).

While some aspects of this research replicate past studies in the area of software piracy, there are several important contributions of this study. First the cultural dimension of Long Term Orientation has been included in the analysis. To our knowledge this dimension has not been considered in prior research. We were able to establish that this dimension of culture is not related to software piracy, which enables us to gain a more complete picture when considering the cultural dimensions that impact software piracy. This finding is particularly relevant for country-level studies of the piracy phenomenon in Asia.

Secondly, past studies, (e.g. Ronkainen, & Guerrero-Cusumano, 2001) used data from 1998 while this research employed the most recent data available (from 2009). In the elapsed time between these two studies (11 years) there have been significant changes to the world economic landscape. It is important to study changing environmental conditions to determine if the findings from previous research are still applicable. These changes include the emergence of China, India and the Pacific Rim countries as economies that play a significant role in the world today. China has recently emerged as the second largest economy in the world. Additionally the following events and trends have occurred: the events of September 11, 2001, the emergence of the Internet as a global phenomenon, the explosion of global trade and commerce and the 2008 global economic crisis. Each of these events has had major impacts to the world's economy and global economic conditions. Despite all these changes and major events in the world economy this research has demonstrated and replicated results from past studies.

Thirdly, there has been substantial progress in the development of statistical tools to deal with missing information. In the past, use of listwise and casewise deletion methods were common, with the disadvantage of removing information from parameter estimates and hypothesis tests. In this research we used multiple imputation to improve the precision of our parameter estimates using all available data.

Limitations and Future Research

Some of the limitations of this study were discussed with respect to the variables included in the study. The dependent variable in this study is a country's software piracy rate. Software piracy rates are assessed by the Software & Information Industry Association (SIIA.) The SIIA determines the rate of piracy in a country by evaluating computer hardware sales, and projecting the rate of software sales that would be expected with this hardware in the absence of piracy. Since the SIIA is funded by the software industry, there is a potential that there is an incentive to overstate the amount of software piracy. The software industry of course is interested in eliminating piracy since piracy costs the members' money, and higher reported software rates may encourage more vigorous IP activities by governments. There is however no apparent bias by country in the SIIA's approach, therefore it should be acceptable for the purposes of this study. Piracy rate for the year 2009 were used as the dependent variable.

The unit of analysis for this study was at the national level, while software piracy is an individual phenomenon. The aggregate variables used in this study may mask some very interesting difference in people within countries, particularly in the less developed countries. Software piracy in these contexts would of course only occur in those people with access to computers, which would usually be in either a business context or the more wealthy segments of the population. These groups are likely to be quite distinctly different than the populations as a whole in the developing world. Behavior and behavioral intentions of these groups may be studied perhaps through laboratory techniques with foreign graduate students in the U.S. This group may be representative of the populations in the less-developed world that would most likely be involved with software piracy in the home countries. This research should focus on deriving models of individual behavior, which may lead to improved insights for policy and marketing campaigns.

One of the key methods business can employ would be advertising and awareness campaigns. It would also be interesting to study the impact on behavioral intentions toward software piracy in the context of different types of advertising campaigns. There is also some potential interplay between laws and advertising campaigns that could determine under which levels of IP laws would awareness impact behavior.

One additional limitation is the data analysis techniques chosen. The variables in this research exhibit a high degree of multicolinearity. In considering each variable separately, as was done in this study, there is a risk that some of the important linkages between variables are missing. Alternative approaches could be considered such as discriminant analysis or partial least squares approaches may yield additional insight into the behavior of piracy with respect to laws.

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POST PROJECT ASSESSMENT: AN ART AND SCIENCE APPROACH

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ABSTRACT

The post-project assessment is an important, yet frequently overlooked, stage of project management. Projects represent a high investment for most organizations, and the effective use of post project assessments is likely to be one of the most reliable ways of reducing the risk of project failure and maximizing the business value of the project management function. This article describes an art-and science based system for conducting post-project assessments and discusses a case study application of the system and the types of lessons learned.

INTRODUCTION

The post-project assessment is an important, yet frequently overlooked, stage of project management. Projects represent a high investment for most organizations, and the effective use of post project assessments is likely to be one of the most reliable ways of reducing the risk of project failure and maximizing the business value of the project management function.

Sometimes referred to by alternative names such as project review, project debrief and even the dismal-sounding "post mortem", the post project assessment allows lessons learned from projects to be identified and documented as organizational knowledge. By drawing on this knowledge when conducting future projects, the organization is able to build on successful practice and avoid past mistakes in order to ensure that the projects contribute most effectively to the achievement of business goals.

AN UNDER-UTILIZED BUSINESS TOOL?

Despite the many potential benefits of post project assessment, many organizations fail to review their projects on completion: one international study of twenty R&D companies found that 80% of all their projects were not being reviewed and the remainder was reviewed only in an ad hoc fashion, without the use of systematic procedures (Zedtwitz, 2003).

Other researchers have also found research evidence that few organizations routinely conduct post project assessments (e.g. Anbari, Carayannis & Voetsch, 2008; Keegan and Turner, 2001; Kumar), and that when they are used, it is often in an ad hoc or superficial way which does not contribute effectively to organizational learning (Busby 1999; Kululanga & Kuotcha, 2008).

A review of the literature in this area indicates that, of the numerous reasons why organizations don't bother with post-project assessments, the most common appear to be:

1. Time and workload pressures (e.g.Kumar, 1990; Collier et al., 1996; Litsikakis, n.d.)
2. A lack of established assessment procedures or criteria (Kumar,1990; Collier et al. 1996; Kasi et al., 2008)
3. A lack of relevant expertise in assessment data collection and analysis (Kumar, 1990; Collier et al., 1996)
4. Difficulties of accurately recalling project information retrospectively (Kumar, 1990; Kransdorff, 1996; Zedwicz, 2003; Kasi et al., 2008)
5. Fear of blame for project problems or failures (Kumar, 1990; Zedwitz, 2003; Litsikakis, n.d.)
6. A lack of support from senior management (Kasi et al., 2008; Litsikakis, n.d.)
7. Lack of incentives, or the belief that assessments are of little value (McAvoy, 2006; Kasi et al., 2008)

As a result, where project reviews do occur, they are often more of a wrap-up on the project just completed than a learning exercise which will benefit future projects. However, avoiding post project assessments can be a risky and costly strategy for organizations.

The documented high rates of project failure suggest that ineffective project management strategies and poor risk management are widespread, and that organizations are not learning from their project experiences in order to improve project success rates. In an international survey of senior business executives conducted by the Economist Intelligence Unit in 2008, for example, 58% of respondents reported that at least half of their organizational change initiatives over the past five years had not been successful.

Given the likely scale of many organizational transformation projects, this represents a major cost to business, not only in a direct financial sense but also in terms of lost time, damage to staff morale and customer relations and other adverse impacts. Even where smaller projects are concerned, the costs of failure can be considerable, and often far exceed the original intended costs of the project.

AN ART AND SCIENCE APPROACH TO POST PROJECT ASSESSMENT

In order to become established and highly-valued organizational practice, post project assessments must be effective in unearthing the key factors contributing to project successes and failures and translating these into non project-specific information that is useful to the organization. With this precondition as our starting point, Schroeder & Schroeder Inc. developed a Post Project Assessment System based on our proprietary Project Manager Assessment System (PMAS).

The PMAS is grounded in an extensive review of the project management literature as well as a quarter century of experience of project management consultancy which has enabled us to identify at first hand the most important skills contributing to successful project management. The importance of this framework, in the context of post project assessment, relates to the growing research evidence that the high rate of project failure is related to an over-emphasis in project management on formal tools and techniques. Effective project management, it is becoming clear, involves much more than the application of these scientific processes, tools and techniques. What is proving to be just as important in ensuring the success of projects are the "softer", "people-focused" skills which underpin the ability to successfully implement the standardized project management tools and techniques.

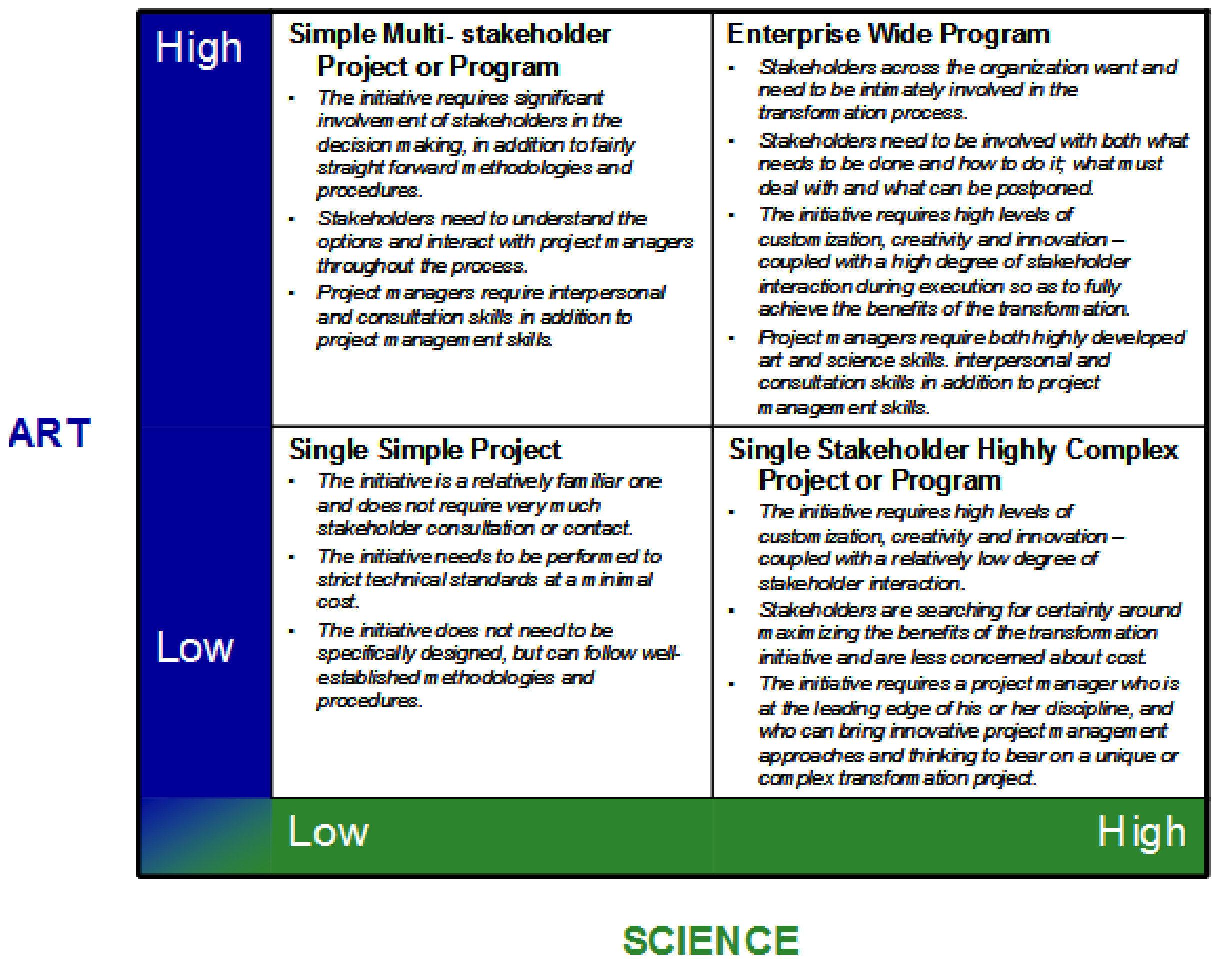
Table 1: EXAMPLES OF ART AND SCIENCE SKILLS IN THE PMAS

Example Science Skills	Description
Requirements Analysis and Project Scoping	Demonstrates and applies the principles, methods and abilities required to clarify and formalize project objectives and scope, including development of project charter, specification of project deliverables and impact analysis.
Financial Resource Planning and Management	Demonstrates and applies the principles, methods and abilities required to estimate financial resource requirements to achieve project goals, including cost-benefit analysis, and to secure, manage and monitor these cost-effectively.
Project Time Planning and Management	Demonstrates and applies the principles, methods and abilities required for estimating, planning and monitoring project activity time requirements and durations.
Project Governance	Demonstrates and applies the principles, methods and abilities required to establish and maintain an effective project governance structure.
Risk Identification and Management	Demonstrates and effectively applies knowledge of methods and tools used for risk assessment and management.
Example Art Skills	**Description**
Leadership	Engages, influences, inspires and guides others to meet goals; effectively represents team or organization to range of stakeholders.
Business Acumen	Demonstrates apparently instinctive understanding of the strategies and resources needed to achieve business success and growth, and how to implement these.
Strategic Awareness	Understands and consistently works towards the organizational strategy, mission and objectives. Also demonstrates awareness and understanding of internal and external stakeholder perspectives and addresses these effectively.
People Acumen	Demonstrates apparently instinctive ability to make sound judgments of the characters, traits and abilities of people, and their likely 'fit' to project team requirements.
Intuition/ Emotional intelligence	Easily achieves understanding of situations, problems and people – including one's own strengths, limitations and emotions - and is able to identify most appropriate course of action without the need for detailed analysis and reasoning.

In PMAS, we define those aspects of project management which rely on established tools and techniques as the “science” and the softer people-focused skills as the “art” of project management. Some examples of the science and art skills included in this framework, with brief descriptions of each, are shown in Table 1.

Our approach also recognizes that every project is different, and will require a unique combination of art and science skills; if this is not achieved, the project manager and project team are likely to face difficulties in completing the project successfully. Examples of project “types” and their typical mix of art and science skills are shown in Figure 1.

Figure 1. Types of Projects and their Position on the Art and Science Skills Scale



Within this general framework, our Post Project Assessment System (PPAS) was designed to generate an understanding of project performance in relation to the art and science skills defined in our framework, taking into account the nature of the project and its skill requirements. It was also designed to reflect a set of best practice principles of project assessment, developed on the basis of a review of the project management literature and published guidance.

1. A commitment to organizational learning: the organizational culture and processes must support reflective learning and facilitate the transfer of stored knowledge to new projects and initiatives.
2. A no-blame culture: individuals must be assured that they can be honest and open in expressing their views and divulging information about their project experiences, without fear of reprisal.
3. Confidentiality and anonymity: participants in the assessment must be assured that the information they contribute will be treated in complete confidence and that their responses will not be attributed to them personally in the assessment report.
4. Continuous monitoring: key milestone mini-reviews should be held and the outcomes documented during the project.
5. The inclusion of a range of data collection techniques including both quantitative and qualitative methods, to provide a comprehensive and holistic understanding of the project.
6. The inclusion of a phase-by-phase review of the project with each participant, in order to assist the recall process and ensure that no important details are overlooked.
7. The need to generate and document post project assessment results in a concise, user-friendly format which can readily contribute to organizational learning and the ongoing improvement of the project management function.
8. The importance of adding value to the assessment process through insightful interpretation of the assessment results and translation of the outcomes into practical, useful lessons learned and recommendations.

The PPAS uses two main methods of data collection in order to generate both quantitative and qualitative data from project team members and from other stakeholders. These consist of:

A self-completion electronic survey questionnaire in which project team members are asked to rank:

1. The relative importance of specified "art" and "science skills" to the project, and the perceived performance of the project team as a whole against each of these art and science skills
2. The relative importance of specified "art" and "science skills" to their own role or area of responsibility, and their own self-rated project performance against each of these art and science skills.

Follow-up interviews intended to provide additional information to explain or clarify the findings of the online survey:

1. In particular, the interviews are used to identify any negative impact of any significant gaps between project skill requirements and team performance, as well as any positive impacts of strong performance in relation to the art and science skill areas.
2. The interviews are also used to examine the participants' experiences and perceptions of what happened at each phase of the project, and their views on the project overall.

Additionally, a review of project documentation and key milestone review data forms an important component of the assessment, providing background information on the nature of the project and its goals, and enabling us to incorporate key learnings generated during the course of the project.

CASE STUDY EXAMPLE

The Schroeder & Schroeder Post Project Assessment System was first trialed on completion of a project for the design and implementation of a new Enterprise Information System for an Ontario-based product stewardship organization. The project team had faced some major challenges in conducting this project which had required, in particular, the application of high levels of art skills on the part of the project manager and other team members. For example:

1. The organization was operating in a newly evolving industry sector with few established best practices on which to draw
2. Most client team members were new to the organization and had limited knowledge of the business requirements
3. The project involved the insourcing of IT services that had previously been carried out by external service providers; these organizations held important data and know-how required for the success of the project
4. The agreed project implementation model involved a dispersed project team consisting of sub-contractors
5. A very tight timescale for implementation of the project solution, to enable the organization to meet externally-imposed for data reporting

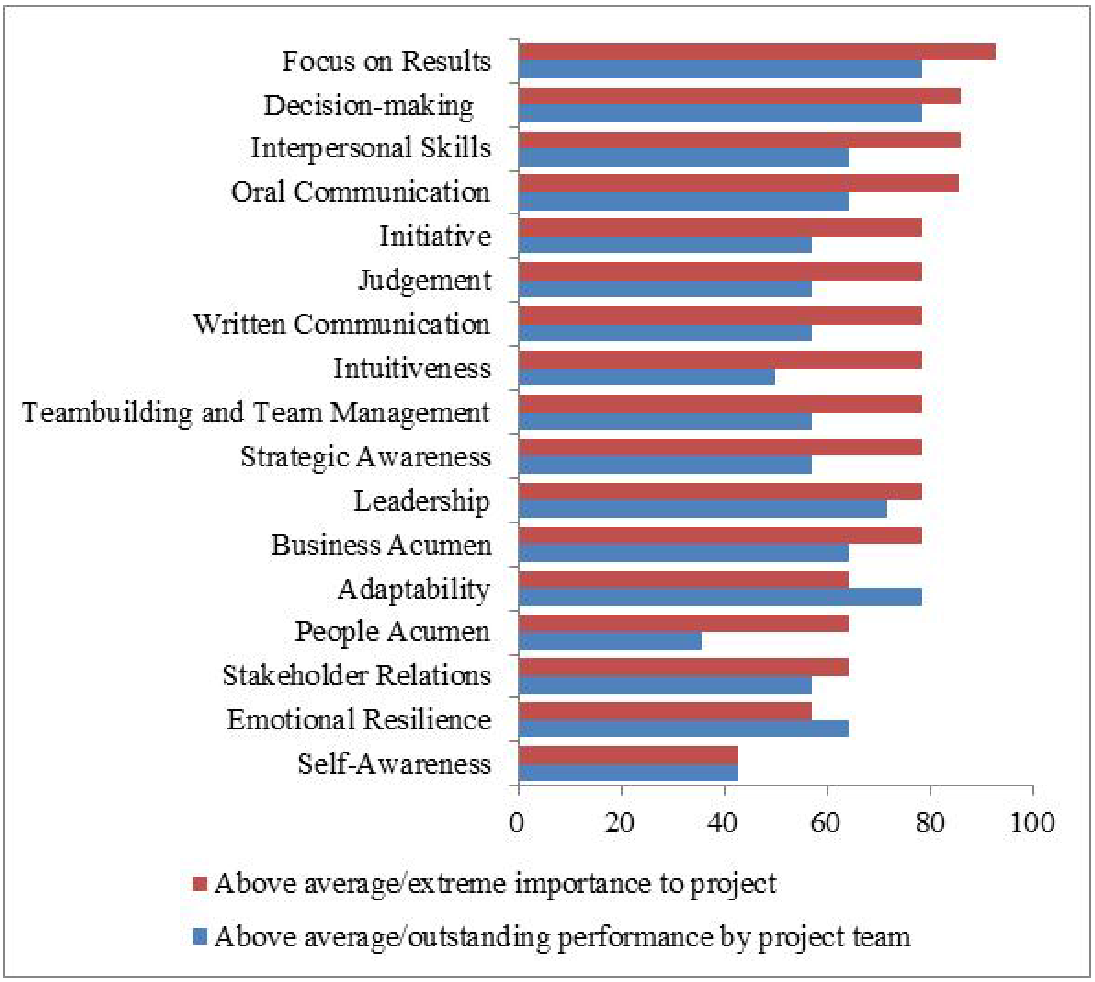
Despite these challenges, this proved to be a successful project, the outcomes of which were well received by the client. We conducted a post project assessment to ensure that any key lessons were documented and could be used to inform the design of similar projects, which are becoming increasingly common in the rapidly developing product stewardship sector.

