ELSEVIER

Information & Management 39 (2001) 109–116

INFORMATION & MANAGEMENT

www.elsevier.com/locate/dsw

# Criticality of data quality as exemplified in two disasters

Craig W. Fisher[a,*], Bruce R. Kingma[b]

[a]*Information Systems, Marist College, Poughkeepsie, NY 12601, USA*
[b]*School of Information Studies, Syracuse University, Syracuse, NY 13244, USA*

Accepted 18 January 2001

**Abstract**

The explosion of the space shuttle *Challenger* and the shooting down of an Iranian Airbus by the USS *Vincennes* were the result of two serious consumer software and management errors. Both disasters have been reviewed in detail in the literature, providing a variety of plausible explanations for the cause of the disasters. However, our review sheds new light on the problem. Disasters such as these certainly involve many factors and we do not claim to be purporting a new single factor theory. But we show that there were visible data-quality problems in the systems. After discussing the importance of data quality, we point to the specific problems in these two cases. It is believed that management, especially in a world so dependent upon information, should pursue an aggressive plan of treating information as a critical product. © 2001 Elsevier Science B.V. All rights reserved.

*Keywords:* Data quality; Information; Challenger; Vincennes

## 1. Introduction

Poor data quality is prevalent in both private and public sector organizations, yet the public hears little about data quality when major disasters are reviewed. Instead, psychological and sociological theories, such as groupthink, macho, and *can-do* attitudes, framing of the question, public pressure, human factors, organizational decay, bureaucracy, etc. are used to explain the causes of the disaster. These theories are important to help explain flawed decision-making, however, too little emphasis has been given to data quality during reviews of major disasters.

Decisions are often based on available information. If this is flawed, or the process of integration of the data is flawed, or its communication is flawed, then decisions based on that data are more likely to be flawed. This paper reviews two case studies involving flawed decision-making that have received much attention in the literature, but little attention from a data-quality perspective. These are the space shuttle *Challenger* and the USS *Vincennes*/Iranian Airbus disasters.

NASA launched the space shuttle *Challenger* on 28 January 1986 amid internal controversy about the safety of the O-rings in cold temperatures. The Presidential Commission that investigated the disaster cited flawed decision-making for allowing the launch in the face of evidence suggesting a possible problem. Many reasons have been given for the flawed decision-making; however, attention to certain data-quality problems was noted. These flaws in the *Challenger* decision-making process fall into five categories: accuracy, completeness, consistency, relevance, and fitness for use.

* Corresponding author. Tel.: +1-845-575-3000;
fax: +1-845-575-3605.
*E-mail address*: craig.fisher@marist.edu (C.W. Fisher).


PII: S0378-7206(01)00083-0

The USS *Vincennes* mistakenly shot down an Iranian Airbus on 3 July 1988, killing 290 civilians. Several explanations have been given for the flawed decision to attack a civilian aircraft, but data-quality problems were paramount. The flaws occurred in the categories of: accuracy, completeness, consistency, fitness for use, and timeliness.

The purpose of this paper is to review the disasters from a data-quality perspective. We argue that management should treat information as a critical product and not merely as a byproduct of processes [20]. An aggressive approach to managing information might have avoided the data-quality problems.

## 2. Data quality

Data quality is one of the critical problems facing organizations today. As management becomes more dependent on information systems to fulfill their missions, data quality becomes a larger issue in their organizations. Poor data quality is pervasive and costly [31,36]. "There is strong evidence that data stored in organizational databases are neither entirely accurate nor complete" [23]. In industry, error rates up to 75% are often reported, while error rates up to 30% are typical [35]. Problems with data quality may lead to real losses, both economic and social. Davenport states, "no one can deny that decisions made based on useless information have cost companies billions of dollars" [14].

Poor data quality has many impacts on decision-making. People make choices based on limited resources (data), and misinformed people tend to make poor decisions [22]. It is clear that wrong data is likely to result in wrong decisions.

## 3. Data-quality variables

While there is no single definition of data quality, accuracy, timeliness, consistency, completeness, relevancy, and fitness for use are among the variables most frequently used [51].

