2015

Cognitive Engineering: What's Old Is New Again

Ronald John Lofaro

COGNITIVE ENGINEERING: WHAT'S OLD IS NEW AGAIN

Ronald John Lofaro, PhD
Embry-Riddle Aeronautical University Worldwide, adjunct Associate Professor; (FAA ret.)
Orange Beach, AL 36561

The views and opinions expressed in this paper are solely those of the author. They do not necessarily represent the positions or policies of any private, public or governmental agencies

This paper presents what began as a specific task analysis methodology developed in the context of what then was called knowledge engineering. The resultant model was based on Fleishmann's concept of underlying abilities coupled Delphi techniques and small group dynamics. Core features were the use of small groups of Subject Matter Experts (SMEs) and, a highly structured workshop environment. The model was termed the Small Group Delphi Paradigm (SGDP). As time past, its usage in a variety of aviation venues, ranging from selection to training proficiency, resulted in modifications and refinements. Thus, it became more than just a task analysis even being used, e.g., in identifying civilian managerial and employee core competencies. However, it seemed that, while in the literature multiple times, there was not a measure of general useage. This is not the case today, as will be shown, plus ways to technologically up-date the SGDP.

Knowledge engineering (KE) is defined as follows: "... an engineering discipline that involves integrating knowledge into computer systems in order to solve complex problems normally requiring a high level of human expertise." (Feigenbaum and McCorduck, 1983). For a succinct overview of KE see Studer, Benjamins and Fensel (1998). Some of the possible uses and functions of KE: articulation and assessment of an issue/problem; development of a knowledge-based system structure for dealing with issues/problems; obtaining and structuring relevant information and knowledge; developing tests for validation of the obtained information/knowledge. Since the mid-1980's, KE has grown in use and importance concomitant with the advances in computer memory, capabilities and useage. Additionally, KE is often an iterative process with many challenges. Thus, KE can be seen as somewhat more art than engineering. There are no neat boundary lines as to what constitutes KE. Knowledge engineering is also linked to cognitive science and socio-cognitive engineering where the knowledge is produced by socio-cognitive aggregates (mainly humans); this was one rationale for the SGDP. Cognitive engineering (CE) areas include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training as these may relate to human-system design. Therefore, CE has mainly replaced KE as the term used in such efforts.

A subset of CE/KE is the Delphi technique/process. Traditional Delphi techniques include anonymity of response, multiple iterations, convergence of the distribution of answers and, a statistical group response (Judd, 1972). A seminal paper on the Delphi process was written by a then-Rand Corporation employee (Brown, 1968) and may be available from Rand or from American Society of Tool and Manufacturing Engineers (ASTME), now known as Society of Manufacturing Engineers.

A modification to Delphi processes is the small group Delpi paradigm (SGDP). The SGDP took the Delphi process in another direction by modifying it via merger with elements of group dynamics in order to have interactive (face-to-face) Delphi workshops. This modification resulted in a paradigm for using small groups of subject matter experts (SMEs). The SGDP can be used for any project that requires that a set of SMEs be used to identify, evaluate, and criticality rank tasks (an enhanced task analysis), identify core needs/skills, recommend modifications to equipment, procedures and training. Finally, the SGDP can be used to sharpen, modify and revise existing methodologies. As Meister (1985) had noted, “The (Delphi) methodology is by no means fixed…[it] is still evolving and being researched." This is as true

now as it was when Meister stated it. In point of fact, with the leaps in communication methods and related technology, even more so.

The Initial SGDP

The development of this modified Delphi, the SGDP, involved the merger of a specific knowledge engineering technique (Delphi), with Fleischmann's theories of underlying abilities (Fleishmann and Quaintance, 1984; revised 2000) and some principles of group dynamics. It was the result of a specific issue and difficult problem: to provide US Army Aviation Command with a unified aviator candidate selection test that also indicated which of the current rotorcraft would be the optimum operational aircraft for the candidate upon completion of initial training. The SGDP methodology was used in four workshops-one for each of the then-operational U.S. Army rotorcraft. These workshops had small groups of aviator SMEs, carefully selected and brought in from both the continental United States (CONUS) and overseas Army bases, in a highly structured set of face-to-face workshops sessions.

