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Evaluating IT Applications for Innovative Construction Management

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Summary
The construction management has been under pressure to reduce operating costs and to improve productivity using innovative information technologe (IT) solutions conformed to structural characteristics, site conditions and past experiences. Given the growing emphasis on effectiveness and efficiency in construction projects, there is an imminent need to develop a formal procedure to select the best IT application for each proposed construction project and research and development (R&D) project. As there are numerous factors that have to be considered in selecting appropriate IT in a given situation, decision-makers need to have multicriteria decision-making ability. To enable them to make the most appropriate decision in any situation, it is important that effective tools incorporating multicriteria decision-making techniques are available. In this paper, an Analytic Network Process (ANP) model is conducted for the selection of appropriate IT application for innovative construction management prior to construction or research. The paper concludes that the ANP is a viable and capable tool for conducting IT application selection in multicriteria decision-making environment.

1 Introduction
Construction management aims to provide professional service that applies effective, efficient and economical management techniques to the design, planning, procurement, and construction of a construction project lifecycle from inception to completion for the purpose of controlling time, cost, quality, safety, healthy and pollution, etc. (CMAA 2003). According to the *PMBOK® Guide* (PMI 2000), there are five process groups in project management, including initiating processes, planning processes, executing processes, controlling processes and closing processes. Despite there are similar kinds of process groups in construction management, the construction industry has its specific contents of process groups in project management such as the generic design and construction process protocol (GDCPP) on construction projects (Kagioglou *et al*. 1998), where the processes of construction management were divided into four broad stages with respective ten phases within them as presented below:

- Pre-project stage:
  - Demonstrating the need
  - Conception of need
  - Outline feasibility
  - Substantive feasibility study and outline financial authority
- Pre-construction stage:
  - Outline conceptual design
  - Full conceptual design
  - Coordinated design, procurement and full financial authority
- Construction stage:
  - Production information
  - Construction
- Post completion stage:
  - Operation and maintenance

On the other hand, the design and construction process was also mapped into eight sub-processes (Activity Zones), including Development, Project, Resource, Design, Production,

Facilities, Health & Safety, Statutory & Legal, and Process Management. Although some leading construction enterprises such as Alfred McAlpine, AMEC, BAe, BNFL, CRISP, IAI, Carillion, and Christiani Nielsen, etc. have adopted the GDCPP (Thorpe 2001), the process protocol is still under development so as to consummate its broad feasibility and adoptability in the construction industry. On the other hand, the applications of IT in construction management can only be easily adopted by construction managers or contractors if such applications are developed to deal with management operations in specific processes in construction projects. However, the problem to select appropriate IT applications for innovative construction management has not been solved despite numerous R&D outputs have been fast accumulated in the past ten years. For this purpose, this paper will focus on developing decision support model for contractors to select appropriate IT solutions.