Figure 2 shows the graphical representation of aggregated data from the self-completion surveys, to demonstrate how this presentation format enables us to see at a glance the main strengths of the project team in relation to the perceived art skill requirements of this project, as well as areas for improvement where performance was ranked considerable lower than requirements.

In the case of this project, the survey findings suggested that there had been scope for improvement in the areas of interpersonal skills and people acumen. The in-depth interviews enabled us to explore the reasons for this finding, and to ensure that any conclusions we drew from it were well-grounded in evidence from the project.

It was found, for example, that a number of team members had been appointed whose skill sets were not seen to match the requirements of the project and who were felt to have caused delays and unnecessary difficulties at some stages of the work. This may have been reflected in the survey findings regarding performance in relation to people acumen, a skill which is particularly important in recruitment of suitable team members. Areas of weakness in interpersonal skills are often reflected in disagreements and conflicts during the project which are not readily resolved; indeed, we found evidence of this during certain phases of the project and were able to draw out some of the likely reasons for these which could be avoided in similar project situations.

Figure 2: Perceived importance of "art" skills, and assessment of project team performance



With regard to science skills, the interviews revealed the importance of including a good mix of business and technical expertise when specifying requirements and planning the project work. In this project, there was evidence of insufficient technical input in the early stages, which resulted in additional unanticipated workloads and time requirements later in the project.

Overall, however, the interview findings reflected the success of the project, with the majority of interviewees stressing their satisfaction with the project experience and praising, in particular, the leadership and organizational skills of the project manager. Another key lesson drawn from this was that the appointment of a project manager highly skilled in both art and science is a critical success factor in this type of project, in which there are particularly challenging people-related situations to deal with as well as the need to complete a very demanding project within budget and to a very tight timescale.

Whilst these findings represent only a small proportion of the learnings generated from this exercise, they serve to illustrate the potential of the PPAS for integrating data from the survey and in-depth interviews to provide a comprehensive assessment and to generate practical information for use in planning and implementing similar projects.

CONCLUDING COMMENTS

As research increasingly reveals the importance of art and science in project management, as well as the business costs of project failure, it might be expected that organizations will gradually adopt more systematic approaches to improving their project management performance and mitigating project risks. In this context, post project assessments will play an important role in demonstrating “what works” in effective project management and how performance can be improved. The art and science approach helps to ensure that project assessments focus on the factors known to be associated with successful project management, so that deviations from this can be readily identified and addressed.

To conclude, some of the potential business benefits of post project assessments, which can be of significant value to the organisation, include:

1. Reduced cost and increased efficiency – there is no longer a need to reinvent the wheel every time a project is conducted. The organization is able to get up to speed quickly, building on established effective practice in the process of specifying and planning projects, dealing with stakeholders and managing project scope, among other project management tasks.
2. Reduced risk – the potential for project failure can be greatly reduced by using prior project experiences to anticipate risks and take mitigating action based on knowledge of what works.
3. Higher return on investment – organizations will be better equipped to design and deliver projects intended to generate increased business revenue or reduce operating costs.
4. Improved team-working and organizational culture – a well-designed project assessment system helps promote transparency, trust and accountability, and can lead to improved morale, co-operative working and reduced risk of conflict between organizational members.
5. Better control and improved efficiency – the system provides a method for tracking improvements in project management over time.

6. An enhanced project management function – the organization is able to identify specific strengths and weaknesses in project management, so that ways of improving this function can be identified and implemented.
7. Improved resource planning – organizations will become more aware of the skills and expertise within the organization and how best to deploy individuals and teams in order to achieve positive project outcomes.

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MODELING AND PREDICTING TRAFFIC ACCIDENTS AT SIGNALIZED INTERSECTIONS IN THE CITY OF NORFOLK, VA

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ABSTRACT

This paper is an extension of the previously completed study of accident-patterns in the City of Norfolk (Maheshwari & D'Souza, 2006). The multiple-regression model developed in the previous study was based on variables related to intersection geometry. In this study, additional intersection factors are accounted for, which include speed limit, road signage, vegetation and traffic light data. Despite the expanded data set, many other factors like signal type, signal policies, road closures, road conditions, and condition of road signs which could possibly impact the traffic accidents, were not available at the time of the study. The motivation behind this research is based on the literature that indicates that the intersection topography/design factors and traffic management rules might contribute to the traffic accidents.

The objectives of this research were to develop comprehensive statistical exploratory and predictive models for intersections accidents in the City of Norfolk, VA. The research analysis was conducted in three phases. First, a linear regression model was developed using the same techniques applied in the previous study. This was done to establish a baseline model for a comparison of results. At the second stage, an exploratory data analysis technique (two-step cluster method) was used in which the study sample of 58 intersections was divided into two separate groups of clusters according to the type of roads meeting at the intersection arterial, collector and/or local roads. The first cluster consisted of the intersections between a major arterial road and a collector or local road, whereas the second cluster was made up of intersections of a major arterial road with another arterial or a large collector road. Two separate linear regression models were developed for each cluster.

An independent sample of 15 intersections was used for validation of these regression models. All three models, showed about 15% to 21% variation between actual and predicted accident rate values. In each case, however, the deviation between actual and predicted accident values was statistically insignificant. The second cluster deviation was the least, suggesting that the regression model for the intersections between major arterial roads or large collector roads had a somewhat better predictive power than the model for intersections between major arterial roads and collector or local roads.

INTRODUCTION

The main objective of this research was to study the signalized intersections in the City of Norfolk to delineate intersection geometry, road signage and other design factors which may be contributing significantly to traffic accidents. This research project is an extension of the previously completed study on the accident-patterns in the same city in which a multiple-regression model was developed on a selected set of intersections for the City. The City of Norfolk is one of the largest and oldest cities in the Hampton Roads region; and is home to roughly quarter million people. It is one of the most congested cities in the region by the population density. Furthermore, in 2006 the Hampton Roads had the highest crash incidents in the state compared to other regions on the basis of millions of VMT (vehicle mile traveled) (Nichols, 2007). The City of Norfolk contributed roughly 17% of those crashes in the region with annual traffic accident count of approximately 5,400. These data suggest that the traffic safety study could be useful to the City and to the Hampton Roads region.

There is evidence in the literature suggesting that road design factors could impact the traffic safety. Several highway engineering factors like lane widths, shoulder widths, horizontal curvature, vertical curvature, super-elevation rate, median and auxiliary lane were estimated and designed based on some traffic safety considerations. Additional factors like road signage, vegetation, line of sight of a traffic signal, horizontal and vertical curvature, and number of driveways close to an intersection have also been reported to have an impact on traffic safety. To study the impact of these factors along with traffic control rules, researchers have utilized a variety of statistical models (Maheshwari & D'Souza, 2010; 2006). The most popular model is the multivariate regression model where the dependent variable is generally based on traffic accidents and a set of independent variables include roadway design, traffic control, demographic variables and more. To mitigate the impact of large variability among the accident rates on different intersections, a negative binomial model was employed in the regression analysis. Regardless of statistical techniques used, research results show a relationship between the various roadway design and control factors with traffic accidents. Research also indicates divergence on the importance of individual factor on traffic safety. There is also a reported difference based on the regional demographic factors indicating regional accident rate differences due to interactions between design and control factors and the local driving population. Therefore, this study was designed to investigate the impact of the road design factors on the traffic accident rate in a local area.

The previous multiple regression model established a relationship between road design factors and accident rates but the predicted value from the model showed significant variability from the actual accident rate (Maheshwari & D'Souza, 2010). To improve upon the results from previous study, both, the data set (expanded independent variables) and statistical techniques were modified. Data on speed limit, vegetation and road signage were included in the dataset, along with exploratory statistical method and cluster analysis to enhance the predictive power of the regression model. Road signage data was limited to speed limit, name of the next street, turn lane, next signal, chevrons and other safety related posting. The objectives of this proposal were to:

1. Develop an exploratory statistical model that would provide a valid explanation of traffic accidents. A set of geometric, design, control and road signage factors would be used as independent variables for model development.
2. Validate the statistical model developed at step one.

LITERATURE REVIEW

Automobile accidents contribute to the staggering amount of property damage and the large number of deaths in the United States. According to the Insurance Information Institute, New York (Hot Topic and Issues Update: Auto Crashes, 2006), 42,636 people died in motor vehicle crashes in 2004 alone and an additional 2,788,000 people were injured. There were over 6 million police reported auto accidents in 2004. It is reported that about 50% of crashes occur at the intersections (Hakkert & Mahalel, 1978; National Highway R&T Partnership, 2002). It is obvious from everyday experience and from reports in literature that traffic volume is the major explanatory factor for traffic accidents (Chao, Quddus, & Ison, 2009; Keay & Simmonds, 2005; Mohamed & Radwan, 2000; and Vogt, 1999). However, studies have been carried out showing that design and other related factors contribute towards 2% to 14% of accidents. Ogden, et al., (1994) reported that about 21% of the variation in accidents was explained by variations in traffic flow volume, while the remaining majority of the variation was explained by other related factors. Vogt (1999) provides a good review of the factors, which has been considered in past research studies; these factors include channelization (right and left turn lane), sight distance, intersection angle, median width, surface width, shoulder width, signal characteristics, lighting, roadside condition, truck percentage in the traffic volume, posted speed, weather, etc. Besides these factors, researchers have also considered other details such as ditches, side-slopes, surface bumps, potholes, pavement roughness, pavement edge drop-offs, etc. (Graves, et al., 2005; and Viner, 1995).

The relationship between the accidents and pertinent factors is usually established using multivariate analysis (Corben & Foong, 1990; Hakkert & Mahalel, 1978; Keay & Simmonds, 2005; Ogden, et al., 1994; Ogden and Newstead, 1994; Vogt, 1999). Keay & Simmonds (2005) used hierarchical tree regression to analyze accidents on the rural roads in Greece. They reported that geometric factors like the number of lanes, serviceability index, pavement types, road friction and such are important contributing factors to accidents. They also found difference between tow-lane and multi-lane rural roads. A study by Corben and Foong (1990) led to development of a a seven-variable linear regression model for predicting right-turn crashes at signalized intersections. This model explained 85% of the variance of accident occurrence.

Another regression technique, quantile regression, used factors like median, types of traffic controls, number of lanes and left-turn lane which can be used to identify risk prone intersections (Qin, Ng, & Reyes, 2005).

In a FHWA study by Harwood, et al., (2000), quantitative data on accidents and other factors were combined with the expert's judgment about design factors as well as expected impact of these design factors on the accident rate. Mountain, Fawaz & Jarrett (1996) showed in a British study that the road design features "link length" relates to accident rate, especially in dual carriageway. Retting, et at. (2001) studied the effect of roundabout on the traffic accidents and found that replacing signals or stop signs with roundabouts could reduce traffic accidents. Road design factors like, the curve radii, spiral lengths, lane width, shoulder width, and tangent lengths are shown to relate the collision frequency (Easa and Mehmood,2008). It was exhibited through a comprehensive study of Korean road accident data that three categories of factors influence the accident rate: road geometric condition, driver characteristic and vehicle type (Lee, Chung & Son, 2008). Wang, Quddus and Ison (2009) studied roadways based on congestion and reported that besides traffic volume, segment length, number or lanes, curvature and gradient also influence the accident rates. Malyshkina and Mannering (2010) studied the impact of design exceptions allowed in the highway construction on the traffic accident rate (design exception: safety deviation in roadway design factors). They found that exceptions don't necessarily increase accidents in their dataset. In another analysis of the data of 10 Canadian cities, Andrey (2010) related weather and accident rates and found that accident rates drop in severe weather.

The literature shows that multiple statistical models are used for traffic accident analysis. It is evident that negative binominal or Poisson distribution is often employed in relating the frequency of accidents to design factors (Lord, Guikema, Geedipally, 2008; Malyshkina and Mannering, 2010; Shankar, Manning and Barfield 1995; and Wang and Abdel-Aty, 2008). The technique is largely used to account for the higher variability in the frequency of accidents at different intersections. For example, Shankar, et al., (1995) used negative binomial distribution to show interaction between roadway geometric factors and weather accidents. They showed that certain geometric elements are more critical during the severe weather conditions. Milton, Shankar, & Mannering (2008) used a logit model to include several parameters like weather, type of traffic, and road geometry.

Many researchers have studied various road signs and their relationship to road safety. Carson and Mannering (1999) studied the effect of ice warning signs on ice-accident frequencies and severities in the Washington state. They reported that actual signs may not have significant effects on the accident rates as other road design factors accounted for all the variability in the accident rates. It has also been reported that the common signs like speed signs, for example, are not always used by drivers to adjust speed, however, drivers do pay attention to these signs (Zwahlen, 1987). In a study of signage for severe bend in a road in France, Milleville-Pennel, Jean-Michel, & Eliseother (2007) found that drivers do pay attention to the severity signage but invariably underestimated the severity of the bend in the road. Cruzado and Donnell (2009) reported that drivers reduced vehicle speed based on a variable speed measurement device on the highway, but effect disappeared when the device was removed. Road signage does affect driver behavior; however, its impact on safety is inconclusive.

In recent years, researchers have applied data mining techniques along with statistical modeling to determine the impact of major factors like traffic volume and road design characteristics along with minor factors such as potholes and surface roughness. Graves, et al., (2005) reported about the impact of potholes and surface roughness on accident rates. However, due to the paucity of data, a clear link could not be established between these surface factors (pot holes, roughness, etc.). Washington, et al., (2005) performed an extensive study to validate previously reported accident prediction models and methods by recalculation of original model coefficients using additional years of data from a different state. The study reported that in addition to traffic volume, other factors should be considered on a case-by-case basis for a given site.

Earlier studies show that a variety of factors affect the traffic accidents including road geometry, layout and traffic control factors. However, there is divergence of opinion on which factors have influence safety the most. Also, there are regional differences in the importance of factors which influence safety. Similarly, studies on rural highways are not directly applicable to urban settings as the traffic pattern and other factors differ at rural and city intersections. Furthermore, before and after studies may be less valuable in rural settings as road design changes are not made as often as in a city with growing traffic volume. Moreover, the literature shows that traffic accident analyses are commonly conducted in a larger geographical area (one or more states). This research was built upon past research and evidence from literature to apply a systematic approach of identifying factors in accident-prone intersections in a mid size city, Norfolk, VA and analyzing factors, which could significantly influence the accident rates in that specific area.

RESEARCH PROCEDURE

DATA COLLECTION: Data collation was conducted at 73 intersections in the City which included intersections with high as well as low incidents rates during the study period of 2000 through 2004. This sample set was divided randomly in two samples of 58 and 15. The larger sample was used to develop statistical models for accident rate and the smaller sample was used for validation of the model. At each intersection, data was collected on road geometry, road signage, and other related factors.

ANALYSIS: Development of statistical models used data collected from intersections and accident database. Linear correlation, cluster analysis and regression methods were used to analyze the data. The statistical models were developed to establish relationships between physical factors and accident rates as well as to predict the future accident rate based on those physical factors**.**

VALIDATION OF MODELS: Validated statistical models developed in the previous step to determine the accuracy of models. Despite a large variation between predicted and actual values, differences between predicted and actual values from the models were statistically insignificant.

REVIEW OF RESULTS AND MODELS: A review of results showed that there is a large variability in the difference of the predicted accident rates from the models and actual values of accident rates. These models could possibly be improved if more data, like light control timing, road closures, etc. were available and data was collected during the accident time frame.

METHODOLOGY

This research is a continuation of an earlier study by Maheshwari & D'Souza, (2010) which focused on intersections with high accident rates. In this research, the stratified data sampling technique was used. The set of signalized intersection was divided into two groups of intersections based on the total reported accidents during 2000 to 2004. Our of a total of 73 intersections selected of which 39 were from high accident rates (average accident rate of more than 10 per year) and rest of the intersections was selected from the low accident rate group (average accident rate of less than 10 accidents per year). The sample of 73 intersections was randomly divided into two parts of 58 and 15 intersections. The larger sample was used to develop statistical models and the smaller sample was used for the validation of these models. Also unlike the previous study where several data points were discarded due to lack of traffic volume data--Average Daily Traffic (AADT), in this study the entire dataset was used. As traffic volume data was highly correlated to the geometric design factors such as total number of lanes, turn lanes, etc., its effect on the regression model, therefore, is not significant after the total number of lanes and turn lanes were included in the regression model.

The City of Norfolk has accumulated traffic accident data in an electronic format for the past 11 years from 1994 through 2004. Only accidents related to single vehicles were considered in the study due to technical limitations of importing multi-vehicle information into the available database. The City's accident database was developed from individual police accident reports that currently included the type of accident, road conditions, traffic signs and corresponding signals, drivers' actions, vehicle(s) conditions, demographic data, nature of injuries, and other related information, all of which are subsequently entered in the City's accident database. The traffic accidents without a police report were not included in this database therefore those accidents were excluded from this study.

The traffic volume data, Annual Average Daily Traffic (AADT), was not available for many intersections. Annual Average Week day Traffic (AAWDT) for 2003 and 2004 was available instead. This data was provided by the Hampton Roads Planning District Commission (HRPDC) which is the metropolitan planning organization (MPO) for Hampton Roads, VA. The traffic count data on the several local and feeder roads were also not available.

The accident models were developed using a generalized linear model (GLM). First, a regression model was created using the entire data set. To refine this model, a two-step cluster analysis was performed. This analysis created two clusters of intersections. The membership in these clusters was largely based on the type of intersection. One cluster made up the intersections of two major arterial roads and the other cluster was generally made of a major arterial road and a local road. Two separate regression models were developed for each cluster.

COLLECTED DATA

The data collection was carried out on site between May and September 2010. The variables are defined in the Table 1. Data on a total of 104 different independent variables was collected. Additionally, data on Annual Average Week Day Traffic AAWDT and accident rate (dependent variable) were obtained from related sources.

Table 1: DEFINITION OF THE VARIABLES

No.	Variable Name	Definition	No.	Variable Name	Definition
1	$RTLN_i$	Number of right only turn lanes on i^{th} leg (i=1,2,3,4) of the intersection	15	$SGNS_i$	Sign next street name on i^{th} leg (i=1,2,3,4) of the intersection
2	$LTLN_i$	Number of left only turn lanes on i^{th} leg (i=1,2,3,4) of the intersection	16	$SGOT_i$	Sign others on i^{th} leg (i=1,2,3,4) of the intersection
3	$STLN_i$	Total number of straight only lanes on i^{th} leg (i=1,2,3,4) of the intersection	17	$VEGE_i$	Vegetation on i^{th} leg (i=1,2,3,4) of the intersection
4	$TOLN_i$	Total number of lanes on i^{th} leg (i=1,2,3,4) of the intersection	18	$DRWC_i$	Drive-ways commercial on i^{th} leg (i=1,2,3,4) of the intersection
5	$LNLN_i$	Left turn lane length on i^{th} leg (i=1,2,3,4) of the intersection	19	$DRWR_i$	Drive-ways residential on i^{th} i^{th} leg (i=1,2,3,4) of the intersection
6	$LNRN_i$	Right turn lane length on i^{th} leg (i=1,2,3,4) of the intersection	20	EXTR	Extra safety features on i^{th} leg (i=1,2,3,4) of the intersection
7	$MEDN_i$	Median on i^{th} leg (i=1,2,3,4) of the intersection	21	$PEDX_i$	Ped -Xing (signalized) on i^{th} leg (i=1,2,3,4) of the intersection
8	MEDT	Median type(physical type) on each leg	22	$RAIL_i$	Railway line on i^{th} leg (i=1,2,3,4) of the intersection
9	$PAVE_i$	Shoulder/ pavement on i^{th} leg (i=1,2,3,4) of the intersection	23	$OVUN_i$	Over/under pass on i^{th} leg (i=1,2,3,4) of the intersection
10	PAVT	Pavement type (physical type) on each leg	24	$SIG2_i$	Signal within 200' on i^{th} leg (i=1,2,3,4) of the intersection
11	$SPLT_i$	Speed limit on i^{th} leg (i=1,2,3,4) of the	25	$RTLT_i$	Right lane turn signal on i^{th} leg

Table 1: DEFINITION OF THE VARIABLES					
No.	Variable Name	Definition	No.	Variable Name	Definition
		intersection			(i=1,2,3,4) of the intersection
12	$SGLG_i$	Sign for street light on i^{th} leg (i=1,2,3,4) of the intersection	26	$LTLT_i$	Left lane turn signal on i^{th} leg (i=1,2,3,4) of the intersection
13	$SGTL_i$	Sign for turn lane on i^{th} leg (i=1,2,3,4) of the intersection	27	AAWDT	Average annual weekday traffic
14	$SGCH_i$	Sign chevron on i^{th} leg (i=1,2,3,4) of the intersection	28	ACCT	Total number of intersection accident from 2000-2004

The data on the physical attributes included intersection design, geometry and signage. The design factors included number of lanes, type of lanes, existence of a median and shoulder, and other safety features. Other geometric factors included the presence of vegetation, number of driveways within 250’ of the intersection (both commercial and non-commercial) and more. The control factors included the presence of other traffic signals within 250’, speed limit, restricted left or right signal and more. Signage variables included signs for the next street name, sign for next light, sign for turn lanes, and other safety signs.