*Accuracy* generally means that the recorded value conforms to the real-world fact or value. Accuracy refers to lack of errors and is considered by consumers of data to be the most important characteristic of data quality [3].

*Timeliness* implies that the recorded value is not out-of-date. Data must be available in time to influence the decision, and therefore can vary based upon the decision-maker and circumstance; a strategic planner may use information that is several years old, but a production manager must have recent data [4].

*Completeness* refers to "the degree to which values are present in a data collection". It focuses on whether all values for all variables are recorded and retained.

*Consistency* means that the representation of the data values is the same in all cases. It implies that there is no redundancy in the database and that referential-integrity is enforced.

Data *relevance* refers to the applicability of data in a particular issue by a particular user [47]. Relevant data can be used directly in solving a business problem.

Data quality may be best defined as *fitness for use* [44]. Data must be presented in a format that serves the user's purpose and stated in terms familiar to that user. Fitness for use is relative; what may be useful to engineers may not be useful to administrators. The format of information presentation influences the choice processes of decision-makers [41,43].

There may be relationships between these variables. Ballou and Pazer found that when timeliness is critical, more attention should be paid to accuracy, and vice versa [2]. Kacmer [21] found an interaction between format and user response accuracy, where text displays led to fewer errors than graphical ones.

## 4. Moderator variables

Moderator variables influence the way that decision-makers use information. Three factors to consider are: information overload [48], experience levels of the decision-makers [33], and time constraints [54].

### 4.1. Information overload

This occurs when there is too much information and too little time to respond. Normally, there should be a balance between processing time and the information being processed. Information overload affects data quality through filtering (completeness), erroneous responses (accuracy), and time (timeliness). Many researchers have discussed its impact on data quality [1,6,9,10].

### 4.2. Experience level

This may seem important, but there are conflicting implications. On the positive side, experienced professionals have an increased sensitivity to the possibility of errors. Direct experience with errors improves performance in detecting them. If a decision-maker is familiar with the data, the decision-maker may be able to use intuition to compensate for problems [12]. Fisher [17] found that experts pay more attention to information about data quality than novices. However, there are potential dangers in assuming that an intuitive feel for the data is positive. Prior experience influences confidence, but may not influence accuracy [32]. It is possible that a "feel for the data" might allow a person to rely too much on perception. For example, in Gilliland's Business Relocation task, the experimental data on Michigan was set up as the worst-rated relocation alternative. However, many people chose Michigan, because they had prior positive experience with Michigan [19]. People without knowledge of Michigan correctly placed it much lower. This suggests that a novice may be more attentive to new information than an expert. A stock forecast task, in which novices were found to be more accurate than "semi-experts", supports this [53].

### 4.3. Time constraints

Time is a critical variable in many processes. Time constraints cause processing changes and lessen accuracy. Time pressure is experienced whenever the time is perceived as being shorter than normally required [45]. Decision-makers may use simplifying heuristics under time pressure [30,40,50], may attempt to work faster [8], or may process only a subset of the total information. Under moderate time pressure, subjects accelerate and become more selective. Under severe time pressure, people accelerated, filtered, and relied upon more attribute-based processing.

## 5. The space shuttle Challenger

NASA launched the space shuttle *Challenger* on 28 January 1986. Moments after lift-off, solid rocket booster O-ring joint seals burst, resulting in an explosion that destroyed the shuttle and killed seven people. There is no doubt that the failed O-ring caused the accident [38]. The O-rings did not reseal properly after being subjected to pressure during lift-off under cold weather conditions. The cold, brittle O-rings allowed gases to leak; this then caught fire, burnt through the sides of the fuel tanks, and caused the explosion [7]. NASA had been aware of the O-ring problem for several years and had conducted special investigations 6 months before the accident. The results of these investigations indicated that problems remained. In addition, an engineer, R. Boisjoly, wrote a letter in July 1985 stating that the O-ring problem could cause a catastrophic failure. The Presidential Commission investigating the accident found that NASA used a flawed decision-making process to approve the launch. The elements of the flawed decision-making process were incomplete and misleading information, conflicts between engineering data and management judgements, and a structure that allowed information about problems to bypass key managers [25].