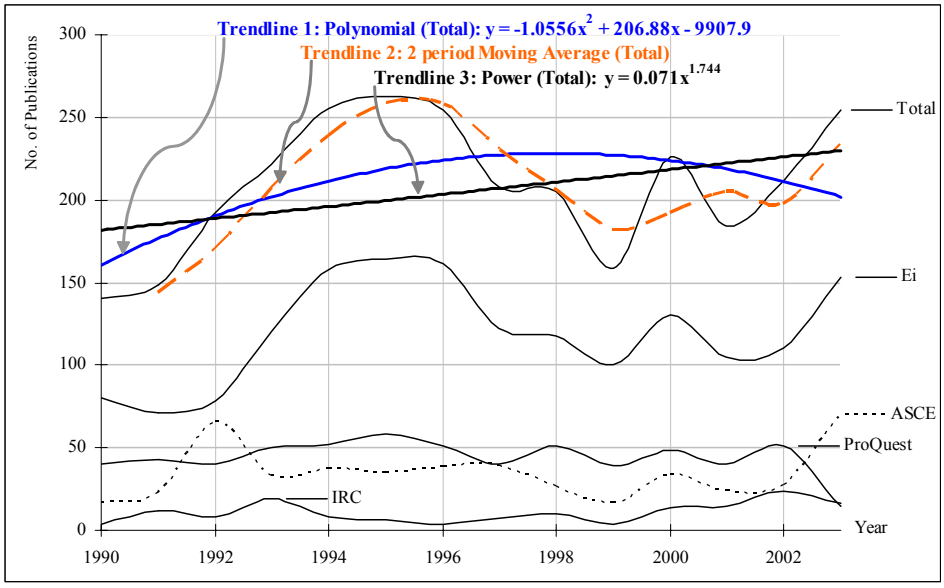
2 Innovative IT applications

In order to identify mature IT applications in the construction industry, we conducted a comprehensive literature review on academic and professional publications. It has been observed that while the construction industry is familiar with the use of a few general commercial computer software applications for construction management such as computer-aided design (CAD) tools, construction estimation tools, and construction scheduling tools etc. (AGC 1996, Tang 2001, and Green 2003), the outputs of academic research for innovative IT applications have been abundant. As shown in Table 1, since 1990 the use of IT in the construction industry began to increase significantly (Green 2003).

Table 1: Publications for Innovative IT applications since 1990

Organization	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
ASCE	16	23	66	33	37	35	38	39	26	16	34	24	27	70
EiEV2	80	71	78	120	158	164	161	122	118	100	130	105	110	153
IRC	4	12	8	19	8	6	4	7	10	4	14	15	24	16
PQDD	40	43	40	50	52	58	51	40	51	39	48	40	51	15
Total	140	149	192	222	255	263	254	208	205	159	226	184	212	254

Chart



Note: ASCE- American Society of Civil Engineers, U.S.A.
EiEV2- Engineering Village 2, Elsevier Engineering Information Inc., U.S.A.
IRC- The Institute for Research in Construction, National Research Council, Canada
PQDD- ProQuest Digital Dissertations, UMI (University Microfilms), U.S.A.
2003*- Data collected as of July 2003.

Further data analysis of the total number of these applications results in three statistic lines (see Table 1). The regression analysis is used to conducted statistic analysis. The regression analysis is a form of statistical analysis used for forecasting, which estimates the relationship between variables so that a given variable can be predicted from one or more other variables. By using regression analysis, one can extend a trendline in a chart beyond the actual data to predict future values. Firstly, Trendline 1 gives the result from polynomial regression analysis; it reflects that the research outputs of innovative IT applications claimed a top around 1999 and the trendline starts to decline, which is consistent with the notable depreciation at the same period on the NASDAQ Chart (Schultze and Schulz 2002). Secondly, Trendline 2 illustrates the result from a 2 period moving average regression analysis. The moving average is a sequence of averages computed from parts of a data series, which smoothes out fluctuations in data and shows the pattern or trend more clearly. It shows that research outputs of innovative construction IT applications reached its peak between 1995 and 1996. During this period most contractors were planning to invest in IT regardless of their profits, and profitable firms more frequently believed that IT yielded a cost and market advantage (AGC 1996). Trendline 2 began to climb up from the valley at 1999. Thirdly, Trendline 3 indicates the result of the power regression analysis, which gives a curved line that is used with data sets that compare measurements that increase at a specific rate; it indicates a long-term upward tendency of research outputs in innovative IT applications.

For the two regression models conducted for Trendline 1 and Trendline 3 in Table 1, the y represents the total number of publications for innovative IT applications in a year, and the x represents the number of the year in which the total number of publications on innovative IT applications are to be examined. According to the statistic result based on the 2 period moving average regression analysis and the power regression analysis, the total number of publications on innovative IT applications increases with the increase of time.

However, factors that inhibit a higher IT take-up in the construction industry have also identified through a number of surveys of the use of IT carried out in many countries for a variety of purposes (Howard, et al. 1998). For example, an annual survey of information technology practices in the construction industry recently conducted by ZweigWhite (2002) found that 64% of the 135 firms responding to a 188-item survey in January and February 2002 reported their improvements to communications and connectivity as their biggest IT successes. But 27% reported problems with remote access and communications as their biggest IT failure. In addition, a five-year trend toward more complex office networking was found to continue. Every firm responding had at least one local area network and 94% have at least one leased-line, full-time Internet connection. All but 5% have public Websites. Some 49% reported there were plans to implement a network or intranet. On the other hand, an eight-month research project was conducted in 2000 in order to identify the engines for change to meet the challenges set by C21 (1999) for the construction industry in Singapore to become a world-class industry (Dulaimi, et al. 2001), and the research revealed that the absence of strategic development and utilization of IT was the second major problem faced by the construction industry in Singapore, and thus prevented companies from achieving significant improvements in their activities. According to the results from these surveys, IT could not be developed and utilized to an optimal level due to the perceived high start-up costs involved. This leads to low level of use of IT in the company. Many firms use IT for simple word processing and spread sheet functions, and do not exploit other potential such as for e-commerce, Internet and even email. Construction industry participants also could not use more IT because of the lack of a standardized system of classifying and sharing of information to allow increased usage of IT. As a result, the following major problems are identified which exist on the way to successful implementation of IT (Tang 2001):