For each intersection, 104 different physical attributes data were collected. However, 24 of these variables were rarely present, therefore were ignored from further analysis. The traffic volume for the 49 intersections was computed based on the Annual Average Week Day Traffic (AAWDT) data obtained from Hampton Roads Planning District Commission. The total AAWDT for each intersection was calculated by adding traffic (AAWDT) traffic count on both roads of the intersection. The total AAWDT at an intersection is the sum of the average of AAWDT for the each road as follows:

$$\text{Intersection total AADT} = [(\text{Traffic Volume on the Leg 1 or 2}) + (\text{Traffic Volume on the Leg 3 or 4})]$$

Out of the 73 intersections for which topographical data was collected, AAWDT was available for only 49 intersections for the years 2003 and 2004. AAWDT data on several feeder and local streets could not be obtained from the published sources. The accident data between 2000 through 2004 were collected from the City’s accident database.

RESULTS AND ANALYSIS

Although topographical data for each leg of the intersection was collected, the accident data was not available for each leg due to missing and/or incomplete information on the police reports or the datasets that was provided to the research team. Therefore, composite topographical variables were created for each intersection by adding values of a variable from each leg of the intersection, i.e., instead of the total number of lanes on the each leg of the intersection, a composite variable was created by adding all lanes on each leg of the intersection. The length of left turn lanes (LNLN) and length of right turn lanes (LNRN) were calculated using a scoring system for lane length. The lane length scores (between 0 and 5) were assigned based on the length of the lane at a given leg of an intersection and then the assigned score was multiplied by the number of turn lanes at that leg of the intersection. Certain variables, like shoulder, overpass, underpass, etc., were excluded from the study as very few intersections in the study had those physical attributes. A list of all independent variables used in the analysis is provided below in Table 2. These composite variables were inputted into the regression models as well as in the cluster analysis as the independent variables.

Table 2: Independent Variables Used in the Analysis

No.	Variable Name	Definition
1	RTLN	Total number of right only turn lanes (sum of all restrict right turn lanes on the intersection)
2	LTLN	Total number of left only turn lanes (sum of all restrict left turn lanes on the intersection)
3	TOLN	Total number of lanes on the intersection (sum of all lanes on the intersection)
4	LNLN	Left turn lane length (Total length of left turn lanes)*
5	LNRN	Right turn lane length (Total length of right turn lane)*
6	MEDN	Median (total number of legs with physical medium)
7	SPLM (Max)	Maximum speed limit among all legs of intersection
8	SPLA (Avg)	Average speed limit of all legs of intersection
9	SGLG	Sign for street light (total number of legs with sign for approaching light)
10	SGTL	Sign for turn lane (Total of number of legs with sign for approaching turn)
11	SGNS	Sign next street name (total number of legs with signs for next street)
12	VEGE	Vegetation (total number of legs with vegetation)
13	DRWC	Drive-ways commercial (total number of commercial driveways within 200’ of intersection)
14	DRWR	Drive-ways residential (total number of residential driveways within 200’ of intersection)
15	DRWT	Total Drive-ways (total number of driveways within 200’ of intersection)
16	PEDX	Ped -Xing (total number of legs with signalized pedestrian crossing)
17	SIG2	Signal within 200' (total number of signals within 200’ of the intersection understudy)
18	LTLT	Left lane turn signal (total number of legs with signal for left turn)
19	AAWDT	Average annual weekday traffic

To ascertain the association between dependent and independent variables, Pearson correlation coefficients were calculated. The value correlation coefficients are shown in Table 3.

Table 3: Correlation Coefficient

No.	Variable	Correlation Coefficient	p-value 2-tail test	Significance
1	RTLN	0.509	0	Yes
2	LTLN	0.417	0.001	Yes
3	TOLN	0.569	0	Yes
4	LNLN	0.516	0	Yes
5	LNRN	0.41	0.001	Yes
6	MEDN	0.284	0.031	Yes
7	SPLM	0.586	0	Yes
8	SPLA	0.596	0	Yes
9	SGLG	-0.058	0.666	No
10	SGTL	0.357	0.006	Yes
11	SGNS	0.48	0	Yes
12	VEGE	-0.05	0.711	No
13	DRWC	0.339	0.009	Yes
14	DRWR	-0.106	0.427	No
15	DRWT	0.245	0.064	No
16	PEDX	0.078	0.563	No
17	SIG2	0.006	0.967	No
18	LTLT	0.388	0.003	Yes
19	AAWDT	0.53	0	Yes**

It is evident from the above table that the six variables, namely: sign next light, vegetation, number of residential driveways, total number of driveways, pedestrian crossings, and signals within 250', are not showing any significant associations with accident rates. However, the absence of the linear relationship does not preclude a possibility of a non-linear relationship. To test if any of the variables in Table 3 have a non-linear relationship, logarithmic, inverse and exponential relationships were tested for these variables. Total number of sides with medians showed a significantly better exponential relationship (higher value of R-square.) Thus for the regression model, a transformed median variable (MEDTRAN) was used instead of a total number of median (MEDN). This is an exponential transformation of the variable, i.e, MEDTRAN is eMED. A linear regression model using a forward step-wise method was developed. All significantly correlated variables and transformed variables were used in the analysis. Coefficients of the regression model are presented below in Table 4.

Table 4: Linear Regression Coefficient

Variable	Coefficients
(Constant)	-85.483
TOLN	7.060
SPLM	2.885
LTLN	-7.542
MEDTRAN*	-.382

The linear model analysis showed that regression accounted for 59.2% of the variability in accident rates. The analysis of variance (ANOVA) of the regression model showed that the variability explained by the model was significant with p-value <0.000.

From the Table 4, the regression model (Model 1) can be written as:

$$ACCT = -85.483 + 7.060*TOLN + 2.885*SPLM - 7.542*LTLN - 0.382*eMEDN---(1)$$

This result is significantly different than the previous study (Maheshwari & D'Souza, 2010), even though the R-square value is roughly the same. However, it includes speed limit as a factor, which was not considered in the previous study.

To validate these results, the regression model (Model 1) was used to predict the total number of accidents in a different sample of 15 intersections. It was found that the model was predicting lower than the actual number of accidents. The predicted value of the accident rates was on an average more than 21% lower than the actual recorded value of the accident rates although a t-test conducted to test the significance of the difference between the actual and predicted values was found to be insignificant with p-value of 0.91. Table 5 shows the results.

Simple exploratory data analysis technique (two-step cluster analysis) was used to further analyze the dataset. Clustering was performed to create statistically significant groups of intersections. The categorical variables used for the cluster analysis were the total number of sides with median (MEDN), total number of sign for turn lane (SGTL), total number of signs for the next street (SGNS) and total number of legs with restricted light for left turn (LTLT). Two statistically different clusters were formed. Cluster 1 has 31 intersections and cluster 2 has 27 intersections. A closer look at these clusters shows that cluster 2 was largely made up of the intersections of two major arterial roads, and cluster 1 was made up of intersections between a local/feeder street and an arterial road. Membership of these clusters is presented below in Tables 6 and 7.

Table 5: Difference Between Predicted and Actual Accidents (Model 1)			
Intersection Number	Actual Accident	Predicted Accidents	Diff
1	217	112.9	104.1
5	54	81.9	-27.9
19	36	59.4	-23.4
20	59	70.1	-11.1
25	97	62.3	34.7
30	39	70.6	-31.6
33	61	88.7	-27.7
37	142	105.3	36.7
39	308	125.6	182.4
40	291	118.5	172.5
42	73	124.0	-51.0
50	16	69.1	-53.1
59	66	68.2	-2.2
67	51	42.1	8.9
73	98	69.7	28.3
Average	**107.2**	**84.6**	**22.6**

Table 6: Cluster 1 Member Intersections					
No.	Street 1	Street 2	No.	Street 1	Street 2
3	Hampton Blvd	Baker St	47	Colley Ave	27th St
6	Hampton Blvd	49th St	48	Colonial Ave	27th St
7	Hampton Blvd	38th St	52	Ocean View Ave	1st View St
8	Hampton Blvd	Princess Anne Rd	54	Ocean View Ave	Chesapeake St
9	Hampton Blvd	Beechwood Ave	55	Ocean View Ave	Capeview Ave
11	Little Creek Rd	Diven St	56	Monticello Ave	26th St
12	Little Creek Rd	Ruthaven Rd	57	Tidewater Dr	Widgeon Rd
21	Brambleton Ave	Granby St	58	Tidewater Dr	East Bay Ave
22	Brambleton Ave	Monticello Ave	60	Tidewater Dr	Norview Ave
28	Tidewater Dr	Princess Anne Rd	61	Tidewater Dr	Willow Wood Dr
29	Tidewater Dr	Goff St	62	Tidewater Dr	Cromwell Dr
32	Chesapeake Blvd	Sewells Point Rd	68	Colonial Ave	27th St
34	Military Hwy	Johnstons Rd	69	Monticello Ave	27th St
44	Granby St	Willow Wood Dr	70	Church St	27th St
45	Granby St	21st St	72	Little Creek Rd	Azalea Garden Rd
46	Colley Ave	26th St			

Table 7: Cluster 2 Member Intersections					
No.	Street 1	Street 2	No.	Street 1	Street 2
2	Hampton Blvd	Little Creek Rd	35	Military Hwy	Norview Ave
4	Hampton Blvd	Admiral Taussig Blvd	36	Military Hwy	Azalea Garden Rd
10	Little Creek Rd	Granby St	38	Military Hwy	Princess Anne Rd
13	Little Creek Rd	Old Ocean View Rd	41	Military Hwy	Poplar Hall Dr
14	Little Creek Rd	Tidewater Dr	43	Military Hwy	Corporate Blvd
15	Little Creek Rd	Sewells Point Rd	49	Granby St	Bayview Blvd
16	Little Creek Rd	Military Hwy	51	Ocean View Ave	4th View St
17	Little Creek Rd	Chesapeake Blvd	53	Ocean View Ave	Chesapeake Blvd
18	Brambleton Ave	Colley Ave	63	Tidewater Dr	Lafayette Blvd
23	Brambleton Ave	St Pauls Blvd	64	Newtown Rd	Kempsville Rd
24	Brambleton Ave	Boush St	65	Kempsville Rd	Kempsville Circle
26	Brambleton Ave	Tidewater Dr	66	Newtown Rd	Center Drive
27	Tidewater Dr	Va Beach Blvd	71	Little Creek Rd	Halprin Ln
31	Chesapeake Blvd	Norview Ave			

It is clear with some knowledge of the City of Norfolk road network that two clusters represent two different types of intersections. Cluster 1 is generally made up of the intersection of a local and a major arterial road and cluster 2 is made up of two arterial roads. One predictive model may not work for these two clusters the same way. Therefore, two different regression analyses were performed, one for each cluster.

To perform the regression analysis for each cluster, a similar process was followed as in the previous model. First, Pearson correlation coefficients were calculated to delineate variables significantly associated with the accident rate. Both clusters show a different set of independent variables to be significantly associated with the accident rate. Tables 8 and 9, show the correlation coefficients for each cluster.

Table 8: Correlation Coefficient For Cluster 1			
Variable	Pearson Correlation Coefficient	p-Value	Significance
RTLN	0.286	0.118	
LTLN	0.034	0.857	
TOLN	0.146	0.432	
LNLN	0.048	0.796	
LNRN	0.061	0.742	

Table 8: Correlation Coefficient For Cluster 1			
Variable	Pearson Correlation Coefficient	p-Value	Significance
MEDN	0.157	0.400	
SPLM	.636**	0.000	Sig
SPLA	.498**	0.004	Sig
SGTL	0.024	0.898	
SGNS	0.094	0.614	
DRWC	0.080	0.670	
LTLT	0.189	0.308	
AAWDT	0.187	0.458	

Table 9: Correlation Coefficient For Cluster 2			
Variable	Pearson Correlation Coefficient	p-Value	Significance
RTLN	0.234	0.240	
LTLN	0.293	0.138	
TOLN	0.511	0.006	Sig
LNLN	0.512	0.006	Sig
LNRN	0.156	0.437	
MEDN	-0.272	0.170	
SPLM	0.381	0.050	Sig
SPLA	0.442	0.021	Sig
SGTL	0.260	0.190	
SGNS	0.285	0.150	
DRWC	0.363	0.063	Sig
LTLT	-0.047	0.817	
AAWDT	0.462	0.030	Sig

Table 8 shows that the maximum speed limit is the most important factor for the intersections of a local road and a major arterial road (cluster 1). Whereas Table 9 shows the factors other than speed limit like total number of lanes, length of left turn lanes and the number of commercial driveways are also significantly associated with the accident rates for cluster 2 (intersection of two major arterials roads). Regression models for clusters 1 and 2 are presented in Table 10. Both models are statistically significant with p-values <0.0001 for the ANOVA testing of the models. R-square for cluster 1 is 0.53 and for cluster 2 is 0.52. This R-square is slightly less than the R-square in Model 1 when all intersections are put as one group for regression analysis.

Table 10: Linear Regression Coefficient			
Cluster 1		Cluster 2	
Variable	Coefficients	Variable	Coefficients
(Constant)	-83.19	(Constant)	-35.41
SPLM	3.78	SPLA	3.44
LTLN	-9.5	TOLN	4.05
TOLN	3.3	LNLN	1.34

The regression models for each cluster can be written as:

Regression Model 2 for cluster 1
ACCT = -83.19 + 3.78*SPLM -9.50*LTLN + 3.30*TOLN------------------(2)

Regression Model 3 for cluster 2
ACCT = -35.41 + 3.44*SPLA + 4.05*TOLN + 1.34*LNLN----------------(3)

Validation of regression Models 2 and 3, resulted in a statistically insignificant difference (p-value approximately 0.57) between the predicted and actual value of the total number of accidents. However, cluster 1 model (Model 2) was under-predicting the total number of accidents by 15% and cluster 2 (Model 3) was over-predicting the same variable by 17%. Results are presented in the Tables 11 and 12.

Table 12: Validation of Model 2 For Cluster 1			
No.	Actual ACCT	Predicted ACCT	Diff (Actual-Predicted)
1	217	145.7	71.3
20	59	91.9	-32.9
25	97	130.6	-33.6
33	61	124.1	-63.1
39	308	148.3	159.7
40	291	161.6	129.4
59	66	95.7	-29.7
73	98	123.2	-25.2
Average	149.6	127.7	22.0

Table 13: Validation of Model 2 for Cluster 2			
No.	Actual ACCT	Predicted ACCT	Diff (Actual-Predicted)
5	54	81.9	-27.9
19	36	28.9	7.1
30	39	63.1	-24.1
37	142	95.1	46.9
42	73	89.4	-16.4
50	16	75.5	-59.5
67	51	47.4	3.6
Average	**58.7**	**68.8**	**-10.1**

DISCUSSION

This study attempted to expand the earlier study conducted to relate traffic accidents and physical attributes of signalized intersections in the City of Norfolk. The previous study was based on a smaller biased sample that included the high accident rate intersections, and had excluded some important intersection design and control factors. In this study, a larger sample of 73 random intersections was selected. Furthermore, the previous study did not include speed limits, vegetation, and road signage data in the model. The analysis, conducted in the previous section, shows that speed limit was a significant variable in regression models where as vegetation and road signage did not play any role in the regression models. The R-square of the overall model (Model 1) remained at around 60% as in the previous study, but validation results improved significantly. There was no statistical difference between the model's predicted value and the actual value of the accident rates whereas the model in the previous study failed to validate the results.

The analysis techniques used in this study included the additional an exploratory technique: of cluster analysis of the sample. The two-step clustering showed two distinct groups of the intersections in the analysis. Both clusters had different regression models as different variables showed an association with accident rates in the different clusters. The clusters were largely based on the type of intersections. Accident rates showed a large dependence of the maximum speed limit when a major arterial intersects a local road, whereas other variables such as length of left turn lanes and total number of lanes play a significant part when two major arterial roads intersect. Two separate regression models for two different clusters were developed (Model 2 and Model 3). Differences in the predicted and actual value of the accident rates were statistically insignificant for the regression models for both clusters.

A stepwise regression technique was used for all three regression models to eliminate the affect of multicollinearity. The models resulting from the forward stepwise regression were modified by changing the "entering" variable criteria. However, the "entering" variable criteria were not changed to simply include all variables. All the regression models resulted in a lower than expected value of R-square (less than 60%).

The low values of R-square (57% to 59%) in all three models indicate that there is significant room to improve statistical models. This improvement can be achieved either by more causal variables which were not considered or were not available at the time of study, or by using different statistical techniques. As stated in the literature review, engineering variables like horizontal and vertical radii, grade of the road, etc. along with the traffic control rules could be affecting the accident rates, yet this data could not be collected. Furthermore, weather, road closures and other variables could be included to improve explanation of the accident rate variability, but such data was not available. Similarly, a larger sample will allow better factor analysis or other pattern recognition techniques to be applied that could improve predictability of the models. Despite these shortcomings, this research has a practical application, especially in predicting accident rates in cluster 2. Cluster 2 shows several significant variables in the model (Model 3) as well as the regression model of this cluster show strong prediction capability as the average difference between predicted and actual values was statistically insignificant. This model (Model 3) can provide some insight in designing intersections.

CONCLUSIONS AND RECOMMENDATIONS

This study of accident rate analysis of the signalized intersections at the City of Norfolk is based on a stratified sample of 73 intersections. The intersection data set was divided into two groups, namely, high and low accident rate intersections before sampling intersections for this study. The first regression model was developed based on the entire sample and it accounted for approximately 60% of variability in the accident rate. To enhance the results, the sample was separated in two different groups using the two-step cluster analysis. The resultant groups from the cluster analysis were largely divided based on the type intersection (i.e. intersection of two major arterial roads and intersection of a major arterial road and a local road). Even though the cluster based regression models could not reduce the amount of variation explained (R-square of less 60%), it was clear that the factors which affect different group of intersections, are not the same. Intersections of two major arterials require a different set of variables to explain the accident rate variability compared to the set of variables needed to explain accident variability of the intersections between a local road and a major arterial road. Some of the major findings are listed below:

1. The maximum speed limit on any leg of an intersection between local road and arterial road is the most significant factor. Other topographical factors contributed explain little variability of the accident rate and therefore contribute little to the regression model.

2. When designing an intersection between a major arterial and local road, maximum speed limit of all legs approaching the intersection should be kept as low as possible to reduce accident rates.
3. Total number of lanes, length of left turn lanes and average speed of all legs of an intersection are significant factors when two major arterial roads intersect each other.
4. When designing an intersection between two major arterial roads, the following road design factors should be considered to reduce accident rate:
    a. Reduce speed limit on each leg of the intersection,
    b. Increase total number of lanes, and
    c. Increase the length of left turn lanes, wherever possible.
5. A simple regression model can predict accident rate variability within tolerable limits, i.e., the difference between predicted and actual accident rates is statistically insignificant.