There were four levels of reviews, as well as a final decision-making body, the Mission Management Team. Regardless of the status of other levels and components, failure to meet standards at any level could halt the launch process, e.g. Thiokol, Inc. was a Level IV contractor responsible for the solid rocket booster, a failed O-ring test at this level should have stopped the process.

At 17.45 h on 27 January, Thiokol objected to the launch, citing the engineers' lack of confidence of the O-rings in cold weather. This objection should have stopped the launch. However, the NASA Level III manager challenged Thiokol management, and, after 6 h of debate, Thiokol agreed to launch.

Several theories have been offered to explain NASA's flawed process. Some have highlighted the role of perception as a contributing factor. Some have argued that groupthink was a key factor, because NASA Level III managers deliberately controlled information feedback by not passing concerns to upper management. Additional theories address narcissism and organizational decay [42], interactions of images and technology [29], information format [49], incomplete information statistics [46], technology and organizational culture mismatches, economics and public pressure [52].

### 5.1. Management information system

A management information system (MIS) provides information to management in a usable form. A DSS uses a comprehensive database, mathematical models, and ad-hoc inquiry facilities. The comprehensive integrated database is at the heart of these systems. A key factor in their success is the quality of the data behind the system, while the database should have minimal redundancy and maximum reliability [27].

There were serious data-quality problems in NASA's MIS, including database inconsistencies and errors, reporting violations, lack of modeling for trend analysis, and poor integration of components and tests.

### 5.2. Database

There were several types of problems in the NASA database. First, the O-rings were misclassified and misreported. In some cases, the O-rings were classified as redundant meaning other equipment backed up the O-rings. In other cases, the redundancy was not reported, and this designated the O-rings as critical equipment vital to the success of the mission. This is therefore both a *consistency* and *accuracy* problem. A data dictionary with one definition for each data element might have prevented the miscoding information in the database [16].

A second failing was that critical components were not cross-referenced with test plans. It was almost impossible for NASA to verify that hundreds of critical components had received the right tests, because there was no list that cross-referenced them with components (*completeness*). The dictionary should have contained relationships between all related data elements. These have been available since the mid-1970s [26]. Cross-references would have made the critical items list a better management tool.

A third failing was that it was *inaccurate*. One manager had proposed that NASA close the O-ring problem as resolved, but there was no agreement to do so. Despite this, the O-ring issue was closed without an authorizing signature.

### 5.3. Reporting

The Rogers Commission stated that there were flaws in the reporting system. NASA middle-level managers did not inform upper managers about Thiokol's objections. There were unreported waivers of launch constraints; all should have been reported to upper management. These violation flaws left upper management with *incomplete information*.

NASA middle managers did not alert system reliability and quality assurance engineers (SR&QA) to the launch debates, as required. Thus, SR&QA had *incomplete information*. A database combined with mathematical models allows decision-makers to examine relationships between variables. This facility could have helped articulate the *relevancy* of temperature to O-ring erosion incidents and do so *in time*.

In fact, the data needed to analyze the temperature effects on the O-rings was available at the time of the launch, but was not used correctly. The Thiokol engineers used *incomplete* data in their regression graphs [46]. Bunn, the Marshall Space Center Director, said, "Even the most cursory examination of failure rate should have indicated that a serious and potentially disastrous situation was developing" [38].

For managers to use visual information, it must be in a form acceptable to them [28]. Engineers used charts that were in a format familiar to engineers, but not well understood by the decision-makers (*fitness for use*). Thus, while the Thiokol engineers believed that the shuttle was not safe, they had difficulty articulating that belief.

Interaction between *fitness for use* and *domain-specific experience* also occurred: it is difficult to see interrelationships between components and only the most experienced people develop insights into component interrelationships [34].

In the *Challenger* case, partly due to staff reductions, NASA personnel became buried by information overload. Consequences included the difficulty of finding *relevant* data, a decrease in innovation in decision-making, a lack of ability to *verify data*, and an inability to determine *data completeness*.