- lack of local construction based and user-friendly IT applications for conducting effective and efficient construction management,

- absence of reengineering in construction management to widely combine information and communication technologies (ICTs) across disciplines,
- low awareness at management levels of the potential benefits of high-level integrated implementation of IT in construction management,
- high cost on initial development and uncertain return on investment, and

low IT literacy among construction personnel to initiatively increase use of IT as an integrator in construction management.

3 Innovative construction management using IT

The fact that the rate of IT take-up in the construction industry does not follow the upward tendency of the R&D of IT innovation in construction management indicates that the R&D in construction IT has to work out some cost-benefit, high-efficient, and user-friendly solutions for conducting effective and efficient project management. As a matter of fact, there are many evidences of successful innovative IT applications in project management. For example, Thomas and Bone (2000) examined three major infrastructure projects in UK in order to demonstrate how innovation contributed to achieving challenging targets set by Egan (1998) for the construction industry, and they found that the technical innovation through IT adoption is the second most frequently emerged item among fourteen improvement areas in these construction projects. The authors of this paper further studied their report and found the three innovation themes include supply chain management and partnering, risk and value management, and technical innovation, which were regarded as three areas of innovation in the report (Thomas & Bone 2000). These themes can also be used to indicate the degree of adopting IT innovation in these construction projects. Thus, this paper provides a set of indicators to evaluate various IT applications for innovative construction management so as to find the best IT solution for contractors at construction planning stage in order to help them to achieve the Egan improvement targets by using the selected IT solution.

Table 2 gives a list of selected indicators for innovative construction management using IT. There are three main kinds of indicators summarized in Table 2, including Egan improvement targets, Project management innovation themes, and Academic responses to industry challenges.

Table 2: Indicators for innovative construction management using IT

(EIT) Egan improvement targets (Egan 1998, and Thomas & Bone 2000)			
(CPC) Capital cost (-10%)	(PDB) Predictability (+20%)		
(CTT) Construction time (-10%)	(PDT) Productivity (+10%)		
(DFT) Defects (-20%)	(TOP) Turnover & Profits (+10%)		
(ADT) Accidents (-20%)			
Project Management Innovation themes (Thomas & Bone 2000)			
(SCAMP) Supply chain management and partnering			
(TIP) The initiative process	(COC) Co-ordinating committee		
(DRP) Dispute resolution procedure	(FAE) Facilitator & monitoring and performance evaluation		
(INC) Internal communications	(CAP) Contractual and Partnering innovation		
(DAC) Design and construct contract	(PCA) Preferred contractor approach		
(RIVLM) Risk and value management			
(DSM) Disposal of surplus material on site	(MIG) Minimization of import of granular materials		
(ALD) Alternative designs	(SCL) Stabilized capping layer		
(SWM) Site-won materials	(STD) Structural redesign		
(RIT) Reducing imported topsoil	(MMF) Mammal fencing		
(TENIT) Technical innovation			
(EDM) Electronic data management	(OBM) Observational method		
(AMS) Modern asset management strategy	(EMP) Environmental programme		
(ARTIC) Academic responses to industry challenges (Luck, et al. 1997)			
(IC1) To place greater emphasis on the assessment of the impact of buildings on the environment.			
(IC2) To translate the client's expectations from the initial briefing process into a specification of services.			
(IC3) To place more importance on IT support to construction site processes.			
(IC4) To integrate the processes of design, construction and operation of buildings.			
(IC5) To capture final built form upon completion using built drawings or building model.			
(IC6) To place greater emphasis on post occupancy evaluation of the interaction of people and buildings.			
(IC7) To conduct supply-chain management of contractors, sub-contractors, specialists and suppliers.			
(IC8) To evaluate the constructability of design.			
(IC9) To systematically study buildings in use for information about performance and guidelines.			
(IC10) To use green design information.			
(IC11) To link up the flow of information amongst project participants.			
(IC12) To enable performance prediction tools as an integrated suite of tools with appropriate user interfaces.			
IT Innovation themes (Luck, et al. 1997)			
(ITIV) Visualisation			
(VBM) Buildability model	(V3D) 3D model	(VVR) Virtual Reality	(VMM) Multi-media
(VVV) Visualisation	(VRM) VRML	(VQT) QuickTime VR	(VCD) CAD
(ITII) Intelligence			
(IKB) Knowledge-base system	(IDM) Data mining	(ICR) Case-based reasoning	(IEM) Energy modeling
(IKM) Knowledge management		(IKE) Knowledge elicitation	(IIM) Intelligent material
(ITIC) Communication			
(CDC) Data communication	(CBC) Bar-coding	(CSC) Site communication	(CSW) CSCW
(CWC) Wireless communication	(CIN) Internet	(CAI) Auto identification	(CEC) Ecommerce
(COD) Online product database	(CIA) Intranet	(CPJ) Paperless jobsite	
(CAC) Automated data capture	(CED) EDI	(CES) Exchange standards	
(ITIT) Integration			
(IDB) Database	(IID) Integrated database	(IDW) Data warehousing	
(IOO) Object-oriented programming	(IOM) Object modeling	(IOL) Object libraries	
(IIM) Information management	(ICE) Concurrent engineering	(IPM) Product modeling	
(IDI) Data integration standards			