Despite some significant results, this study had many clear limitations:

1. Accident data is 6 years old compared to the recent data collection on the roadways.
2. All three regression models were unable to account for more than 40% of accident variations.
3. Predictive capabilities of the models were statistically significant, but it has a limitation. The statistical significance was influenced due to high variability in the predicted and actual accident rate, i.e., standard deviation of the difference of predicted and actual accident rate was very high.
4. Impact of the controllable factors could be better studied if data was collected over time to capture the effects of the changes made at the intersections.
5. Many design factors and other data were not available. These factors could have an impact on the accident rates (e.g., signal policy, road closure, etc.)
6. Sample size was still very limited: 58 intersections for modeling and 15 intersections for validation.

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CROSS-SALE IN DUAL-CHANNEL DECENTRALIZED DISTRIBUTION SYSTEM

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ABSTRACT

Consider multi-channel distribution system for two substitutable products. The products reach the end consumers through a two-echelon supply chain involving two manufacturers and two retailers. Each manufacturer sells the product through its own retail channel and may also use each other's retail channel at its choice. Distribution channels are also substitutable. Using price competition and game theoretic approach, we find the same products can be sold at a higher price in the cross-sale channel than in its own retail channel; the first movers in doing cross sale enjoy advantages in terms of higher profits; Although manufacturers charge lower wholesale prices and retailers charge lower retail prices, complete cross-sale system is still the best configuration in terms of the highest profits for all manufacturers and retailers; and most importantly, cross-sale does improve the system profit dramatically for both partial cross-sale and complete cross-sale distribution systems.

Key Words: Cross-Sale, Product Substitutability, Channel Substitutability, Supply Chain

INTRODUCTION

Manufacturers may sell their products exclusively through a single retailer and certainly may also "cross-sell" their products via other retail channels. Businesses define cross-sale in many different ways. In supply chain system, cross-sale is usually defined as selling products through different distribution channels and is commonly observed in practice.

In this article, we study two manufacturers, each producing a single substituting product, sell the products through their own retailers and may also use each other's retail channel at their choice. Distribution channels are also substitutable. Depending upon the manufacturers' decisions, three different channel structures may rise: exclusive system (where both manufacturers sell their products exclusively through their own retailers), partially cross-sale system (where one manufacturer sells through both retailers and the other sells only through its own retailer), and complete cross-sale system (where both manufacturers sell products in both retail channels). We use price competition and game theoretic approach to model above framework. This paper is intended to answer the following questions: Is it always beneficial to have cross-sale in terms of charging higher prices and obtaining more profit? How do product substitutability and channel substitutability affect cross-sale decision?

The remaining of the paper is organized as following: Section 2 reviews related literature. Section 3 describes the game theoretic model. Section 4 summarizes the results and analyses. Conclusion and future work are presented in Section 5.

LITERATURE REVIEW

One stream of literature is about supply chain system (in)efficiency, channel conflict, and mechanism to achieve coordination. A comprehensive review of this stream is provided by Cachon (2003). This stream typically considers a single manufacturer selling identical products through different channels, for example, exclusive retailer, internet, or a hybrid channel. Ahn et al. (2002) study the competition between decentralized retailers and manufacturer's centralized distribution channel under price competition. Chiang (2003) finds that a single manufacturer may sell the product through direct channel to alleviate the double marginalization observed in the decentralized retail channel. Tsay and Agarwal (2004) review the modeling of channel conflict and coordination. We focus on cross-sale between channels and consider two manufacturers which sell substitutable products through decentralized distribution channels.

The two-manufacturer-two-distribution channel system has been studied by marketing and operations literature from different perspectives. Two distribution channels can be either centralized (owned by the manufacturers) or decentralized (owned by independent retailers). McGuire and Staelin (1983) study the impact of product substitutability on Nash equilibrium channel configurations and they further extend their research by incorporating quantity discount and various cost structures into their model (1986). Cachon et al. (2008) and Chiou (2009) address the effect of large product variety on consumers and retailer. Also many researchers are interested in how vertical competition strategies affect channel performance under various pricing strategies in a decentralized supply chain system, like Moorthy (1987, 1988), Gupta and Loulou (1998), and Lee and Staelin (1997). Cross-sale does not occur in any of these papers.

Within the framework of exogenous channel configurations and multiple retailers, Choi (1996) studies price competition under product and retailer differentiations for different decentralized channel configurations. Moner-Colonques el al. (2004) find retailer differentiation drives cross-sale under price competition in a decentralized channel system. But there will be no cross-sale if retail store differentiation is not observed in the above two articles. Our work studies whether cross-sale is a beneficial strategy for decentralized manufacturers and retailers.

MODEL

Consider multi-channel distribution system for two substitutable products, denoted by 1 and 2, produced by two manufacturers. The products reach the end consumers through a two-echelon supply chain involving manufacturer(s) and retailer(s). Multi-channel systems studies in this paper involve two manufacturers and two retailers. The manufacturers, denoted by M_1 and

M_2, each have their own decentralized retail channels, the two retailers are denoted by R_1 and R_2 respectively. Product i, produced by M_i, is certainly sold through R_i and may also be sold through R_j, where $i = 1,2$ and $i \neq j$. The two channels are also substitutable. Product substitutability and channel substitutability create different horizontal competitions. One dimension of competition is introduced by considering cross-sale decision of the same product between different channels; while the other dimension of competition is introduced by substitutable products. Several multi-channel distribution systems are considered as below.

Figure 1: Cross-Sale Distribution System Configurations

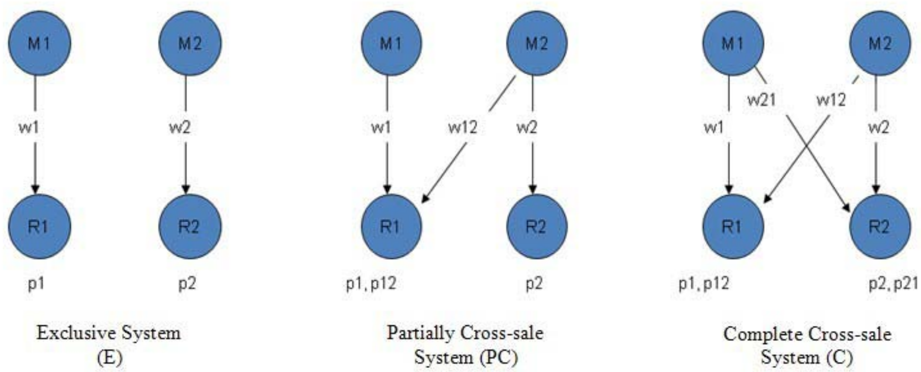


Figure 1 schematically describes these configurations. The *exclusive system* (denoted by E) is a fully exclusive system where each manufacturer produces its own product and sells it through its own retail channel. It serves as a benchmark for the cross-sale systems. In this system, each manufacturer, M_i, decides the wholesale price, w_i, and retailer R_i, decides the corresponding retail price, p_i, where $i = 1, 2.$ The *partial cross-sale system* (denoted by PC) involves one manufacturer produces and sells its product, product 1, through its own retail channel exclusively; while the second manufacturer produces and sells its product, product 2, through both retailers. For product 1, M_1 decides its wholesale price, w_1, charged to R_1 and retailer R_1, decides its retail price, p_1. For product 2, M_2 decides its wholesale price, w_2, charged to R_2 as well as its wholesale price, w_{12}, charged to R_1 and then retailers R_2 and R_1, decide the corresponding retail prices, p_2 and p_{12}. So w_2 and w_{12} are wholesale prices and p_2 and p_{12} are retail prices of product 2 sold in different channels (for a double subscript, the first subscript refers to retail channel and the second one refers to product). Certainly in this configuration, the positions of manufacturers are interchangeable. The *complete cross-sale system* (denoted by C) involves both manufacturers sell their products through both retailers. For product 1, M_1 decides the wholesale price, p_1, charged to retailer R_1 and also the wholesale price, p_{21}, charged to retailer R_2. For product 2, M_2 decides the wholesale price, p_2, charged to retailer R_2 and also the wholesale price, p_{12}, charged to retailer R_1. So w_1 and w_{21} are wholesale prices and p_1 and p_{21} are retail prices of product 1 sold in different channels. Symmetrically, w_2 and w_{12} are wholesale prices and p_2 and p_{12} are retail prices of product 2 sold in different channels. The decisions of the three systems are shown in figure 1and also summarized in the following table:

Table 1: Distribution System Decisions

		Manufacturer M_1	Retailer R_1	Manufacturer M_2	Retailer R_2
Decision(s)	E	w_1	p_1	w_2	p_2
	PC	w_1	p_1, p_{12}	w_2, w_{12}	p_2
	C	w_1, w_{21}	p_1, p_{12}	w_2, w_{12}	p_2, p_{21}

Without loss of generality, we assume the common marginal production cost for each product is 0. No fixed cost of production is considered and that the production and delivery are assumed to be instantaneous.

The competition is modeled by the following demand functions for exclusive system (E).

$$q_i = 1 - p_i + (\alpha + \beta)(p_j - p_i), i, j = 1, 2, i \neq j, \quad (1)$$

where $q_i, i = 1, 2$, is the demand for product i. α denotes channel substitution, β denotes product substitution and $\alpha, \beta \in (0,1)$. In particular, the products are perfectly differentiated when $\alpha = \beta = 0$. This type of demand function is standard in economics and marketing literature modeling substitutability (Gal-Or, 1991; Raju et al., 1995). Moreover, Lee and Staelin (2000) show that a linear demand function involving substitutable products is indeed consistent with reasonable buyer behavior and market characteristics.

$\Pi_{M_i}^j$ is used to denote the profit of manufacturer M_i for a specific configuration j, where $i = 1, 2$ and j = E, PC, C. The total supply chain profit (the sum of the profits of manufacturers and retailers) under configuration j will be denoted by Π^j (no subscripts).

The exclusive system serves as a benchmark for the cross-sale systems. The profit maximization problems of M_i and R_i are

$$max\, \Pi_{M_i}^E = w_i\,[1 - p_i + (\alpha + \beta)(p_j - p_i)],$$
$$max\, \Pi_{R_i}^E\, (p_i - w_i)(1 - p_i + (\alpha + \beta)(p_j - p_i)), \text{ where } i, j = 1, 2, i \neq j.$$

The solution of the above optimization problem yields the following results:

$$w_1^* = w_2^* = \frac{2 + 3(\alpha + \beta)}{(\alpha + \beta)^2 + 7(\alpha + \beta) + 4},$$
$$p_1^* = p_2^* = \frac{2[2(\alpha + \beta)^2 + 6(\alpha + \beta) + 3]}{(\alpha + \beta + 2)[(\alpha + \beta)^2 + 7(\alpha + \beta) + 4]},$$
$$q_1^* = q_2^* = \frac{(\alpha + \beta)^3 + 5(\alpha + \beta)^2 + 6(\alpha + \beta) + 2}{(\alpha + \beta + 2)[(\alpha + \beta)^2 + 7(\alpha + \beta) + 4]},$$

$$\Pi_{M_1}^{E*} = \Pi_{M_2}^{E*} = \frac{28(\alpha+\beta)^2 + 17(\alpha+\beta)^3 + 3(\alpha+\beta)^4 + 18(\alpha+\beta) + 4}{(\alpha+\beta+2)[(\alpha+\beta)^2 + 7(\alpha+\beta) + 4]^2} \ ,$$
$$\Pi_{R_1}^{E*} = \Pi_{R_2}^{E*} = \frac{[(\alpha+\beta)^3 + 5(\alpha+\beta)^2 + 6(\alpha+\beta) + 2][(\alpha+\beta)^2 + 4(\alpha+\beta) + 2]}{(\alpha+\beta+2)^2[(\alpha+\beta)^2 + 7(\alpha+\beta) + 4]^2} \ .$$

For the reason of brevity, between partial cross-sale system (PC) and complete cross-sale system (C), only C is described here. PC will have similar formulations.

Under a cross-sale system, both manufacturers sell their products through both retailers. Following the decision notations summarized in table 1, the demand function (1) is extended to

$$q_1 = 1 - p_1 + (\alpha+\beta)(p_2 - p_1) + \beta(p_{12} - p_1) + \alpha(p_{21} - p_1),$$
$$q_2 = 1 - p_2 + (\alpha+\beta)(p_1 - p_2) + \alpha(p_{12} - p_2) + \beta(p_{21} - p_2),$$
$$q_{12} = 1 - p_{12} + \beta(p_1 - p_{12}) + \alpha(p_2 - p_{12}) + (\alpha+\beta)(p_{21} - p_{12}),$$
$$\text{and } q_{21} = 1 - p_{21} + \beta(p_2 - p_{21}) + \alpha(p_1 - p_{21}) + (\alpha+\beta)(p_{12} - p_{21}).$$

The profit maximization problems of manufacturer M_i and Retailer R_i are

$$max\ \Pi_{M_i}^{C} = w_i q_i + w_{ji} q_{ji}$$

And

$$max\ \Pi_{R_i}^{C} = (p_i - w_i) q_i + (p_{ij} - w_{ij}) q_{ij}, \text{ where } , i, j = 1, 2, i \neq j.$$

The first order conditions of retailers' profit functions (it is easy to verify that the second order conditions are satisfied) yield:

$$p_i^{C*}(w_1, w_2, w_{12}, w_{21}) = f_i(w_1, w_2, w_{12}, w_{21}, \alpha, \beta), i = 1, 2,$$
$$p_{ij}^{C*}(w_1, w_2, w_{12}, w_{21}) = f_{ij}(w_1, w_2, w_{12}, w_{21}, \alpha, \beta), i, j = 1, 2, i \neq j.$$

and then

$$q_i^{C*}(w_1, w_2 w_{12}, w_{21}) = g_i(w_1, w_2, w_{12}, w_{21}, \alpha, \beta), i = 1, 2$$
$$q_{ij}^{C*}(w_1, w_2 w_{12}, w_{21}) = g_{ij}(w_1, w_2, w_{12}, w_{21}, \alpha, \beta), i, j = 1, 2, i \neq j.$$

The two manufacturers select their wholesale prices by solving the following problems

$$\max_{w_i} \Pi_{M_i}^{C} = Q_i(w_1, w_2, w_{12}, w_{21}, \alpha, \beta), i = 1, 2.$$

The equilibrium wholesale prices w_1^*, w_2^*, w_{12}^* and w_{21}^* can be found by solving the 1st-order conditions. Once w_1^*, w_2^* , w_{21}^*, and w_{12}^* are known, the equilibrium prices, quantities, and profits as well as the total profit can be calculated accordingly. The wholesale prices, retail prices, order quantities, manufacturers' profits, retailers' profits are symmetric with respect to the two products. This is because of the assumption of symmetric cost structure for the two products. This assumption is not critical to our model. Rather, it allows us to compare and contrast different systems elegantly. Similarly, we can solve for the equilibrium prices, quantities, and profits of partial cross-sale system (PC). All these results can be obtained easily through using Maple or Matlab but the structures of the results are lengthy. So for the sake of brevity, we don't list them here.

RESULTS AND ANALYSES

Theorem 1: *At equilibrium, the following relationships hold,*

(a) $p_1^E > p_1^{PC} > p_1^C,\ p_2^E > p_2^{PC} > p_2^C,\ \text{and}\ p_{12}^{PC} > p_{12}^C;$
(b) $w_1^E > w_1^{PC} > w_1^C,\ w_2^{PC} > w_2^C,\ \text{and}\ w_{12}^{PC} > w_{12}^C;$
(c) $p_{12}^{PC} > p_2^{PC}\ \text{but}\ w_{12}^{PC} \lesseqgtr w_2^{PC};$
(d) $p_{12}^C > p_2^C\ \text{and}\ p_{21}^C > p_1^C\ \text{but}\ w_{12}^C \lesseqgtr w_2^C\ \text{and}\ w_{21}^C \lesseqgtr w_1^C.$

Theorem 1 captures both the vertical and horizontal changes in prices due to cross-sale. Part (a) of Theorem 1 states that comparing the retail prices of the same products in the three distribution systems, complete cross-sale system offers the best price to consumers. Part (b) says complete cross-sale system is also beneficial for retailers to get lower wholesale prices.

Both p_{12} and p_2 are the retail prices of product 2. The former is the cross-sale price in R_1 and the latter is the price in its own channel, R_2. p_{21} and p_1 are also the retail prices of the same product, product 1, but in different distribution channels. Parts (c) and (d) of the theorem state within the same cross-sale system, the same product can be sold at a higher price in the cross-sale channel than in its own retail distribution channel. This is counter intuitive because people would think the price would go down in the cross-sale channel due to more direct competition from the rival.

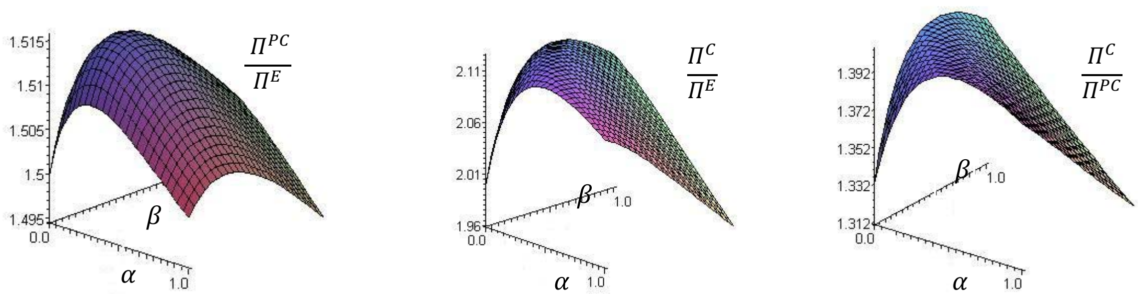
Theorem 2: At equilibrium, the following relationships hold,

(a) $\Pi_{M_1}^{PC} < \Pi_{M_2}^{PC}\ \text{and}\ \Pi_{R_1}^{PC} > \Pi_{R_2}^{PC}$
(b) $\Pi_{M_1}^C > \Pi_{M_1}^E > \Pi_{M_1}^{PC}, \Pi_{M_2}^C > \Pi_{M_2}^{PC} > \Pi_{M_2}^E,\ \Pi_{R_1}^C > \Pi_{R_1}^{PC} > \Pi_{R_1}^E,\ \text{and}\ \Pi_{R_2}^C > \Pi_{R_2}^E > \Pi_{R_2}^{PC};$
(c) $\Pi^C > \Pi^{PC} > \Pi^E.$

Theorem 2 has important implications. Part (a) states that the first movers (M_2 and R_1) in doing cross sale enjoy advantage in terms of higher profit when only partial cross-sale occurs. So both parties have incentive to move first. Parts (b) and (c) say that although the wholesale prices and retail prices of complete cross-sale system (C) are the lowest among the three distribution systems, (C) still generates the most profits for both manufacturers and retailers. So not only consumers but also manufacturers and retailers will all benefit from cross-sale systems.

Theorem 3: $\frac{\Pi^{PC}}{\Pi^{E}}$, $\frac{\Pi^{C}}{\Pi^{E}}$, and $\frac{\Pi^{C}}{\Pi^{PC}}$ achieve their minimums when $\alpha = \beta = 1$. And the minimums are 149.5%, 196.2%, and 131.2% respectively.

Figure 2: Comparison Among Different Systems



Theorem 3 quantifies the benefits of cross-sale systems. Partial cross-sale can improve the system profit by at least 49.5% and complete cross-sale can improve the system profit by at least 96.2% compared to no cross-sale at all, which is almost doubled profit. Even from partial cross-sale system to complete cross-sale system, the total system profit can be further improved by at least 31.2%. So cross-sale does improve the system profit dramatically. This explains why it is rare to see exclusive retail system in business world.

SUMMARY AND CONCLUSIONS

Cross-sale in supply chain distribution system is often observed in practice. In this paper, we use price competition and game theoretic approach to model decentralized duopolistic distribution system where two manufacturers, each producing a single substituting product, sell the products through their own retail distribution channels and may also use each other's retail channel at their choice.