Filtering of information to reduce its volume may remove data necessary for a *complete* picture. For example, the original objections by the Thiokol engineers clearly stated, "O-ring temperature must be greater than or equal to 53 degrees F at Launch". However, the memorandum detailing Thiokol's final management position failed to include this statement.

The single, foremost expert on the O-rings, Roger Boisjoly, wrote letters and made mid-night phone calls in an attempt to stop the launch. Administrators, with much less domain-specific experience overrode his objections and ordered the launch.

## 6. The USS Vincennes and Iran Flight 655

On 3 July 1988, the US Navy Cruiser USS *Vincennes* fired two missiles at an aircraft it believed to be a hostile military jet in attack mode. State-of-the-art technology aboard the *Vincennes* apparently misidentified the aircraft, resulting in the destruction of an Iranian Passenger Airbus (Iran Flight 655). Data-quality problems may have contributed to the decision that brought 290 people to their deaths.

At least four official investigations of the USS *Vincennes* incident were conducted. From 13 July until 19 July 1988, Admiral Fogarty conducted the first, which was published on 28 July 1988. The second was a Medical Report, dated 7 August 1988; it was conducted to help clear discrepancies between the crews' report of the aircraft's posture and the computer system's report of the aircraft's posture. The US Senate Committee on Armed Services conducted the third investigation in September 1988. Finally, the Defense Policy Panel of the House Armed Services Committee conducted the fourth in October 1988 [15,37].

Analysts and scholars have offered multiple explanations as to the cause of this disaster, including an inexperienced crew having poor reaction to combat [5], insufficient time to verify data, incomplete training, a computerized battle-management system that was designed for the open sea instead of the closed-in Persian Gulf [11], hostilities in the area that created an environment conducive to incorrect interpretations [13], and failure of the state-of-the-art battle management system [40].

Rogers said, "The USS *Vincennes* is one of the US Navy's newest and most technically advanced ships, an anti-air warfare (AAW) cruiser equipped with the world's finest battle management system. Aegis is capable of simultaneously processing and displaying several hundred surface and air radar tracks. Its great tactical advantage is the speed with which it determines course, speed and altitude." [39].

Research has shown that the Aegis System did not make errors in identification, but that errors manifested themselves in the socio-technical seam of the overall system. An MIS includes the interfaces and people that use those interfaces. When looked at from this perspective, data-quality problems become apparent, and knowledge of them might have prevented the disaster.

### *6.1. Data quality*

Data quality was a major factor in the USS *Vincennes* decision-making process. Problems were manifested in the use of wrong target identifiers, incomplete information, conflicting information, voice-communication problems, and information overload. In addition, there may have been interactions with experience level, time pressure, and information overload.

When multiple USS ships simultaneously identify an aircraft, multiple track numbers are initially assigned to the entity. The Aegis System resolves these duplicate numbers to a single, unique track number, TN*xxxx*. However, the system recycled the numbers that had been assigned initially; this reuse of the identifiers was at the heart of the disaster. An *inconsistency* error occurred at the socio-technical seam, the interface. Human users may see the initial number and not realize that the computer has replaced it with another; there was no system alert to notify users of the system's reuse of the number. In the example, a target identifier, TN4474, was used twice — once to identify Flight 655, and then (later) to identify a fighter plane that was 110 miles away. The identifier used to track Flight 655 changed from TN4474 to TN4131. Seconds before firing, the *Vincennes* Captain asked for the status of TN4474 and was told it was a fighter, descending and increasing in speed. He and his crew had been discussing and tracking the radar blip of Flight 655, and then confused its tracking number, TN4131, with the fighter's number, TN4474. When the Captain gave the order to fire, the *Vincennes* shot down TN4131 rather than TN4474. If the duplication of identifiers had been recognized, the involved parties could have avoided the disaster [15].

*Incomplete* information resulted from the computer-generated displays, large display consoles (LDCs), displaying objects as white dots in half-diamonds for hostile aircraft or in half-circles for friendly aircraft.