In order to use these indicators to evaluate and select the best IT solutions for project management in the appointed construction project, the authors of this paper further developed a decision-making model in which all these indicators are integrated into an Analytic Network Process (ANP) and the ANP model is described in Figure 1.

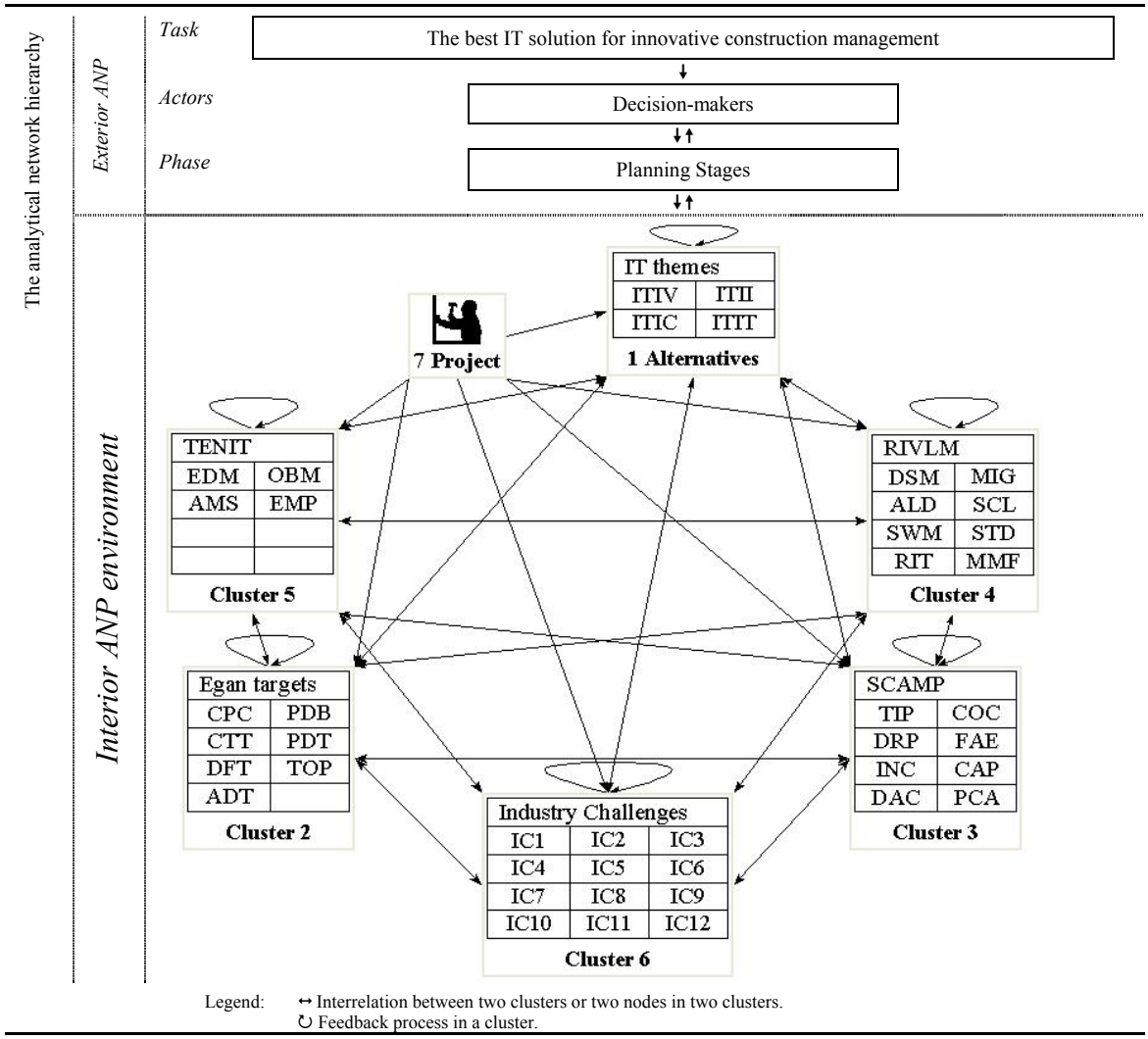


Figure 1: A decision-making model for construction IT applications evaluation

The ANP decision-making model for construction IT applications evaluation includes an exterior environment and an internal environment. In the exterior ANP environment, the downward arrow indicates the process of transferring data required by the ANP, the upward arrow indicates the process of feedback with evaluation results from the ANP, and the feedback process (loop) between the exterior environment and the internal environment indicates a circulating pipe for environmental priority evaluation of alternative IT solutions for innovative construction management.

In the internal ANP environment, connections among seven clusters and 50 nodes are modeled by two-way and looped arrows to describe the interdependences existed. The seven clusters are IT Solution Alternatives (Cluster 1), Egan improvement targets (Cluster 2), Supply chain management and partnering (Cluster 3), Risk and value management (Cluster 4), Technical innovation (Cluster 5), Academic responses to industry challenges (Cluster 6) and Project character (Cluster 7). In correspondence with the seven clusters, there are 50 nodes including four nodes in Cluster 1, seven nodes in Cluster 2, eight nodes in Cluster 3, eight nodes in Cluster 4, four nodes in Cluster 5, twelve nodes in Cluster 6, and seven nodes in Cluster 7. Concerning the interdependences between any two clusters and any two nodes, the ANP model structured here is a simple ANP model containing feedback and self-loops among the clusters, but with no control model, because there is an implicit control criterion with respect to which all

judgments (paired comparisons) are made in this model: IT solution for innovative construction management. For example, when comparing the node Disposal of surplus material on site (DSM) in cluster Risk and value management (Cluster 4) with node Internal communications (INC) in cluster Supply chain management and partnering (Cluster 3), the latter is obviously more important for adopting IT solutions, and similarly the relative importance of the clusters can be decided under the same implicational criteria. Table 1 lists the indicators used in constructing the ANP model and the corresponding references from which the indicator is retrieved.

There are 39 kinds of IT applications involved in the four IT themes summarized in Table 2, although the ANP model conducted in Figure 1 does not provide an alternative cluster for all of them and considers their four IT belongingness only, specific IT solutions such as e-commerce system and project management information system can also be evaluated as specified items in the alternative cluster in the ANP model. In other words, the ANP model conducted in Figure 1 can be generally employed to evaluate any IT solution of the same kind. With the help of the ANP model developed in this research, the authors of this paper further studied all publications listed in Table 1 and found that the most mature IT applications in construction management exist in the following three areas:

- Procurement: E-Commerce System
- Automatic Identification: Barcode and Radio Frequency Identification System
- Documentary: Construction Project Information System

The implementation of these IT applications has enabled contractors to achieve high effectiveness and efficiency in construction management.