We found that the same product can be sold at a higher price in the cross-sale channel than in its own retail channel; the first movers in doing cross sale enjoy advantages in terms of higher profits; Although manufacturers charge lower wholesale prices and retailers charge lower retail prices, complete cross-sale system is still the best configuration in terms of the highest profits for all manufacturers and retailers; and most importantly, cross-sale does improve the system profit dramatically for both partial cross-sale and complete cross-sale distribution systems.

Like all other models in marketing or operations literature, our model is not free from assumptions. We assume a zero production cost demand. This allows us to get analytically tractable results and derive interesting insights. Similar assumption has often been made in lots of literature. Our assumption about the structure of the demand function is also standard in economics, operations, and marketing literature. One possible direction of future research is to introduce demand uncertainty into our model. Our model assumes complete information and is symmetric. Relaxing these assumptions can also be potentially interesting extensions.

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MANUFACTURING COMPLEXITY: THE EFFECTS OF COMMON ATTRIBUTES OF MANUFACTURING SYSTEM DESIGN ON PERFORMANCE

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ABSTRACT

Manufacturing operations are complex. In part, this complexity arises from decisions regarding the design of the system, e.g. number of products, breadth of product structure, and number of operations in the routing. Because of the differences in complexity from one operation to another, it is difficult to make comparisons or account for the relative complexity among manufacturers in research. In this article, a large scale simulation of a generic batch-type manufacturing system was conducted to study the impact of eight system design attributes that are common among most manufacturing systems. The results of the study identify the effects of these attributes. Lastly, this article discusses how these effects should be given consideration as managers make decisions about changing a system's design.

INTRODUCTION

If you were to talk to managers of manufacturing plants, you would often hear them something similar to "Our operation is so complex it makes it difficult to manage." Complexity in operations is now being studied more frequently in the literature on management (e.g. Jacobs, 2007; Wu et al., 2002). But what exactly is complexity and what makes systems complex?

It is important to study manufacturing complexity. For the practicing manager, understanding the impact of changes in the manufacturing system design can help them improve operation performance. For researchers, being able to account for differences in manufacturing complexity will help to study the impacts of other issues related to business performance.

I n this article eight elements of complexity in manufacturing systems attributed to the system's design are studied. In the first part of this article, the literature is explored for a definition for a complex system and we identify several measurable elements of manufacturing complexity resulting from the design of the production system. In the next section, the research design is presented including a description of the large scale simulation of a batch manufacturing system used for this study. Lastly, the results are reported with practical conclusions and suggestions for future research.

LITERATURE REVIEW

The Oxford Dictionary defines the term complex as “consisting of many different and connected parts” and “not easy to analyze or understand” (“complex”, Oxford Dictionary). In a review of the literature in the areas of physics, general systems theory, philosophy and medicine, there is no single generally accepted definition of complexity (Flood, 1987; Klir, 1985; Lofgren, 1977; Ashby, 1973; Simon, 1962; Stein, 1989). Casti (1979) proposed a good definition stating that a complex system as one that has a counterintuitive, unpredictable or complicated structure and behavior.

But, how can the things that make systems counterintuitive and unpredictable, i.e., the complexity, be measured? One approach is to measuring the length of the shortest description of a system (Klir, 1985; Lofgren, 1977; Ashby, 1973; Simon, 1962). The longer the description needed to portray a system, the more complex the system is. However, determining what is the shortest complete description of a system is extremely subjective, thus impracticable.

The second approach is to consider the number of elements in the system and the number and type of relationships between these elements (Flood, 1987; Klir, 1985; Lofgren, 1977). This notion can be linked to Simon (1962) who says that a complex system has a large number of parts, whose relationships are not “simple”. By considering this approach, the “things” that make a system’s description longer are taken into account, thus fulfilling the intention found in the first approach.

We recognize that manufacturing systems are complex, because they are unpredictable and often have complicated structures. They are composed of many subsystems and elements, e.g. work centers, machines, components and products. The elements of a manufacturing system have relationships. These relationships are evidenced in documents like a product structure, a labor routing, or a shop layout drawing.

According to Frizelle and Woodcock (1995) and Deshmukh, Talavage, and Barash (1998), manufacturing complexity can be separated into two constituents – static and dynamic complexity. Static complexity is the complexity resulting from the design of the manufacturing system. Dynamic complexity is the result due to the uncertainty that stems from the dynamic nature of system resources as it passes through time (Deshmukh et al., 1998).

Additionally, Gabriel (2008) recognized that there are internal and external causes of manufacturing system complexity. Internal causes are due to things over which management has direct control, e.g. shop layout and amount of equipment. Causes outside of management control are considered external causes of manufacturing complexity, for example, product demand or order cancellations. This study investigates static complexity due to the decisions made internally as one of the initial steps to finding a method to measure manufacturing complexity.

Gabriel (2008) identified constituents of manufacturing complexity in a review of the literature in operations management. Table 1 contains of list of the eleven elements that were identified as being part internal static manufacturing complexity.

Table 1: Internal Static Manufacturing Complexity Elements from Gabriel (2008)
Complexity Element
Product Mix
Product Mix Ratio
Number of components
Product complexity
Process complexity
Integration between processes
Number of machines/resources
Routings
Processing times
Layout
Lot sizes

Product mix refers to the number of end-products offered by a business. Having a greater product mix has been shown to negatively affect manufacturing performance (Foster and Gupta, 1990; Ittner and MacDuffie, 1995; Bozarth and Edwards, 1997). As the number of products offered increased Foster and Gupta (1990) found that manufacturing overhead also increases. The additional overhead was construed to represent the additional effort necessary to control the effects of complexity. They also concluded that the number of components and the bill of materials depth had significant correlations with manufacturing overhead. Kekre and Srinivasan (1990) showed that having a broader product line had a small, but significant negative effect on ROI.

Product complexity refers to the complexity introduced by the things necessary to make the end-products offered by a business. In past research, product structure complexity had a significant effect on performance (Veral and LaForge, 1985; Benton and Srivastava, 1985; 1993; Sum et al., 1993). Product complexity has been measured using the depth and breadth of the product structures and the total number of parts. Component commonality, i.e. the sharing of components among subassemblies and end-products, is an element of product complexity. Collier (1981) and Guerreo (1985) conclude from their results that higher commonality leads to reduced total system costs (primarily measuring the inventory carrying cost), but with a greater amount of workload variability at work centers. So, component commonality may reduce the total number of parts used in a system, but may have deleterious effect on overall manufacturing performance.

Routing complexity can be reflected in the number of routing steps and, similar to the number of components, the commonality among the routings in a manufacturing system. Monahan and Smunt (1999) found that systems with high levels of routing commonality outperformed systems with random routings. From research on scheduling, computational complexity is reached in short order when there are more than four or five work centers in systems where there are multiple operations and where product routings differ. If the scheduling of small systems is complex, then simply having more work centers in a system may add complexity.

RESEARCH DESIGN

The Measureable Elements of Internal Static Manufacturing Complexity

Eight elements of static manufacturing complexity were identified related to the past literature that met the accepted operational definition of complexity – numerosity and describing relationships between system elements. These eight are listed in Table 2.

The concept of product mix was extended to include a measurement of comparable volumes of each end-product produced by a system. The effect of the other elements could likely be different if they were not "weighted" by the relative volumes of the end-products. For example, if there was a highly dominant end-product in terms of volume produced, then the size of its product structure, routing, etc. will likely have a greater effect than those elements associated with an end-product produced in very low volumes. The product mix ratio was included to capture this.

Table 2: Measureable Elements of Internal Static Manufacturing Complexity

Static Complexity Elements	Definition
Product Mix	The number of end-products produced in a manufacturing system.
Product Mix Ratio	The proportion of production volume attributed to the largest volume end-product.
Product Structure Depth	The number of levels in a product structure for an end-product.
Product Structure Breadth	The maximum number of manufactured items at a single level in an end-product's product structure.
Component Commonality	A measure of the shared used of components.
Number of Routing Steps	Number of distinct manufacturing operations that items require based upon their manufacturing routing.
Number of Work Centers	The number of work centers in a manufacturing system.
Routing Commonality	A measure of the degree of similarity of routing sequences among manufactured items in a system.

Measures of Manufacturing Performance

The purpose of this research is to determine if and how these eight elements of internal, static, manufacturing complexity affect the performance of manufacturing systems. Three typical performance measures are mean flow time, mean lateness and mean tardiness of orders. These capture the speed of delivery (mean flow time), the company's duel concerns about completing orders too early or late (mean lateness), and the customer's concern for orders arriving late (mean tardiness). Because it is obvious that systems with more complexity would have longer flow times, mean flow time was not included as one of the performance measures used in this study.

Since, as stated by Casti (1979), the behavior of a complex system is difficult to predict, the variation in flow time, lateness, and tardiness are needed in order to evaluate the unpredictability of system outcomes when complexity changes. Therefore it is important to include performance measures that capture the level of unpredictability in a system, which may be done by evaluating the variance of system measures. Also, practicing managers are interested in having stable mean flow times so that they may have a better estimate of their manufacturing lead time. As the variation of mean flow time increases, more "slack" must be built into the manufacturing lead time to ensure on-time delivery to the customer. At the same time it is desirable that the variance in lateness be small so that the system doesn't have orders that ship very late or are completed early and must be held in inventory for a long time. Likewise, it is important to monitor the variability of tardiness, so that the degree of unpredictability of systems, as it appears to customers, can be evaluated. Therefore the standard deviations of flow time, lateness and tardiness were included as performance measure in this study.

Hypothesized Performance

Systems having more end-products will likely have more components. Therefore they will also have a greater variety of items to be manufactured. The increase in end-products and manufactured components, together, likely leads to a greater number of routings that are diverse. Hence, there will be greater opportunity for shop congestion, thereby increasing flow time variability for orders. Systems with greater variability in flow time will have greater variability in order lateness and tardiness. So, it is hypothesized that systems with more end-products will perform worse than systems with fewer end-products.

> *H1: Systems with a larger product mix will have higher mean order lateness and mean order tardiness, and higher standard deviations in order flow times, lateness and tardiness.*

As the product mix ratio moves from having a dominant end product to being more evenly spread among all products, there is likely to be increased interaction among the product and component flows. The queuing at each work center will become unpredictable. There will be shifting bottlenecks as shop congestion increases, leading to an increase in flow time variance. As flow time variance increases, the variance of lateness and tardiness also will increase. So, it is hypothesized that systems with a dominant end-product will perform better than systems with a volume spread more evenly across end-products.

H2: Systems with the production volume spread evenly across its end-products will have greater mean order lateness and mean order tardiness, and higher standard deviations in order flow times, lateness and tardiness than systems with an end-product that accounts for a large proportion of production volume.

Lower commonality among manufactured components increases complexity. With less component commonality there will be more manufacturing orders for the different components with diverse routings. This increases shop congestion and contributes to variation in flow times according to Vakharia et al. (1996). As flow time variance increases, the variance of lateness and tardiness also will increase. Therefore, it is believed that systems with low component commonality will perform worse that system with higher component commonality.

H3: Systems with a less component commonality will have higher mean order lateness and mean order tardiness, and higher standard deviations in order flow times, lateness and tardiness than systems with more component commonality.

As product structures become broader and deeper, the timing of the completion of orders for components affects the ability to release the order for the parent parts. The mis-timing of manufacturing order arrivals will likely lead to the delayed completion of components needed for the parent part, thereby increasing the mean lateness and tardiness of an order for an end product (Russell and Taylor, 1985) as well as the variation in order these measures.

H4: Systems with end-products having broader product structures will have higher mean order lateness and mean order tardiness, and higher standard deviations in order flow times, lateness and tardiness than systems end-products that have narrower product structures.

H5: Systems with end-products having deeper product structures will have higher mean order lateness and mean order tardiness, and higher *standard deviations in order flow times, lateness and tardiness than systems end-products that have shallow product structures.*

It is construed that complexity increases when the average number of routing steps in the product structure of end-products increases. More routing steps will lead to more required set-ups and more opportunity to queue at work centers during the flow of a manufacturing order for all manufactured items. Flow times will vary due to the unpredictability of the queuing that occurs, increasing the variance of flow time. As flow time variance increases, the variance of lateness and tardiness will likely also increase. An increase in the variance of tardiness could increase the mean tardiness or orders.

H6: Systems with manufacturing items having longer routings will have higher mean order lateness and mean order tardiness, and higher standard deviations in order flow times, lateness and tardiness than systems with manufacturing items having shorter routing.

When there are more work centers in a manufacturing system manufacturing complexity increases. Assuming the same overall shop utilization, systems having a greater number of work centers will have and increased opportunity for bottleneck shifting. This increases unpredictability of manufacturing order flow times, hence increasing the variation of flow times. As flow time variance increases, the variance of lateness and tardiness also will increase.

H7: Systems having more work centers will have higher mean order lateness and mean order tardiness, and higher standard deviations in order flow times, lateness and tardiness than systems with fewer work centers.

As routing commonality decreases, complexity increases, because there are more diverse routings, which can lead to shifting bottlenecks. Shifting bottlenecks lead to less predictability of flow times, meaning increased variation of flow time Monahan and Smunt (1999). As flow time variance increases, the variance of lateness and variance of tardiness also will increase. An increase in the variance of tardiness will mean there will be an increase in mean tardiness.

H8: Systems with less routing commonality will have higher mean order lateness and mean order tardiness, and higher standard deviations in order flow times, lateness and tardiness than systems with more commonality among routings.

Experimental Design

A simulation was used to gather a large sample of performance data for systems which varied across the eight measureable elements of internal, static, manufacturing complexity. The simulated shop modeled a batch manufacturing system. In a survey by Safizadeh, Ritzman, Sharma, and Wood (1996), the largest portion of their respondents (32%) identified themselves as primarily batch shops. Batch shops would also be more likely to experience a wider range of the eight complexity elements investigated.

Each of the elements of internal, static, manufacturing complexity was set at one of two levels for each simulation. This study was interested in confirming a belief about each element on an exploratory basis. The levels of each of the elements represented an experimental factor. The factor settings are shown in Table 3. It is recognized that the relative "tightness" used to set due dates has an effect on performance when performance is measured by how well those due dates are met. In order to evaluate the possible effect that due date setting may have, due dates were set using TWKCP, total work content for the critical path, which incorporates a due date tightness factor, k.

TWKCP is the sum of all the operation times in the longest chain of the product structure. The TWKCP method (as used in Collier, 1981) was selected for setting due dates because it considers that operations occurring on the other branches of the product structure may occur in parallel to those of the critical path. In this study, the longest chain is the product structure branch with the largest total per unit processing time and included the set up time at each operation.

Table 3: Table of Experimental Factors

	Levels	
Complexity Factor	High Setting	Low Setting
Product Mix – (PM)	5	2
Product Mix Ratio (PMR)	All equal	1 Dominant/Others equal
Product Structure Depth (D)	5	2
Product Structure Breadth (B)	5	2
Component Commonality (CC)	0 %	~30 %
Number of Routing Steps (RS)	10	4
Number of Work Centers (WC)	10	4
Routing Commonality (RC)	0 %	~50 %
Due Date Tightness Factor (k)	30% orders late	10% orders late

In the proposed simulated shop, orders for end-products were randomly created. The end product and quantity attributes were assigned to each order as it is created. The bills of materials and routings were set in advance for each item. The quantity of specific parts and the duration of each routing step was a function of the randomly generated order size. Once the orders were generated, due dates were set using total work content of the critical path (TWKCP) and order release timing was determined working backward from the order due date for the end product.

The Simulation

Five end-products were created for the simulation. In experiment at the low setting for P, there were only two end-products. The same two end-products were used at the high level for factor P with an additional three end-products.

The low setting for Product Mix Ratio (PMR) occurred when there is a dominant end-product, that is, one end-product having a large proportion of unit sales. At both levels of PMR, the percent volume of the dominant end-product was four times greater than the proportion of the other end-product(s). The non-dominant end-products had equal proportions, i.e. the same unit volumes. When the number of end-products (P) factor is at the low setting, end-product 1 had 80% and end-product 2 had 20% of the volume. At the high setting of P, end-product 1 had 50% of the volume and the remaining four end-products each had 12.5% of the total unit volume.

Product structures for each manufactured item at the high level of the product structure depth, the high level of product structure breadth, and at the low level of component commonality were generated first. There were five end-products having two levels of product structure depth, two levels of product structure breadth, and two levels of component commonality (5 x 2 x 2 x 2) resulting in a total of 40 products structures. The product structures for the low level of product structure depth and breadth and the high level of component commonality were created as variants based upon the initial sets of product structures. To the extent possible, the components within the product structures for end-products and the relationships of these components, i.e. their product structures, were maintained across the experiment. The five product structures that were designed to be deep and broad were generated to have "branching" occur at various levels among the product structures in order to obtain diversity in the experiments. These product structures also were designed so that the number of components at the lowest level ranged from two to five to avoid accidentally biasing the experiment. Each of these product structures had nine components (with one exception) to allow enough opportunity for achieving the high setting for component commonality but simplified the process of generating product structures. The product structures created to achieve low product structure breadth and high product structure depth were designed in a similar manner. An attempt was made to keep the total components in each product structure at five. There was one exception to allow the opportunity to achieve the high setting of component commonality.

Component commonality was designed to occur at a variety of levels in the product structures. To the extent possible, the relationships in the product structures of components were kept consistent across experiments in order to model reality. Using the initial "no commonality" product structures, a variety of components were made common among the end-products, but none were common with more than three end-products.

Routings were prepared in advance for each item corresponding to the levels of the three routing factors - the number of routing steps, the number of work centers, and the routing commonality. Routings for each manufactured item for the high level of the number of steps at the low level of routing commonality were generated first. Routings were then varied based upon these initial routings to create the routings for the low level of routing steps and the high level of routing commonality. At the high level of routing commonality, manufactured items were selected so that 50% of the routings had an identical sequence. To the extent possible, the same items were selected among the various sets of product structures for the settings for product structure depth, product structure breadth, and component commonality.

Routings were generated randomly for each manufactured item. Routings for the high level of RS were created first. For each routing step, a work center was randomly assigned, each having an equal likelihood (uniform) of being assigned. The only rule was that consecutive routing steps could not be assigned to the same work center. Run times per unit for each item for each step were generated randomly using a uniform distribution with a mean of 0.1 and a range from 0.05 to 0.15 hours. The mean of 0.1 hours was chosen to make the average ratio of set-up to unit run time equal to 10. This was in line with the setting developed by Krajewski et al. (1987).

For each manufactured item, the routing sequence of work centers visited and processing times were generated for the high setting of RS and WC and the low setting for RC. Routings for the low setting RS are created for each manufactured item by truncating the routing for the high setting of RS. The run time portion of the processing time was adjusted proportionally for each routing step so that the total of the run times was the same for high and low settings for the number of routing steps.

To achieve the high setting for routing commonality (RC), items were selected within the product structures created based upon the four experimental factors for product structure. The items were selected from a variety of end-products and at a variety of levels within the products structure. These items were arbitrarily made to have common routings to 1) attain the high setting of routing commonality and 2) have items with common routings at various product structure levels. The selected items were changed across all product structure settings. The original processing times were maintained in the same sequence as the original routing.

The set-up time is set arbitrarily to 1.0 hour. Set-up time was included in the shop design primarily to measure the effect of component commonality. When manufacturing orders for the same item are processed consecutively they will require a single set-up. To avoid introducing a bias to the experiment, the same set-up time (1 hour) was designated for all items for all operations.

The due date tightness will impact the amount of lateness and tardiness produced by a system. At the high level due dates were "tight", having a lower value for k than when due dates are "loose". The due date tightness factor, k, was established in preliminary runs for the manufacturing system in the experiment that was deemed to be the "simplest". The vale for k was set such that, after the warm-up period, approximately 10% of the orders were tardy. The high setting for k was set, for this "simplest" case, when approximately 30% of the orders were tardy.