The relative length of the white lines projecting from the dots indicates course and speed. The use of relative length for speed restricts the use of relative length for size, and this deprived the *Vincennes*' officers of another visual check. A commercial airbus is much larger than a fighter and a size symbol linked to the air contact would have let the *Vincennes*' crew note that the Flight 655 contact was too large to be a fighter.

Information *inconsistencies* also complicated the decision-making process. Captain Rogers explained "... we had indications from several consoles, including the IDS operator, that the contact's IFF readout showed a mode III [civilian] squawk but more significantly to me, a mode II [military] squawk ... previously identified with Iranian F-14s was also displayed".

Another discrepancy was between the Aegis System's tapes and five crewmembers' reports (*accuracy*). The Aegis System's tapes and system data indicated that Flight 655 was in ascending mode; five crewmen operating separate consoles reported that the aircraft was descending. Captain Rogers stated that the aircraft was at an altitude of between 7000 and 9000 ft at the time of the shooting. Data captured from the system indicated that the aircraft was at an altitude of 13,500 ft. Captain Rogers explained that, "It looks like the system worked the way it's supposed to ... However, there are problems with the way the consoles are designed, the displays are presented, and the communication nets work" (*fitness for use*) [39].

### *6.2. Time*

Captain Rogers reported that he believed that the *time constraint*, less than 4 min, was critical in the decision-making process. In addition, his commanding officer did not have enough time to validate, as per normal procedures, the information that Rogers presented [39].

### *6.3. Experience*

A Captain with over 20 years of Naval experience made a faulty decision, but he had limited experience with the advanced technological battle management system and no combat experience. Admiral Fogarty requested a psychological evaluation of the Captain, officers, and crew. The team of psychologists reported that inexperience in warfare, stress, and misjudgements due to stress, and unconscious distortion of data played a major role in the crew's misinterpretation of the Aegis System data [18].

However, managers should ensure that systems maximize clarity of output if the systems are to be successful. The degree of instructiveness of the output can minimize the potential to misinterpret and distort data. Output quality is a top factor in information systems success [24].

## 7. Summary

It is clear that the quality of the information was not a top priority in either case. In the space shuttle *Challenger* case, there were 10 incidents of poor data quality spread over five of the six categories of data quality. In the USS *Vincennes* case, there were eight incidents of poor data quality spread over five of the six categories of data quality. Given that there are many other factors, psychological, sociological, communication, and cultural, it still remains difficult to believe that proper decisions could be made with so many examples of poor data quality. Management must be strong advocates of quality management.

## References


[1] J. Angus, Filter Info Fast, Information Week, 5 May 1997, p. 629.

[2] D.P. Ballou, H.L. Pazer, Designing information systems to optimize the accuracy-timeliness tradeoff, Information Systems Research 6 (1), 1995, pp. 51–72.

[3] D.P. Ballou, R.Y. Wang, H.L. Pazer, G.K. Tayi, Modeling information manufacturing systems to determine information product quality, Management Science 44 (4), 1998, pp. 462–484.

[4] D.P. Ballou, G.K. Tayi, Enhancing data quality in data warehouse environments, Communications of the ACM 42 (1), 1999, pp. 73–78.

[5] J. Barry, R. Charles, The inside story of how an American Naval Vessel blundered into an attack on Iran Air Flight 655, Newsweek, 13 July 1992, pp. 29–39.

[6] S. Belardo, H.L. Pazer, A framework for analyzing the information monitoring and decision support system investment tradeoff dilemma: an application to crisis management, IEEE Transactions on Engineering Management 42 (1995) 352–358.

[7] T.E. Bell, K. Esch, The fatal flaw in Flight 51-L, IEEE Spectrum 24 (2), 1987, pp. 36–51.