4 Conclusion and Recommendations

This paper presents three appropriate IT applications for innovative construction management based on a comprehensive literature review related to the R&D of IT applications in the construction industry in the past ten years, as well as evaluation results from the ANP decision-making model. The three types of IT applications, including e-commence system for procurement of construction material and equipment, bar-coding and RFID system for construction material and equipment management on site, and construction management system for documentary and knowledge management, are the primary means of IT solutions for innovative construction management.

This paper contributes to existing theory of IT applications in construction in forms of statistic analyse and decision-making model, which partially overcomes the essential problem in IT applications in construction management: the lack of effective quantitative analytical result and decision-making support. Specifically, this study has made the following contributions:

- This research has developed an ANP decision-making model for adopting IT applications in construction. The ANP model can be used to select the best IT solution for innovative construction management.
- The primary IT applications selected for innovative construction management from the ANP model are e-commence system for procurement of construction material and equipment, bar-coding and RFID system for construction material and equipment management on site, and construction management system for documentary and knowledge management.

The ANP model can be further developed to a web-based environmental information and knowledge management system for contractors to select their primary type of IT application in construction. Besides the development of the decision-making system, further research is also required in the development of fully user-oriented tools of the three primary types of IT applications, and their integration in a prospective system. In summary, this paper has identified a framework for developing a quantitative approach to IT application in construction, and three

primary IT applications for innovative construction management through the ANP decision-making process, the decision-making model and the selected essential IT applications for innovative construction management have provide a good starting point for IT in practice as well as for further research in this area.

5 References

AGC (1996). Reader Profile: Constructor Readers Are Your Best and Future Customers. *Constructor Magazine*. The Associated General Contractors (AGC) of America. <http://www.agc.org/content/public/NewsBulletins/reader_profile.inc> (9 February 2004).

C21 (Construction 21 Steering Committee) (1999). Re-Inventing Construction. Ministry of Manpower and Ministry of National Development, Singapore.

Deloitte & Touche (2000). *Insights in Construction: Fourth Report on the Nation's Leading Construction Companies*. A Joint Survey by Deloitte & Touche and The Associated General Contractors of America. <http://www.deloitte.com/dtt/cda/doc/content/AGCfinal.pdf> (9 February 2004).

Dulaimi, M. F., Ling, F. Y. Y. and Ofori, G. (2001). Building a World Class Construction Industry: Motivators and Enablers. Department of Building, School of Design and Environment, National University of Singapore. Singapore: Singapore University Press Ltd.

Egan, J. (1998). Re-thinking construction. DERT, London.

Green, S. (2003). Technology Foresight Report: Progress through Partnership (1995). In Construction Reports 1944-98. Edited by Murray, M., and Langford, D. (2003). Blackwell Science Ltd. UK. 164-165.

Ho, F. W. H. (2002). Hong Kong as an Information Society. (2002 Edition) Technical Secretariat, Census and Statistics Department, Central Government Offices, Hong Kong Special Administrative Region, China.

Howard, R., Kiviniemi, A. and Samuelson, O. (1998). Surveys of IT in the Construction Industry and Experience of the IT Barometer in Scandinavia. *ITcon: Electronic Journal of Information Technology in Construction*. Vol.3, 45-56. <http://www.itcon.org/1998/4/paper.pdf> (9 February 2004).

Luck, R., McGeorge, D. and Betts, M. (1997). Research Futures: Academic Responses to Industry Challenges. Construction IT Centre of Excellence. UK.

Schultze, O. and Schulz, B. (2002). Nasdaq Composite-Analyse vom 14.06.2002. <http://www.buero-dr-schulz.de/DAX/DAX-Archiv/15_06_2002/indexcompx.html> (9 February 2004).

Tang, H. (2001). Construction for Excellence: Report of the Construction Industry Review Committee. Central Government Offices, Hong Kong Special Administrative Region, China.

Thomas, G. and Bone, R. (2000). Innovation at the cutting edge: The experience of three major infrastructure projects. CIRIA Publication C548. London.

ZweigWhite (2002). 2002 Information Technology & E-Business Survey of A/E/P & Environmental Consulting Firms. ZweigWhite. <http://www.zweigwhite.com/cgi-

local/SoftCart.exe/bookstore/p-svinf03.asp?L+aa0019820+lylp8645ffd662d6+1076320668> (9 February 2004).