The time between order arrivals was a stochastic element of the experiment used to better model the real world conditions faced by manufacturing systems. It was determined by sampling from the exponential distribution with a predetermined mean as done in similar studies (e.g. Barman and LaForge, 1998; Fry et al., 1989; Kanet and Hayya, 1982). To maintain consistent mean shop utilization, the mean order arrival interval was adjusted based on preliminary simulation runs. For this study, the average utilization at the bottleneck work center was set at 85%. This has been a common mid-range setting used in the past (Barman, 1998; Pierreval, H. and N. Mebarki, 1997; Fry et al., 1989).

Orders were generated to include a random order quantity for each end-product in the product mix. The average total order size was approximately 200 units. The average order size for each end-product was based upon the specific product mix ratio for the experimental run. The simulated system encountered variation in order sizes. This was accomplished using a coefficient of variation of 0.30 for the demand for each end-product. The orders sizes were generated using a truncated normal distribution where the minimum order size is zero and the maximum is twice the mean order size.

To make experimental conditions as consistent as possible, each end-product was assigned a specific random number stream to be used in all experimental runs. Therefore, for experiments having the same settings of P and PMR, order sequence and quantity was identical for each end-product.

The release dates for manufacturing orders for components at the end of each product structure branch were calculated using the total work content (TWK) method (Goodwin and Goodwin, 1982) as soon as an order arrives. The order release for the lowest level component on the critical path of a product structure coincided with the order arrival date. By using the same due date tightness factor, k, for manufacturing order releases, orders had the same opportunity to complete as their "sister" items in the product structure.

Parent items in the product structure were released at the time that the manufacturing order for last order for the required children items was completed. This gave the manufacturing orders for parent items an opportunity to be released early or late, thus providing clearer evidence of the impact of system complexity on performance. If the order release for parent items were set using some other release rule, it might have artificially inflated the flow time, lateness and tardiness statistics.

A dispatch rule that is simple to employ in industry, as well as simulation experiments is earliest order due date (EDD) with ties broken using the order of arrival to the work center (FCFS). EDD for orders has been shown to be in the group of best performing dispatch rules under a wide range of product structure complexity in an assembly shop (Fry et al., 1989). By using EDD the primary reason for late order completion would be due to the system design, i.e. the internal, static, manufacturing complexity.

The batch means method was used to make the simulation runs for each experimental combination. Replication of experiments was used to capture the variance of dependent variables. A pilot simulation run was made at each of the 256 experimental combinations to determine the "worst case" time until steady state is achieved. This transient period was used to determine the size and number of replications. Each experimental run contained a "batch" of 15 independent replications in accordance to literature (Schmeiser, 1982; Pritsker, 1986).

The number of orders in a replication for all experiments was the determined by the amount of time needed to clear the transient period for the worst-case multiplied by the average orders per hour. During the steady state period the average orders per hour were determined. Thus, for every replication in every experimental run, the same number of orders was evaluated. The longest transient period observed was 28,500 hours. This yielded an average of 91 orders. To ensure a long enough observation period, the replication size used was 200 orders, more than twice as long as the warm-up period. The statistics were accumulated for 200 consecutive orders to avoid censoring data (Blackstone et al., 1982). For each experiment, data was collected beginning with order 201 and ending with order 400. An interval equal to one replication batch was left between batches where statistics were not collected to maintain independence of batches. This was the same for all experiments.

All units in a manufacturing order remained with the order during processing. No "batch-splitting" occurred. Each manufacturing order had the required components to fulfill a requirement for a parent item which was sized to fulfill the requirement for a specific customer order for an end-product. No inventorying occurred. No loss of product occurred. Every order was completed for its entire order quantity. The transfer time for moving a manufacturing order between work centers was ignored (i.e. transfer time = 0). There was a single server (i.e. machine) at each work center. There was no maximum queue size at any queuing point, e.g. work center.

RESULTS

The simulation was conducted using AweSim simulation modeling software. An initial review of the data revealed that the normality assumption and homoscedasticity requirement of

ANOVA techniques were not met. So each DV was transformed as $Y = Y^{1/2}$ because this reduced both skewness and kurtosis for each DV.

After transforming the DVs, an inspection of the bivariate correlations indicated that all five DVs were highly correlated. Many of the bivariate correlations between DVs exceeded 0.90. Since high amounts of multicollinearity between DVs can confound statistical test results, a factor analysis was used to create a single factor that represents overall manufacturing performance. Principle components analysis using SPSS statistical software extracted a single factor from the transformed DVs explaining 92.4% of the variation in the five DVs. This single factor, MFGPERF, was considered to represent overall manufacturing performance.

Conclusion to Hypotheses

To determine which of the eight static complexity elements were significant, an omnibus ANOVA was completed using the MFGPERF. Table 4 shows the results of the ANOVA. Overall, the model containing the eight elements explained 57% (adjusted R^2) of the variation in MFGPERF. Six of the eight elements were significant using a 1% significance level. Neither component commonality nor the number of operations factors explained variation in the overall manufacturing performance variable.

Table 4: Results from Omnibus ANOVA (MFGPERF)

Source	Type III Sum of Squares	df	Mean Square	F	Significance	η^2
Corrected Model	4377.3	9	486.37	1129.9	.000	
Intercept	.0	1	.00	.0	1.000	
k	149.3	1	149.27	346.8	.000	0.019
P	58.5	1	58.52	135.9	.000	0.008
D	729.4	1	729.40	1694.5	.000	0.095
B	1194.9	1	1194.87	2775.8	.000	0.156
CC	1.5	1	1.50	3.5	.062	0.000
PMR	18.5	1	18.54	43.1	.000	0.002
OPS	.1	1	.13	.3	.583	0.000
WC	2220.8	1	2220.83	5159.1	.000	0.289
RC	4.3	1	4.27	9.9	.002	0.001
Error	3301.7	7670	.43			
Total	7679.0	7680				
Corrected Total	7679.0	7679				
Adjusted R Squared = .570						

Individual ANOVAs were conducted for the five performance measures. Table 5 summarizes the results providing the effect size and the significance for each complexity element. The effects size was measured using eta-squared (η^2), representing the proportion of variance explained by an individual variable.

Table 5: Summarized Results of ANOVAs for the Five Performance Measures

	Performance Measure				
Factor	S_{FT}	L_{MEAN}	S_L	T_{MEAN}	S_T
K	n.s.	0.063	0.006	0.045	0.018
	(0.062)	(0.000)	(0.000)	(0.000)	(0.000)
P	0.024	0.064	n.s.	0.039	0.008
	(0.000)	(0.000)	(0.015)	(0.000)	(0.000)
D	0.251	0.025	0.106	0.044	0.091
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
B	0.120	0.145	0.144	0.154	0.157
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CC	n.s.	n.s.	n.s.	n.s.	n.s.
	(0.860)	(0.118)	(0.023)	(0.009)	(0.013)
PMR	0.010	0.001	0.014	0.011	0.004
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
OPS	n.s.	n.s.	n.s.	n.s.	n.s.
	(0.895)	(0.424)	(0.822)	(0.936)	(0.081)
WC	0.216	0.268	0.282	0.281	0.289
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
RC	0.000	0.000	0.000	0.001	0.001
	(0.006)	(0.004)	(0.005)	(0.001)	(0.001)
Adjusted R^2	0.621	0.566	0.552	0.574	0.567

For all five measures of manufacturing performance, over 50% of the variation in performance was explained by the models containing the eight complexity factors. The adjusted R^2 ranged from 0.552 to 0.621, representing a substantial portion of the variation in each. With two exceptions, all six complexity elements that were significant in the omnibus model were significant for the individual measures of manufacturing performance. One of the two exceptions were that the due date tightness factor did not have an effect on the standard deviation of order flow times. This was expected, since flow time is not affected by due date tightness.

The second exception was that the factor P, the number of end-products, was not significant for the standard deviation of lateness.

Table 6: Marginal Means for the Eight Complexity Elements						
		Performance Measure				
Factor	Setting	S_{FT}	L_{MEAN}	S_L	T_{MEAN}	S_T
K	Lose	n.s.	875	574	381	500
	Tight	n.s.	1125	639	572	611
P	Few	807	875	n.s.	387	516
	Many	680	1125	n.s.	565	593
D	Shallow	551	919	481	383	435
	Deep	962	1076	745	571	688
B	Narrow	607	816	462	312	400
	Broad	891	1194	770	665	733
CC	None	n.s.	n.s.	n.s.	n.s.	n.s.
	Some	n.s.	n.s.	n.s.	n.s.	n.s.
PMR	Dominant Product	783	979	559	426	527
	Equal volumes	702	1013	654	520	582
OPS	Few	n.s.	n.s.	n.s.	n.s.	n.s.
	Many	n.s.	n.s.	n.s.	n.s.	n.s.
WC	Few	946	1270	841	741	803
	Many	563	755	409	263	351
RC	None	734	985	597	460	544
	Some	750	1007	615	484	564

The hypotheses were evaluated using the results of these ANOVAs and an inspection of the marginal means. Table 6 summarizes the marginal means for each complexity factor. Table 7 presents the conclusions for the eight hypotheses. Based upon the results of the omnibus ANOVA, the hypotheses regarding component commonality and the number of manufacturing steps (H3 and H6) were not supported. Additionally, H7 was not supported concerning the effect of the number of work centers. The marginal means for this factor were opposite of what was expected for every measure of performance. There were two other cases were this occurred. The factors P and PMR showed reduced variability in order flow times.

Table 7: Conclusions to Hypotheses		
Hypothesis	Complexity Element	Conclusion
H1	Number of End Products (P)	Supported
H2	Product Mix Ratio (PMR)	Supported
H3	Component Commonality (CC)	Not Supported
H4	Breadth of Product Structures (B)	Supported
H5	Depth of Product Structures (D)	Supported
H6	Number of Routing Steps (OPS)	Not Supported
H7	Number of Work Centers (WC)	Not Supported
H8	Routing Commonality (RC)	Supported

An inspection of the effects for each of the six significant static complexity elements revealed that there were three dominant factors. The depth (D) and breadth (B) of the product structures and the number of work centers in a system (WC) accounted for large portions of the variation in each of the five performance measures. The number of end-products, P, had a moderately effect size, in general. WC consistently accounted for the largest portion of explained variation. This is somewhat troubling, as the factor had the opposite effect on performance that was anticipated.

Post Hoc Analysis

To investigate the unexpected effect of the factor WC, additional analysis was conducted. The design of the simulation was such that the bottleneck work center achieved and average utilization of 85%. However, there was no control for the non-bottleneck work centers. The utilization at these was subject to the stochastic behavior of the system affected by the orders in the systems and the operation times. It was conjectured that there could be several work centers with very low utilizations in the experimental systems having 10 work centers. If this occurs, it might provide a greater opportunity to “catch up” in systems having many work centers, and reduce flow times and, hence, lateness and tardiness. It may even lead to a smoothing of variation in these measures.

The analysis of the protective capacity, the utilization differences, revealed that there was a substantial difference in the amount of protective capacity in systems with four work centers compared to systems with ten work centers. The average protective capacity for systems with four work centers was 15.5%. This is 17.6% lower than the average of systems with ten work centers – 33.1%. This likely contributed to the high effect size for the WC factor. Additionally, it could help, in part, to explain the “reverse prediction” of performance by WC. Because the PC tended to be much larger for experiments with many work centers (ten) than for those with few work centers (four), it is appears possible that performance would improve. The opportunity for a “moving” bottleneck or simultaneous bottleneck work centers is reduced (Lawrence and Buss, 1994) when the mean protective capacity in a system is higher.

To give this consideration, the amount of mean protective capacity (MeanPC) was measured based upon the results from the 512 experimental runs. MeanPC was the difference between the bottleneck utilization and the average utilization at the non-bottleneck work centers. The factor, MeanPC was included as the covariate in a set of ANCOVA models to test for observable effects on manufacturing performance. MeanPC was used to adjust DV scores in order to remove undesirable variance, i.e. noise, and clarify the effects due to factors (Tabachnik and Fidell, 2001).

Table 8: ANOCOVA results for omnibus model (MFGPERF)

Source	Type III Sum of Squares	df	Mean Square	F	Significance	η^2
Corrected Model	4468.91	10	446.89	1,067.64	0.000	
Intercept	86.24	1	86.24	206.03	0.000	
k	149.27	1	149.27	356.62	0.000	0.022
P	136.15	1	136.15	325.27	0.000	0.020
D	816.96	1	816.96	1,951.74	0.000	0.119
B	1,274.33	1	1,274.33	3,044.42	0.000	0.186
CC	1.21	1	1.21	2.89	0.089	0.000
PMR	34.60	1	34.60	82.65	0.000	0.005
OPS	31.91	1	31.91	76.24	0.000	0.005
WC	1,191.68	1	1,191.68	2,846.96	0.000	0.174
RC	3.27	1	3.27	7.81	0.005	0.000
Mean_PC	91.58	1	91.58	218.80	0.000	
Error	3,210.09	7669	0.42			
Total	7679	7680				
Corrected Total	7679	7679				
Adjusted R Squared = .581						

An omnibus ANCOVA was performed to identify the significant static complexity factors. Table 8 provides the results. The covariate, Mean PC, was statistically significant. As a result of including a measure of protective capacity, seven of the eight complexity elements were shown significant at the 1% significance level. Component commonality was the only element not explaining variation in MFGPERF. Adjusted R^2 also increased (statistically significant). This partially supports the conjecture that broad differences in work center differences may have added “noise” that affected the results.

Table 9: Summarized Results from ANCOVAs					
	Performance Measure				
Factor	S_{FT}	L_{MEAN}	S_L	T_{MEAN}	S_T
K	0.000	0.073	0.007	0.051	0.020
	(0.057)	(0.000)	(0.000)	(0.000)	(0.000)
P	0.004	0.075	0.008	0.053	0.021
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
D	0.291	0.035	0.132	0.058	0.114
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
B	0.147	0.171	0.174	0.182	0.188
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CC	0.001	0.000	0.000	0.000	0.000
	(0.000)	(0.265)	(0.102)	(0.631)	(0.296)
PMR	0.006	0.003	0.020	0.016	0.008
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
OPS	0.006	0.002	0.006	0.004	0.004
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
WC	0.144	0.150	0.177	0.161	0.174
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
RC	0.000	0.000	0.000	0.001	0.001
	(0.018)	(0.009)	(0.015)	(0.002)	(0.004)
Mean PC*	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Adjusted R^2	0.635	0.573	0.567	0.583	0.579
Upper value = η^2; lower value = significance					
* Only the significance is reported for the covariate, Mean PC					

ANCOVAs were performed for the five measures of manufacturing performance. Table 9 reports the effect size and the significance for the eight complexity elements for each measure. Two things are worth noting. First, all models explained slightly more variation in performance (according to adjusted R^2) by including MeanPC. Secondly, the effect size for the factor WC substantially decreased while the effect size for the other factors increased. This is further substantiation for the concern about the potential for large differences in utilization between work centers.

Table 10: Adjusted Marginal Means for static complexity elements						
		Performance Measure				
Factor	Setting	S_{FT}	L_{MEAN}	S_L	T_{MEAN}	S_T
K	Lose	n.s.	875	574	381	500
	Tight	n.s.	1125	639	572	611
P	Few	773	849	566	362	487
	Many	712	1154	647	596	625
D	Shallow	539	908	469	372	424
	Deep	978	1088	761	584	702
B	Narrow	590	802	445	299	385
	Broad	912	1211	791	685	754
CC	None	n.s.	n.s.	n.s.	n.s.	n.s.
	Some	n.s.	n.s.	n.s.	n.s.	n.s.
PMR	Dominant Product	775	972	551	419	519
	Equal volumes	711	1020	663	528	590
OPS	Few	704	967	568	439	524
	Many	782	1025	645	506	585
WC	Few	1028	1338	928	820	885
	Many	503	704	352	219	300
RC	None	n.s.	986	n.s.	462	545
	Some	n.s.	1006	n.s.	483	563

Table 10 shows the marginal means for the complexity factors. These marginal means were consistent with those in the ANOVAs. So, although MeanPC eliminated some noise in the variation observed in the systems, it does not explain the unexpected results for WC. Further investigation is warranted for this factor.

CONCLUSION

Eight elements of system complexity common to the design of the system were identified. The results of the analysis indicated that six of these complexity elements have an impact on manufacturing performance. Although these elements were statistically significant, not all appear to be important to practicing operations managers. There are three factors to consider when evaluating decisions involving design of a manufacturing system. These are the number of end-products manufactured (i.e. product mix), the depth of product structures, and the breadth of product structures.

When making decisions regarding expanding product offerings, managers should consider the consequential impact on performance. If no supplementary effort is added to manage the increased complexity, performance will likely worsen. The additional management effort required to maintain current performance levels while expanding the product line will increase manufacturing costs.

The level of vertical integration should also be carefully considered. The findings of this study show that the depth of the products structure affects the predictability of outcomes in a manufacturing system. Even when the in-house cost to make components is lower than the cost to purchase the components, managers must account for the overall impact to performance. This study's findings suggest that systems with deeper product structures have less predictability in performance than systems with shallow product structures, i.e. having less vertical integration. When increasing the amount of vertical integration, additional process management will be necessary to counter the unpredictability that would result, resulting in increased operating costs.

Lastly, understanding the breadth of the product structures in a manufacturing system is important. Product design efforts to combine individual purchased components into a single module would benefit a firm. The breadth of product structures was the factor having the largest effect on every measure of manufacturing performance in this study. Reducing the breadth of product structures would help to improve performance to customer deliveries, reduce finished goods inventories and make completion dates more predictable.

Limitations of this Study

As this was an exploratory study into some of the measurable elements of static manufacturing complexity, the range of manufacturing environments was limited to what could be practically evaluated in a single study. Only two levels of each factor were included in the study to test a broad range of factors. It should be recognized that many existing production systems handle far more than five end-products, which was the high level in this study. At the same time, it might be equally questionable that many systems would have five levels of depth in their product structures.

Another specific limitation was that the type of manufacturing system in the experiments was confined to batch-type systems where random routing of products and components was feasible. There are many other types of systems ranging from job shop to assembly line production and all possible hybrids. So, caution should be used when interpreting the results, because they are not readily generalizable to all manufacturing environments.

Additionally, these simulation experiments used the exponential distribution for the arrival rate of orders. This is typical for such simulations (e.g. Fry et al., 1989; Russell and Taylor, 1985) because it is a simple distribution that was used in simple theoretical queuing systems (Law and Kelton, 2000). However, the exponential distribution used may not be appropriate. Future studies should consider using distributions with much lower variability and no infinite tails. Having used the exponential distribution to generate the time between order arrivals in this study may have created such a large variation that the effects of static complexity could not be detected. This could mean one of two things. First, the complexity factors identified could have a larger effect than resulted from these experiments. Alternatively, the results suggest that it may be the external dynamic complexity arising from the unpredictability in demand that affects performance more than the static complexity.

Future Research

This was an exploratory study of elements considered a part of internal static manufacturing complexity. As such, there are many possible areas for further research. This study limited its scope to static complexity. A likely step would be to extend it by investigating dynamic complexity factors, e.g. control systems, decision-making of managers, equipment breakdown, and maintenance plans.

Perhaps before investigating dynamic complexity, an investigation is needed into the effect observed for the factor WC, the number of work centers. Others, beside this author, have purported that systems with more work centers are more complex, thus they should have experienced decreased performance. The opposite was observed in this study. This may have been due to the type of system simulated or some combination of system parameters. This factor should be investigated in other experimental environments to better understand its effects.

Suggestions for investigating WC would include a new set of simulation experiments that have a greater range in the number of work centers between low and high settings. Additionally, more factor levels should be included. This research showed that the difference in work center utilization is important, so these differences must be carefully controlled. One method to control these is to run preliminary simulations to observe the utilization differences. Item processing times could be adjusted proportionally to increase or decrease work center utilizations so differences are no so extreme.

Additional types of manufacturing systems should also be examined in the future. Batch system with less "random" routings may better reflect real systems. Or hybrid systems that have both a job shop and assembly shop set of operations (Fry et al., 1988) or ones that have a gateway and finishing work center (Barman and LaForge, 1998).

Over 40% of the variation in manufacturing performance was left unexplained. There are either other elements of internal static manufacturing complexity that have not been identified in past literature, or the dynamic complexity elements of this simulation explain the difference. But, it is not likely that a complexity element explaining such a large portion of performance has been missed.