[8] H. Ben Zur, S.J. Breznitz, The effects of time pressure on risky behavior, Acta Psychologica 47, 1981, pp. 89–104.
[9] H. Berghel, Cyberspace 2000: dealing with information overload, Communications of the ACM 40 (2), 1997, pp. 19–24.
[10] M. Boles, Help! information overload, Workforce, 20 September 1997, p. 20.
[11] J.S. Bozman, Doubts on Aegis use in Gulf: Iran Airbus seen as victim of too much technology, Computerworld, 11 July 1988, pp. 1–6.
[12] I. Chengalur-Smith, D.P. Ballou, H.L. Pazer, The impact of data quality information on decision-making: an exploratory analysis, IEEE Transactions on Knowledge and Data Engineering 11 (6), 1999, pp. 853–864.
[13] Congress, US, The 3 July 1988 attack by the Vincennes on an Iranian Aircraft: hearing before the Investigations Subcommittee and the Defense Policy Panel of the Committee on Armed Services, in: Proceedings of the Second Session of the One Hundred Second Congress, US GPO Superintendent of Documents, Washington, DC, 1988.
[14] T.H. Davenport, Information Ecology, Oxford University Press, New York, 1997.
[15] K.A. Dotterway, Systematic analysis of complex dynamic systems: the case of the USS Vincennes, Naval Postgraduate School, Monterey, CA, 1992.
[16] C.W. Fisher, NASA's Challenger and decision support systems, The Journal of Computing in Small Colleges 9 (2), 1993, pp. 145–152.
[17] C.W. Fisher, An empirically based exploration of the interaction of time constraints and experience levels on the data quality information (DQI) factor in decision-making, University at Albany, Albany, NY, 1999.
[18] W.M. Fogarty, Formal Investigation into the Circumstances Surrounding the Downing of a Commercial Airliner by the USS Vincennes (CG 49) on 3 July 1988 (letter to Commander in Chief, US Central Command), Washington, DC: US Navy, 1988.
[19] S.W. Gilliland, L. Wood, N. Schmitt, The effects of alternative labels on decision behavior: the case of corporate site selection decisions, Organizational Behavior and Human Decision Processes 58 (3), 1994, pp. 406–427.
[20] K.T. Huang, Y.W. Lee, R.Y. Wang, Quality Information and Knowledge, Prentice-Hall, Saddle River, NJ, 1999.
[21] C. Kacmer, An experimental comparison of text and icon menu item formats, in: J.M. Carey (Ed.), Human Factors in Information Systems: an Organizational Perspective, Ablex, Norwood, NJ, 1991.
[22] B.R. Kingma, The Economics of Information: a Guide to Economic and Cost-Benefit Analysis for Information Professionals, Libraries Unlimited, Englewood, CO, 1996.
[23] B.D. Klein, User detection of errors in data: learning through direct and indirect experience, Paper presented at the AIS98, 1998.
[24] E.Y. Li, Perceived importance of information success factors: a meta-analysis of group differences, Information & Management 32, 1997, pp. 15–28.
[25] M. Maier, Space Shuttle Challenger Disaster, SUNY Binghamton, 1992.
[26] F.R. McFadden, J.A. Hoffer, Database Management, 2e, Benjamin/Cummings, Menlo Park, CA, 1988.
[27] R.J. McLeod, Management Information Systems: a Study of Computer-Based Information Systems, 6th Edition, Prentice-Hall, Englewood Cliffs, NJ, 1995.
[28] J.A. Meyer, The acceptance of visual information in management, Information & Management 32, 1997, pp. 275–287.
[29] M. Morgan, The Challenger decision: the interaction of image and technology, Human Systems Management 6, 1986, pp. 331–334.
[30] L. Ordonez, L. Benson III, Decisions under time pressure: how time constraints affect risky decision-making, Organization Behavior and Human Decision Process 71 (2), 1997, pp. 121–140.
[31] K. Orr, Data quality and systems theory, Communications of the ACM 41 (2), 1998, pp. 66–71.
[32] P.W. Paese, J.A. Sniezek, Influences on the appropriateness of confidence in judgement: practice, effort, information and decision-making, Organizational Behavior and Human Decision Processes 48 (1), 1991, pp. 100–130.
[33] J.W. Payne, J.R. Bettman, E.J. Johnson, The Adaptive Decision Maker, Cambridge University Press, Cambridge, 1993.
[34] C. Perrow, Normal Accidents: Living with High Risk Technologies, Basic Books, New York, 1984.
[35] T.C. Redman, Data Quality for the Information Age, Artech House, Norwood, MA, 1996.
[36] T.C. Redman, The impact of poor data quality on the typical enterprise, Communications of the ACM 41 (2), 1998, pp. 79–82.
[37] N.C. Roberts, Reconstructing combat decisions: reflections on the shootdown of Flight 655, Naval Postgraduate School, Monterey, CA, 1992.
[38] W.P. Rogers, Report of the Presidential Commission on the Space Shuttle Challenger Accident, United States Government Printing Office, Washington, DC, 1986.
[39] W. Rogers, S. Rogers, Storm Center: the USS Vincennes and Iran Air Flight 655, Naval Institute Press, Annapolis, MD, 1992.
[40] J.A. Savage, Could high-tech have beaten stress? Computerworld, 8 August 1988, p. 19.
[41] D.A. Schkade, D.N. Kleinmuntz, Information displays and choice processes: differential effects of organization, form, and sequence, Organizational Behavior and Human Decision Processes 57 (3), 1994, pp. 319–337.
[42] H.S. Schwartz, Organizational disaster and organizational decay: the case of the National Aeronautics and Space Administration, Industrial Crisis Quarterly 3, 1990, pp. 319–334.
[43] D.N. Stone, D.A. Schkade, Numeric and linguistic information representation in multiattribute choice, Organizational Behavior and Human Decision Processes 49, 1991, pp. 42–59.
[44] D.M. Strong, IT process designs for improving information quality and reducing exception handling: a simulation

experiment, Information & Management 31, 1997, pp. 251–263.
[45] O. Svenson, A. Edland, Changes of pressure under time pressure, choices and judgements, Scandinavian Journal of Psychology 28, 1987, pp. 322–330.
[46] L. Tappin, Analyzing data relating to the Challenger disaster, The Mathematics Teacher 87 (6), 1994, pp. 423.
[47] G. Tayi, D.P. Ballou, Examining data quality, Communications of the ACM 41 (2), 1998, pp. 54–57.
[48] R. Tetzili, Surviving information overload, Fortune, 11 July 1994, pp. 60–64.
[49] E. Tufte, Visual Explanations: Images and Quantities, Evidence and Narrative, Graphics Press, Cheshire, CT, 1992.
[50] G. van Bruggen, A. Smidts, B. Wierenga, Improving decision making by means of a marketing decision support system, Management Science 44 (5), 1998, pp. 645–658.
[51] R.Y. Wang, D. Strong, Beyond accuracy: what data quality means to data consumers, Journal of Management Information Systems 12 (4), 1996, pp. 5–34.
[52] D.A. Winsor, The construction of knowledge in organizations: asking the right questions about the Challenger, Journal of Business and Technical Communications 4 (2), 1990, pp. 7–20.
[53] J.F. Yates, L.S. McDaniel, E.S. Brown, Probabilistic forecasts of stock prices and earnings: the hazards of nascent expertise, Organizational Behavior and Human Decision Processes 49 (1), 1991, pp. 60–79.
[54] D. Zakay, S. Wooler, Time pressure, training, and decision effectiveness, Ergonomics 27, 1984, pp. 273–284.

**Craig W. Fisher** is an Assistant Professor of Information Systems at Marist College in Poughkeepsie, NY. He received his PhD in Information Science in 1999 from the University at Albany. He enjoyed a 20-year career at IBM where he advanced through various information systems middle management positions. He teaches Problem Solving and Programming, Information Systems Policy and Systems Design. His papers have appeared in the *International Academy for Information Management* (*IAIM*) *Proceedings*, *Information Systems Educator's Conference* (2000), and *The Journal of Computing for Small Colleges*.

**Bruce R. Kingma** is an Associate Professor and Associate Dean at the School of Information Studies, Syracuse University. He has a PhD in Economics from the University of Rochester. Professor Kingma's research interests include the economics of digital libraries, scholarly publishing, and library and nonprofit management on which he has published extensively including the following books: *The Economics of Information in the Networked Environment*, *The Economics of Access versus Ownership to Scholarly Information*, and *The Economics of Information*: *A Guide to Economics and Cost-Benefit Analysis for Information Professionals*.