However, the dynamic attributes of the simulations could have had a large effect. Recall, the interarrival time between orders occurred randomly based upon the exponential distribution. Additionally, the order quantity for each end-product was also varied to better model a real system. These two dynamic variables might have confounded the observed effects of the complexity factors. Recall, past literature did purport that environmental dynamicism due to demand variation was part of manufacturing complexity (Kotha and Orne, 1989; Calinescu et al., 1998; and Khurana, 1999). If this was the case, further research should remove these dynamic factors in order to better study the static complexity factors.

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WILLINGNESS TO USE STRATEGIC IT INNOVATIONS AT THE INDIVIDUAL LEVEL: AN EMPIRICAL STUDY SYNTHESIZING DOI AND TAM THEORIES

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ABSTRACT

There exists an abundance of literature regarding information technology and various aspects of organizational performance. What is lacking is an analysis of how IT system innovations are most productively adopted by the individual, and how recognition of the critical success factors to usage of these technologies affects attitudes toward using them prior to the expense of acquisition. DOI and TAM theories were synthesized in this study, resulting in a new research method. My findings show that Relative Advantage, Complexity, and Trialability of innovative technologies are all predictors of the Willingness to Use them. These findings as well as the interesting interactions of some of the independent variables should prove useful to those who seek to understand these phenomena within the crucial context of pre-acquisition of innovative information systems.

INTRODUCTION

The literature strongly indicates that information technologies are crucial to corporate strategy and firm performance. But there remains a lack of study regarding how to determine problems with IT implementations early on, and the successful implementation of solutions to those problems. Without such knowledge, the complete benefits of information technologies to firm strategy and performance cannot be reaped. Discovering what determines successful attitudes toward usage of such technologies at the individual level is critical to firm performance. There already exists an abundance of literature regarding information technology and various aspects of organizational performance (Akkermans, & van Helden, 2002; Chan, Huff, Barclay, & Copel, 1997; & Hitt, Wu, & Zhou, 2002). What is lacking is an analysis of how IT innovations are most productively adopted at the individual level, and how recognition of the critical success factors to usage of these technologies affects attitudes toward using them. In a global and increasingly fast-paced business environment, Willingness to Use IT innovations and the speed with which they are adopted can significantly affect competitive advantage.

The work of Rogers (2003) and Davis, Bagnozzi, & Warshaw (1989), and all subsequent research employing their models, leaves a critical gap in the existing knowledge of this important subject. That gap is precisely what I address in this research, namely identifying and empirically examining pre-adoptive behaviors toward technology adoption and usage. Corporate strategists need a better understanding of predictors of system usage and success before acquisition, adoption and implementation rather than ex post.

RESEARCH QUESTIONS

The overall purpose of this research is testing some key hypotheses from DOI and TAM regarding an individual's Willingness to Use new computer technology. I used the scenario-based research methodology to add to the body of knowledge on the positive or negative impacts of Relative Advantage, Complexity, and Trialabilty on an individual's Willingness to Use a new IT innovation. The new model has Relative Advantage, Complexity, and Trialability as independent variables to predict Willingness to Use. Specifically, I seek answers to the following research questions:

1. How do the Relative Advantage, Complexity, and Trialability of a new technology affect individual Willingness to Use?

2. What combination of Relative Advantage, Complexity, and Trialability creates the greatest individual Willingness to Use new technologies?

3. What informative and useful interactions exist between these variables?

LITERATURE REVIEW

According to Hamel (1996), and Kim and Mauborgne (1997), the life of any business is finite. For companies to survive, the drive for efficiency must be combined with effectiveness through excellence in entrepreneurship. Through the process of innovation, new enterprises must emerge before old ones decay. As Ray Stata, chairman of Analog Devices Inc. (ADI), observes, "Everything has a life, and you always have to be looking beyond that life. The primary job of the CEO is to sense and respond ... with the benefit of inputs from the organization ... and to be an encouraging sponsor for those who see the future" (Govindarajan and Trimble 2004, p. 68.)

Since the early 1980s, considerable research attention has focused on the strategic role of information technologies and their potential for creating competitive advantage (Benjamin et al., 1984; Cash and Konsynski, 1985; Ives and Learmonth, 1984; McFarlan, 1984; Parsons, 1983; Porter and Millar, 1985). This work suggests that IT can be used to create competitive advantage through efficiency improvements, differentiation, and channel domination (Sethi and King, 1994).

Therefore, the importance of this study is to focus on the individual level within the firm to determine critical factors for success, long before systems are purchased and adoption is attempted.

There is a great deal of agreement in the empirical literature that Relative Advantage (Perceived Usefulness) is consistently an attribute that positively affects attitudes toward usage of an innovative technology. However, there is an abundance of conflicting evidence in the literature regarding the effects on attitudes toward use of the other two attributes considered in this study, namely Complexity (Ease-of-Use) and Trialability.

Diffusion of Innovations Theory

I applied DOI theory in this research because it is well established and widely used in information technology (IT) diffusion-related research (Prescott and Conger, 1995 and Choudhury and Karahanna, 2008), and provides an excellent fit with the goal of understanding peoples' initial attitudes toward adopting technology. According to Rogers (2003), *Diffusion* is the process in which an innovation is communicated and adopted through certain channels over time among members of an organization, in order to reach a mutual understanding. Diffusion in this case is the systems and processes that provide the infrastructure for diffusion based information to occur, in that the messages are concerned with new ideas.

There is a wide body of research regarding the concept of diffusion, (internal vs. external, and other variants), however few authors offer specific definitions of the concept (Brancheau and Wetherbe, 1990; Jensen, 2002; Mustonen-Ollila, and Lyytinen, 2003). Drury and Farhoomand (1999) defined it as meaning the spread of an innovation through the set of potential adopters. A great deal of past research findings have centered on the identification of innovation attributes that affect diffusion and the classification of adopters with different characteristics (Tornatzky and Fleisher, 1990).

To paraphrase Rogers definition of the study of diffusion, it is the study of how, why, and at what rate new ideas and <u>*technologies*</u> spread through cultures. This research focuses on diffusion in terms of Willingness to Use and operationalizes the construct using existing and newly created measures.

Relative Advantage (RA)

Rogers defines Relative Advantage as the degree to which an innovation is perceived as superior to the innovation it supersedes. The degree of Relative Advantage is often expressed as economic profitability, as conveying social prestige, or in other ways (Rogers 2003). The nature of the innovation determines what specific type of Relative Advantage (economic, social, and so on) is important to users, although the characteristics of the potential adopters may also affect which specific subdivisions of Relative Advantage are most important.

Complexity (CX)

Complexity can be considered the same as the inverse of Ease-of-Use as discussed in many of the behavioral intent models including the TAM (Wu and Wu, 2005; Lewis and Orton, 2000). Specifically, it is the degree to which an innovation is perceived as relatively difficult to understand and use. Any innovation can be classified on a complexity-simplicity continuum (Rogers 2003) because some innovations are clear in their meaning to potential adopters and some are not.

Trialability (TR)

Trialability is the degree to which an innovation will be available for trial usage before adoption (Rogers, 2003). Innovations available for trial for a period of time are generally more acceptable to individuals than those simply thrust upon them. Personally trying out an innovation is one way for an individual to give meaning to an innovation and to find out how it works under one's own conditions. A personal trial can dispel uncertainty about a new idea (Rogers 2003). Given the potential complexity and requisite business model alterations inherent in PWS systems usage, Trialability may be a very critical factor.

Willingness to Use

Willingness to Use is the dependent variable of interest in this study, and as such is determined by manipulations of the independent variables. Davis (1989) defined the behavioral intent to use technologies as 'User Acceptance,' and Venkatesh et al. (2002) utilized the term 'Use Behavior.' Rogers (2003) uses the term 'Rate of Adoption' to describe his expected behavioral outcome, which is his dependent variable in DOI theory. A Rate of Adoption measure is not suitable for drawing conclusions about an individual's Willingness to Use new technology at a point in time, irrespective of the adoption decisions of other comparison individuals.

Therefore, in the current study, I assess individuals' attitudes toward adoption using Willingness to Use measures widely used in the TAM literature (Purao, and Storey 2008: Son, Kim, and Riggins 2006; Liu and Ma 2005; and Shih, H. 2004). I define Willingness to Use as the extent to which an individual has a positive attitude toward using a new technology.

The Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) of Davis et.al. (1989) is an information systems theory that models how users come to accept and use a technology. In the current study, Rogers's DOI theory provides the basis for my key predictions. However, there is some conceptual overlap between Rogers's perceived attributes and TAM, creating an opportunity for integration.

In addition, research associated with the TAM has provided well-validated measures of Willingness to Use that can be deployed to assess attitudes toward adopting a new technology among individuals at the outset of that technology's introduction without relying on Rate of Adoption measures that require longitudinal measurement and a comparison sample from which to infer rate. This prior versus ex post facto analysis of Willingness to Use is a key contribution of the study. Thus, I used Rogers's DOI and related attributes of TAM to develop the research model and hypotheses, as well as to develop instruments to measure the constructs and relationships in the research model.

The past twenty five years have seen a prolific stream of research on information systems from a variety of theoretical perspectives. The information systems community has considered TAM a parsimonious and powerful model because of its simplicity and amount of usage (Lucas and Spitler, 1999; Venkatesh and Davis, 2000). Lee, Kozar, and Larsen (2003) found 698 journal citations of TAM by 2003. TAM has been applied to different technologies, such as word processors, e-mail, the World Wide Web, Group Support Systems, and Hospital Information Systems, under different situations such as time and culture, with different control factors like gender, organizational type and size, and different subjects, such as undergraduate students, MBAs, and knowledge workers. This variety of applications of the theory has led its proponents to believe in its robustness. The TAM model suggests that when users are presented with a new innovation, such as a software package, a number of factors influence their Willingness to Use it.

Of critical importance to this study are the following constructs developed by Davis (1989):

- Perceived Usefulness (PU) “The degree to which a person believes that using a particular system would enhance his or her job performance." (p. 320)

- Perceived Ease-of-Use (PEOU) "The degree to which a person believes that using a particular system would be free from effort.” (p. 320)

The similarities between these constructs and Rogers’s perceived Relative Advantage and perceived Complexity are intuitively clear. Furthermore, Davis (1989) provided evidence of the relative paucity of scales to measure these two perceived characteristics of using an innovation. He concluded, after a search for appropriate scales, that no validated scales with the desired reliability existed for either construct. He therefore undertook an instrument development process resulting in two scales with Cronbach’s Alphas in excess of 0.90 for each construct (Moore and Benbasat 1991).

HYPOTHESES

The hypotheses were driven by DOI & TAM. Based on both theories, I predicted that individuals would be more willing to use new technology when they perceive it to be high in Relative Advantage, low in Complexity, and high in Trialability:

H1: *Individuals will be more willing to use a PWS system when Relative Advantage is high.*

H2: *Individuals will be more willing to use a PWS system when Complexity is low.*

H3: *Individuals will be more willing to use a PWS system when Trialability is high.*

Research Methodology

I used a scenario-based experiment to manipulate three key perceived attributes of technology highlighted in Rogers' DOI theory: Relative Advantage, Complexity, and Trialability. The scenarios held levels of Compatibility and Observability constant. I assessed participants' Willingness to Use an innovative technology described in each of the eight scenarios by using scales validated both from prior work and in a pilot study.

Participants

Participants were senior level and MBA level business school students enrolled at a mid-size public university in the south central part of the United States. Approval was obtained from the Henderson State University Institutional Review Board. Each participant signed an informed consent form and received extra credit in his or her class in an appropriate amount.

Procedure

Data was collected from students in the capstone undergraduate course in strategy and policy, as well as a graduate course in marketing research and reporting. The capstone course is taken in the students' last semester before graduation, and the marketing research course was, of course, limited to MBA students.

Research Design

I used a 2 (Relative Advantage: high or low) X 2 (Complexity: high or low) X 2 (Trialability: high or low) between-subjects experimental design. Each factor was manipulated via the wording of passages within the scenario, and each participant thus received one of eight experimental scenarios. In order to facilitate as random assignment of subjects to scenarios as possible, all eight were photocopied in stacked, sorted order. Therefore as subjects arrived for the experiment, they were simply assigned the next scenario on the top of the stack.

RESULTS

Relative Advantage

Relative Advantage (RA) had a strong, significant main effect on the RA manipulation check item, $F(1,87) = 63.38$, $\rho < .001$, such that using the PWS was viewed as much more advantageous by individuals in the high condition ($\mu = 5.86$) than in the low condition ($\mu = 3.04$). There were no other significant main effects or interactions. Thus, the Relative Advantage manipulation was successful.

Complexity

Complexity (CX) had a strong, significant main effect on the CX manipulation check item, $F(1,87) = 133.15$, $\rho < .001$, such that the PWS was viewed as much easier to use in the low CX condition ($\mu = 5.94$) than in the high CX condition ($\mu = 2.87$). There were no other significant main effects or two-way interactions involving CX, although there was a significant three-way interaction $F(1,87) = 10.90$, $p<.001$ that showed that Relative Advantage and Trialability interacted to influence the means more in the high Complexity condition than in the low Complexity condition (where the mean values were closer together). However, the PWS was viewed as uniformly easier to use in the low Complexity conditions (μs ranging from 5.69 to 6.08) than in the high Complexity conditions (μs ranging from 1.82 to 3.82). Thus, the relative Complexity manipulation was successful.

Trialability

Trialability (TR) had a strong, significant main effect on the TR manipulation check item, $F(1,87) = 146.13$, $\rho < .001$, such that participants reported that it was much more likely that they would be able to try the PWS out before it was implemented in the in high Trialability condition ($\mu = 6.54$) than in the low Trialability condition ($\mu = 2.34$). There were no other significant main effects or interactions. Thus, the Trialability manipulation was successful.

Compatibility and Observability

As in the pilot study, ANOVAs on the Compatibility and Observability items found no significant main effects or interactions. This suggests that the scenario wording was successful in holding perceptions of these factors constant. The following is an ANOVA summary table:

INDEPENDENT VARIABLES AND INTERACTIONS	F	Sig.
Relative Advantage	31.83	.000**
Complexity	10.83	.001**
Trialability	5.31	.024*
Relative Advantage x Complexity	5.35	.023*
Relative Advantage x Trialability	3.55	.063
Complexity x Trialability	5.41	.022*
Relative Advantage x Complexity x Trialability	0.54	.464

* $\rho < .05$
** $\rho < .01$

There was a strong, significant main effect of Relative Advantage on Willingness to Use, $F(1,87) = 31.83$, $\rho < .001$, such that individuals were more willing to use the PWS when Relative Advantage was high ($\mu = 5.50$) rather than low ($\mu = 4.24$). Therefore, Hypothesis 1 was strongly supported.

There was also a strong, significant main effect of Complexity on Willingness to Use, $F(1,87) = 10.83$, $\rho < .01$. Willingness to Use was higher when Complexity was low ($\mu = 5.25$) rather than high ($\mu = 4.55$). Thus, Hypothesis 2 received strong support.

There was also a significant main effect of Trialability on Willingness to Use, $F(1,87) = 5.31$, $\rho < .05$, such that Willingness to Use was higher when Trialability was high ($\mu = 5.14$) rather than low ($\mu = 4.66$). Therefore, Hypothesis 3 was also supported.

In addition, there was a significant interaction between Relative Advantage and Complexity, $F(1,87) = 5.35$, $\rho < .05$, such that Relative Advantage (RA) had a stronger impact on Willingness to Use when Complexity was high (high RA $\mu = 5.39$ and low RA $\mu = 3.60$) than when Complexity was low (high RA $\mu = 5.61$ and low RA $\mu = 4.86$). This suggests that individuals are fairly willing to use a new technology when Complexity is low regardless of its Relative Advantage, but that when Complexity is high, using the new technology must offer some distinctive advantage to individuals before they will be willing to use it.

There was also a significant interaction between Complexity and Trialability, $F(1,87) = 5.41$, $\rho < .05$. When Complexity was high, individuals were more willing to use the PWS when Trialability was high ($\mu = 5.06$) rather than low ($\mu = 4.02$). However, when Complexity was low, individuals were equally willing to use the PWS whether it was high ($\mu = 5.23$) or low ($\mu = 5.27$) in Trialability. This suggests that when using new technology that is complex, it may be especially important to allow individuals to try the technology out before implementing it.

DISCUSSION

DOI Theory and TAM suggest that an individual's willingness to adopt a new technology is influenced by three critical factors: Relative Advantage, Complexity, and Trialability. Hypothesis H1 stated that individuals will be more willing to use a PWS system when Relative Advantage is high. Results of the ANOVA analysis strongly support this hypothesis, indicating that individuals who perceived a high Relative Advantage from using the PWS system were more willing to use it than those who perceived a low Relative Advantage from using the system. This finding was supported by the ANOVA results of all three dependent variables employed in the study; the primary dependent variable of Willingness to Use, as well as two supporting dependent variables of Rate and Overall Evaluation.

Hypothesis H2 stated that individuals will be more willing to use a PWS system when Complexity is low. The results of this study support this hypothesis with one qualification. Individuals who perceived a low level of Complexity in using PWS were more willing to use it than when the perceived level of Complexity of the PWS was high as tested with two of the three dependent variables. Specifically, H2 was supported by testing of the primary dependent variable of Willingness to Use and the supporting dependent variable of Overall Evaluation. However the test of Complexity in the case of the Rate dependent variable was not significant.

Hypothesis H3 stated that individuals will be more willing to use a PWS system when Trialability is high. Results of the ANOVA analysis strongly supported this hypothesis as well. Individuals who perceived a high level of Trialability before adopting the PWS system showed an increase in Willingness to Use it across all three measures of the dependent variable.

The observed interactions also merit discussion. This study found a significant interaction effect between Relative Advantage and Complexity. This finding suggests that individuals are fairly willing to use a new technology when Complexity is low without regard to its Relative Advantage. When Complexity is high, the new technology must offer a pronounced Relative Advantage before individuals will be willing to use it. This study also found a significant interaction effect between Complexity and Trialability. The analysis indicated when Complexity of a new technology is high, Trialability is an especially important factor. Hands-on experience was found to be crucial to user acceptance of complex information technologies.

One of the primary purposes of this research was to add to the existing theoretical body of knowledge regarding the critical success factors behind information system adoption decisions. To that end, I have added to the existing research in terms of three factors that determine Willingness to Use a new technology.

CONCLUSIONS

The primary contributions of this study are to provide new empirical data on three previously tested independent variables, in an entirely new way. This was accomplished by testing DOI predictions, and illustrating conceptual linkages between DOI and TAM.

The vast majority of academic studies have focused on the rate of adoption of new technologies during implementation throughout organizations. This study is unique in that it focuses on the factors that influence user acceptance of new technologies ex ante, specifically Relative Advantage, Complexity, and Trialability. In addition to obtaining empirical data on these three variables, fascinating interactions between the variables were discovered that were heretofore under researched or not researched at all. The interaction between Relative Advantage and Complexity, as well as that between Complexity and Trialability discovered in this study add substantially to the existing knowledge regarding these phenomena.

The research model is unique in that incorporates attributes of DOI and TAM in assessing a user's willingness to adopt a new information technology. Conceptual linkages between these two theories were created in a novel way. DOI seeks to measure the longitudinal dependent variable of Rate of Adoption of Innovations by using the five independent variables previously enumerated. The TAM seeks to measure the dependent variable of post-adoption Actual System Use through measuring Perceived Usefulness and Perceived Ease of Use. By synthesizing Perceived Usefulness with Relative Advantage, and Perceived Ease of Use with Complexity, this study draws upon two well grounded theoretical bases to explain the behavioral intent of potential information technology adopters.

Although prior studies have actuated similar syntheses of these variables, they have not done so in the unique manner conducted within this study. The novel contribution is in terms of the element of measurement of pre-adoptive behavioral intentions, and the particular variables that this study measures.

Another significant and new contribution to academic research was achieved through the distinctive research design. The research model was tested using three different measures of Willingness to Use which converge on the same results, thus increasing the convergent validity. The 21 item scale used to measure the three dependent variables proved to be extremely reliable.

The design of the scale which included manipulation checks, measures of constant variables from DOI, and reverse scored scale items contributes significantly to the small body of knowledge regarding measuring the behavioral intent of individuals in ex ante IT adoption situations.

To my knowledge, this is the first study to focus on pre-adoption factors within a hybrid model combining DOI and TAM models at the individual level, utilizing a scenario-based research design. The results of this study serve to reinforce the notion that although a great deal of research has preceded in the field of information systems usage, we still as yet do not have a complete understanding of all of the complex variants that go into acquisition decisions.

The findings of the research have important practical implications for potential IT implementations. As never before, the study provides some preliminary evidence concerning the criteria that potential adopters utilize to evaluate IT innovations. This is important in the potential purchase decisions of IT innovations, some of which may have significant strategic implications.

This is also important in the design of information systems and the associated implementation plans that will lead to acceptance and success of information systems. The results of this study should assist managers in identifying and assessing the critical success factors of user acceptance of new information technologies before rather than after acquisition. Prior to investing in what may be mission-critical and costly information systems, managers should gauge their employees' perceptions regarding the Relative Advantage, perceived Complexity, and perceived Trialability of the new technology by the individual prior to acquisition.

This study has shown that individual workers will likely be more willing to use a new technology if they perceive that it will offer them advantages, lack complexity, and allow them a chance to try it out before purchase. Given the problematic and costly history of failures of some enterprise wide systems such as ERPs, this is powerful knowledge that managers can use in order to ensure successful acquisitions and implementations, resulting in greater efficiency and profitability. Rather than falling into the trap of acquiring systems simply because the competition does, along with the attendant fear of operating at a competitive disadvantage, managers are well advised to learn more about the potential likeliness of successful outcomes. In some cases, regardless of system merits, premature acquisitions may by themselves place organizations at competitive disadvantages.

With regard to the findings of interactions between variables found within this study, managers should delve deeper into the nature of a proposed system's attributes before acquisition. For example, if a system is considered to be complex, workers are likely to be more willing to use it if it offers some distinctive advantage to them personally. Additionally, if a system is considered to be complex by workers, managers should plan some pre-adoption hands-on experience in order to ensure successful acquisition outcomes. These are crucial findings as managers might have a tendency to become so engrossed in technical or other details of potential systems that they overlook the importance of considering these factors.

Pending future research, organizational change agents may tailor IT demonstrations, marketing efforts, training programs, and other implementation interventions to emphasize criteria that end users actually employ to make their adoption decisions. This, in turn, should increase the likely effectiveness and efficiency of managerial interventions in the analysis and acquisition decisions of crucial IT applications.

This study represents a solid beginning in a new pre-adoption research area. It appears to nicely replicate some previous organizational-level research on post-adoption perceptions of new technology, extend that work to the new realm of individual pre-adoption judgments of technology, and raise some intriguing new insights. Additional research is called for to expand and enhance the findings.

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STUDY OF ATTITUDES OF COLLEGE STUDENTS TOWARDS USERS AND USABILITY

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ABSTRACT

The differences in attitudes in two groups of subjects: a group of "developers" and a group of "naïve" users is measured. The subjects in the study were undergraduate college students and were assigned to either group according to their answers to a survey. The same survey was used to measure the differences in their attitudes in general towards information system usability and in particular towards the user rights proposed by Karat in 1998 (Karat, 1998). Thirteen years after the Karat principles were proposed, this study presents evidence that both kinds of subjects studied, developers and naïve users, still do not embrace some of Karat's principles. The data presented here shows differences between our sets of naives and developers even while there are both still college students. This study reveals an urgent need to educate both users as well as developers in the needs and rights of information system users.

INTRODUCTION

In 1998 Clare-Marie Karat proposed a User's Bill of Rights (Karat, 1998). The proposal was intended to be a set of goals to "challenge the computer industry to respect and address the needs of computer users, our customers." The fundamental principle of Karat's Bill is that "the user is always right." This principle might require a fundamental change in attitude by the people who produce hardware and software (Wildstrom, 1998).

After so many years of work on usability and user-centered design one would expect that developers and organizations would have embraced usability as an essential component of Information Systems design. But a recent post in a well known blog about Information Systems (Nesbitt, 2011) seems to suggest that in 2011 usability practitioners still find "polarized attitudes towards users." Even though we now often find developers who have been trained in and are sensitive to the principles of good user-centered design it is hard to disagree with Nesbitt when he says that "in most places I've worked users were often treated with an attitude just short of contempt. Developers put in features and functions that they thought the users needed, and ignored any suggestions from the field. Or from anyone else." (op. cit., p).

In the study described here we measure the difference in attitudes towards users and usability in students before, perhaps, too much polarization between future developers and users has occurred. The question is whether any differences, or even antagonism, between developers and users can be detected when the developers are still students and perhaps more susceptible to being educated in the importance of the users' needs.

REVIEW OF THE LITERATURE

Even before Karat's proposal, organizations involved in software development had acknowledged the importance of usability. Mitre published a classic document in 1986 (Mosier & S. L. Smith, 1986). Other companies (Apple Inc, 2009; Microsoft, 2010) have published since design guidelines for user interfaces. There has also been an increasing interest in the usability of special information systems such as Digital libraries (Perez-Carballo, Xie & Cool, 2011; Theng, Duncker, Mohd-Nasir, Buchanan & Thimbleby, 1999). The growing number of users of social networks and the problems caused by their privacy policies resulted in the proposal of a "bill of rights" for social-network users in 2010, at the, 20th CFP (Computers, Freedom, and Privacy) conference (Swift, 2010).

Smith (H. Smith, 1990) says that the antagonism between non-technical managers in business (users) and the technical experts who develop computers systems (Information systems staffs) has been an ongoing organizational concern for more than 20 years. Her study explores the way in which the difference in power status of both groups may influence the difference in attitudes of users and information system managers toward each other in an organization. She further suggests that attempts to improve user-IS attitudes will only work if they somehow alter their power relationship.

Strong et al. (Strong & Neubauer, 2001) report that students apparently found computers more difficult to operate, but were more likely to think themselves responsible for problems with computers than for problems with home entertainment systems or automobiles. Perhaps this difference in how students in that study perceived different technologies may account for differences in their attitudes toward usability.

Mitra and Steffensmeier (Mitra & Steffensmeier, 2000),using evidence from their own studies as well as other studies, report that computer experience, access, and various kinds of computer use are three key variables to changing attitudes towards computers. They report that more experienced users are likely to be less anxious and have more positive attitude toward the computer than less-experienced users. This would suggest that different levels of experience in students may influence not only their attitude towards computers but also their attitude towards other users that they perceive as being less knowledgeable and experienced.

Strong (Strong & Neubauer, 2001) studied the attitudes of students to different technologies such as automobiles, home entertainment systems, and computers. The study found evidence of more frustration with computers than with other technologies. Despite the fact that students apparently found computers more difficult to operate, they were more likely to think themselves responsible for problems with computers than for problems with other technologies. Almost 40% of student surveyed reported that when a computer fails it is probably "because I did something wrong." There is clearly a difference in attitude towards computer systems and attitude towards other technologies: "computers were found to be perceived significantly differently from both home entertainment systems and automobiles in every way" (op. cit.).

There may be a measurable difference in attitudes and expectations between IS users and IS providers (Tesch, Miller, & Jiang, 2005). In their study Tesch et al (op. cit.) examine the impact on user satisfaction of the interaction of the expectation gap between the users and providers of IS and the expectation–proficiency gap. Indeed: "users and IS providers may perceive things differently." The authors emphasize that the key is that "the interaction of users and IS providers during the development process generates realistic user expectations."

Barki et al. (Barki & hartwick, 1994) have measured user participation, involvement, and attitude, during systems implementation. Their data analysis supports some of the basic principles of user-centered design: users who participate in the development process were likely to develop beliefs that a new system is good, important, and personally relevant. Through participation, users may be able to influence the design of a new system, satisfying their needs. They may develop feelings of ownership, as well as a better understanding of the new system and how it can help them in their job.

Davis et al. (Davis, Kettinger, & Kunev, 2009) go further when they demonstrate in their study that IT competence held by both the IS department and user department stakeholders contributes to user satisfaction when developing information systems. In other words not just user participation in the process but participation by knowledgeable users.

METHODS OF RESEARCH

After researching the literature, a survey was developed with questions designed in order to explore the attitudes of subjects toward some usability issues. The participants were undergraduate students enrolled in six sections of business courses, including two business communications course sections. A total of 126 students completed the survey. Students were informed that the survey was anonymous and were not told what was being studied. The names of students were not gathered in either the hard copy or web administrations of the survey.

DEMOGRAPHICS

Of the 126 students who completed the survey, 83 (66%) are male and 43 (34%) are female; 55 (44%) report English as a first language, 71 (57%) report another language; 20 (16%) are 31 or older, while 106 (84%) are 30 or younger; 49 (39%) identify as Asian and 43 (34%) as Hispanic/Latino.

DATA ANALYSIS

We split the subject population (126) into three disjoint sets: DEVELOPER (42 members), NAIVE (43 members), and NEITHER (41 members). The DEVELOPER set is intended to capture the subjects that are more experienced and that are either already developers or intend to become developers sometime in the future. The NAIVE set is intended to capture the more naive, less experienced subjects, who have never participated in development and do not intend to do it in the future. The NEITHER set may include experienced subjects who are not interested in development as well as, somewhat surprisingly, naive users who would like to become developers. We used the survey answers to categorize the differences in attitudes of the DEVELOPER and the NAIVE set. In the following paragraphs the members of the DEVELOPER set are called “developers” while the members of the NAÏVE set are called “naives”.

For subjects to be in set DEVELOPER they must have answered "yes" to the “developer” question: “Do you see yourself as participating in any form of systems development or programming in the future (or have you done it already)” and they should be one of the 61 subjects (we split the subject set in two halves) with the *highest* combined score in the three “skills” questions shown immediately after this paragraph. For subjects to be in the NAIVE set they must have answered either "no" or "don't know" in the “developer” question, and they must be one of the 65 subjects with the *lowest* combined score in the “skills” questions. The “skills” questions just mentioned are the following:

How would you compare your computer skills with those of the average person (compare yourself with your classmates, co-workers, and friends)

a. I’m much more skilled than most people
b. I’m somewhat more skilled than the average person
c. My computer skills are about average
d. I’m less skilled than the average person
e. I’m much less skilled than most people

Rate your skill level writing computer programs
a. Excellent
b. Very Good
c. Good
d. Satisfactory
e. Not Very Good
f. Poor
g. Never written a computer program

How would you rate your skills in terms of information competence and computer technology?

a. Excellent
b. Very Good
c. Good
d. Satisfactory
e. Not Very Good
f. Poor

RESULTS

Table 1 presents a summary of the results of the study.

Table 1: Summary of Results				
	Survey Question	**Naïve**	**Developer**	***P* Value**
1	How often do you feel like the computer just doesn't want to do what you want it to do. Score 4. Always 3. Most of the time 2. About half of the time 1. Sometimes 0. Never	1.3 (Mean)	1.7 (Mean)	0.0054
2	When you are using an information system, a computer program, a website, or any computer device, how often do you feel you are in control of it	83.3% Feel in control most of the time	93.0% Feel in control most of the time	0.0025
3	In the case of a new information system, which do you think is true: a. the system should adapt to the users whatever their level of competency might be. b. The users should train, learn, and change their ways in order to adapt to the new system	55.8 % Feel user should adapt to the system 44.2% Systems should adapt to users	47.6% Feel user should adapt to the system 52.4% Systems should adapt to users	0.2
4	Sometimes it may be necessary to hide from the user what the information system is really doing and how long it may take to do it	16.7% naives agree	40.5% experts agree	0.008
5	When you are using a computer, who do you think should be in control of the interaction	80.6% think the user should be in control	85.8% think the user should be in control	0.2

Table 1: Summary of Results				
	Survey Question	**Naïve**	**Developer**	***P* Value**
6	How much do you agree with the following: "the user has the right to communicate with the technology provider and receive a thoughtful and helpful response when raising concerns. Score: 3: strongly agree 2: somewhat agree 1: somewhat disagree 0: strongly disagree)	2.44	2.79	0.0006
7	Do you feel frustrated or impatient when you have to deal with (or explain things to) people who know less than you about information systems or computers	32.6% naives feel frustrated at least half of the time	40.5% experts feel frustrated at least half of the time	0.15
8	A well designed system does not need any kind of instructions, online or contextual help, or error messages	9.3% naives agree	31.0% experts agree	0.0054
9	Any information system should have easy-to-use instructions (user guides, online or contextual help, error messages) for understanding and utilizing a system to achieve desired goals.	81.4% naives agree	71.4% experts agree	0.14
10	It is the responsibility of the user to learn how to use the system and find whatever information or training materials he/she might need	23.3% naives agree	21.4% experts agree	0.2
11	Do you ever feel frustrated when using an information system, a computer program, a website, or any computer device. Score: 4: Always 3: Most of the time 2: About half of the time 1: Sometimes 0: Never	1.2	1.0	0.075
12	If there is a problem with the use of an information system, who do you think is more likely to be the cause of the problem	36.4% naives blame the users	33.3% experts blame the users	0.4

The means of the answers to the question "How often do you feel like the computer just doesn't want to do what you want it to do" show that both sets (Naives and Developers) feel that the computer "just doesn't want to do what" they want it to do somewhere between "sometimes" and "about half of the time". A value of 1 corresponded to "sometimes" a value of 2 to "about half of the time". The mean for Developers was 1.7 and the mean for Naives was 1.3 with $p = 0.0054$. There is a statistically significant difference between the answers of developers and naives with developers feeling more often that the computer doesn't do what they want it to do. The top 29 subjects who feel the computer doesn't want to do what they want tend to be developers ($p = 0.0005$).

On the other hand, the answers to question "When you are using an information system, a computer program, a website, or any computer device, how often do you feel you are in control of it" show that 83.3% naives feel in control most of the time or always vs. 93.0% for the developers ($p = 0.0025$).

The answers to the question "In the case of a new information system, which do you think is true: **a.** the system should adapt to the users whatever their level of competency might be. **b.** The users should train, learn, and change their ways in order to adapt to the new system" are mixed. 55.8% naives think users should adapt vs. 47.6% of developers. The statistical differences here are not very significant ($p = 0.2$). This means both populations are almost evenly split about this issue.

When subjects had to choose: "**a.** Sometimes it may be necessary to hide from the user what the information system is really doing and how long it may take to do it, **b.** Any information system should provide clear, understandable, and accurate information regarding the task it is performing and the progress toward completion", there was a significant tendency ($p = 0.008$) for developers (40.5%) to think more often than naives (16.7%) that information should be hidden from users.

The answers for question "When you are using a computer, who do you think should be in control of the interaction" show that both developers and naives tend to think the user should be in control. Although the percentage for developers (85.8%) is higher than for naives (80.55%) the difference is not very significant ($p = 0.2$).

For question "How much do you agree with the following: "the user has the right to communicate with the technology provider and receive a thoughtful and helpful response when raising concerns" all naives and all but one developer either strongly agree or somewhat agreed with the statement. Given that a score of 3 would be "strongly agree", and 2 corresponds to "somewhat agree", the developers' score was 2.79, the naives' was 2.44 which shows that developers tended to agree more strongly with the statement ($p = 0.0006$).

The answers for question "Do you feel frustrated or impatient when you have to deal with (or explain things to) people who know less than you about information systems or computers", show that 32.6% naives feel frustrated at least half of the time, compared to 40.5% developers ($p = 0.15$).

For the following question, subjects had to choose which option they agreed with the most:

- **a.** A well designed system does not need any kind of instructions, online or contextual help, or error messages
- **b.** Any information system should have easy-to-use instructions (user guides, online or contextual help, error messages) for understanding and utilizing a system to achieve desired goals.
- **c.** It is the responsibility of the user to learn how to use the system and find whatever information or training materials he/she might need

31.0% developers agree with (a) vs. 9.3% naives ($p = 0.0054$). 81.4% naives agree with (b) vs. 71.4% developers ($p = 0.1401$). 23.3% naives agree with (c) vs. 21.4% developers ($p = 0.2$)

For question “Do you ever feel frustrated when using an information system, a computer program, a website, or any computer device”, the scores for the answers were: "Always" (4), "Most of the time" (3), "About half of the time" (2), "Sometimes" (1), "Never" (0). The naives scored a little higher (1.2) vs. the developers (1.0) with $p = 0.075$.

Answers for question “If there is a problem with the use of an information system, who do you think is more likely to be the cause of the problem” show that of the subjects who chose an answer other than “don’t know” or “nobody”, 36.4% of the naives blame the user vs. 33.3% developers but the difference is not statistically very significant at $p = 0.4$.

DISCUSSION OF RESULTS

Karat's ninth user right says that the user has the right to communicate with the technology provider and receive a thoughtful and helpful response when raising concerns (Karat, 1998). All naives, and all but one developer, either strongly agreed or somewhat agreed with that statement. Developers tended to agree more strongly with this statement.

Karat's first user right states that "the user is always right. If there is a problem with the use of the system, the system is the problem, not the user". In our study both groups blame more often causes other than the user when there is a problem. That is encouraging but still too many developers (33.3%) blame the user a priori.

Karat's 5th user right states that "the user has the right to be in control of the system and to be able to get the system to respond to a request for attention". The majority in both groups feel in control of the information system with the developers feeling more often in control. Both, developers and naives tend to think the user should be in control (naives: 80.55% and developers: 85.8%). Although, again, more developers than users. Perhaps it is not surprising that naives require education even as users.

Karat's 10th user right says that "the user should be the master of software and hardware technology, not vice versa. Products should be natural and intuitive to use". Too many of our subjects think that it is the user the one who should adapt to the needs of the system instead of the system adapt to the user and their needs. More naives, 55.8%, think users should adapt vs. 47.6% of developers. The naives perhaps are resigned to their prior experience interacting with systems in which they had to adapt to the system and not viceversa. It is discouraging that almost half of both populations disagree with the statement that “the system should adapt to the users whatever their level of competency might be”.

Karat's 6th user right states that the user has the right to a system that provides clear, understandable, and accurate information regarding the task it is performing and the progress toward completion. In our study a significant majority of developers (40.5% developers vs. 16.7% of naives) think that “sometimes it may be necessary to hide from the user what the information system is really doing and how long it may take to do it”. This shows a tendency of the developers to want to take control of the interaction away from the user. It shows a tendency to think that the developer knows best what is good for the user. This is seldom a good design principle.

Karat's 4^{th} user right indicates that the user has the right to easy-to-use instructions (user guides, online or contextual help, error messages) for understanding and utilizing a system to achieve desired goals and recover efficiently and gracefully from problem situations. In our study developers tended to agree less with that statement and more with statements such as "a good system doesn't need documentation" or "it is the responsibility of the user”. A disturbingly high percentage of the developers (31.0%) think that “A well designed system does not need any kind of instructions, online or contextual help, or error messages”. This result clearly points to a need to educate developers in their responsibility to provide good documentation and help for the systems they develop. Naives agreed more often with the need for good help and documentation.

Our study suggest that most of our subjects, both naives and developers, feel frustrated explaining things to more naive users between "sometimes" and "half the time". We would have liked to find that the developers were patient with naives. We would not have been surprised to find that the opposite is true. But the truth seems to be that everybody gets impatient, even the naives, with people they perceive as being “less skilled”.

CONCLUSIONS AND RECOMMENDATIONS

In the study reported here we measured the differences in attitudes in two different groups of subjects: a group of “developers” and a group of “naïve” users. The subjects were assigned to either group according to their answers to a survey. The same survey was used to measure the differences in their attitudes in general towards information system usability and in particular towards the user rights suggested by Karat in 1998 (Karat 1998). Karat’s user rights provide a convenient set of reasonable user-centered principles that we would hope prospective developers would embrace. But after 13 year of having been proposed, our study has found evidence that both kinds of subjects studied, developers and naïve users, still do not embrace some Karat's principles. Our results reveal an urgent need to educate both users as well as developers in the needs and rights of information system users.

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