A major consideration in the SGDP design was the possible negative impact of using face-to-face groups for ratings and evaluations. Pill (1970) said that this may dilute the opinions of the real expert. This seemed a strange objection as the subject matter experts (SMEs) selected ARE the real experts. However, if what is meant is that one or more persons in a group may have more expertise in a specific area that is being worked on and the group would defer to them, then the reality (based on the author's conducting seven or so of these) is that the other SMEs recognize, welcome and use that expertise–as their goal is the best result/product possible.

Another objection is that the group dynamics may force ratings and analyses towards a mean or middle ground that does not fully reflect all the SME's views. There are two responses to this: the first is that true SMEs will not allow that to happen because they see themselves (and, are) THE experts.They want the SGDP products to demonstrate that expertise. Pride will forego them from "going along to get along." The second is that the instruction in group work, the trained facilitator and the iterative methodology used in accomplishing the sub-objectives/objectives are all structures in the SGDP process designed to ensure that this does **not** happen.

Therefore, at that time, the use of small groups of SMEs in a non-anonymous Delphi setting seemed to the author to offer strong points and benefits. Thereupon, this paradigm was first used in the development and fielding of a computerized test battery and algorithm that would both select U.S. Army aviator candidates for initial training and, indicate which of the types of operational helicopter they should go into for transition training. The U.S. Army Aviation Center successfully used this test battery and set of algorithms ("Multitrack") in selecting its rotorcraft aviator candidates for over 5 years.(Lofaro and Intano,1989; Lofaro, Intano and Howse,1990; Intano, Howse and Lofaro, 1991). As the author was told by United States Coast Guard (USCG) pilots who had come over from Army Aviation, while he was teaching for Embry-Riddle Aeronautical University (circa 2008), that some? all? of Multitrack was again in use by the Army.

In sum: In first developing and using the SGDP, circa 1985, (Lofaro, 1992a), these aspects of the traditional Delphi were maintained: specified objectives; iterative process; SMEs; consensus. Added to these were the use of small face-to-face groups and group dynamics training/exercises, a large read-ahead package for each SGDP participant, the use of a facilitator, strict protocols for the participants and sessions, as well as a sequential, step-wise plan of attack on the sub-objectives and objectives. Thus, traditional Delphi processes were modified into a new paradigm for small-group projects

The SDGP: Over The Years

This initial effort and the subsequent use of the resultant paradigm, SGDP, in other and varied venues have produced both highly accurate data (that were operationally implemented) and modifications to the SGDP. Every use of the basic SGDP model resulted in some modifications as the objectives are defined, the SMEs are selected and time limits are set. These many SGDP efforts resulted in sharpening,

modifying and revising the original methodology. Over the years, the SGDP...and revisions... have produced eight operational products in aviation, such as air traffic controller (ATC) and x-ray baggage screener selection tests, training criterion for rotocraft maneuver proficiency, crew resource management (CRM) performance evaluation, task analyses and, for the FAA, sets of highly specific managerial/employee core competencies. (e.g., Lofaro,1999; Lofaro, 1998; Lofaro, Gibb and Garland, 1994; Gibb and Lofaro, 1994; Gibb, Lofaro, et al. 1993; Lofaro 1992b). The SGDP has been used in many environments demonstrating a robust flexibility and generalizability of the paradigm. The extensions of the paradigm indicate that it has an applicability over many domains. For a fairly detailed exposition of each aspect of the SGDP, see Lofaro, R.J. and Maliko-Abraham, Helene.
Of particular note is that, circa 2009, the use of face-to-face groups in a Delphi has now become accepted. This is called the Mini-Delphi/Estimate-Talk-Estimate (ETE) with many variations. Some twenty-five years after the SGDP was devised, used and appeared in multiple publications, it has been re-discovered, as it were. More on this later.

The SGDP In 2014 and Beyond

On a personal level, the author is heartened to see his seminal concepts (the coupling of traditional Delphi methods with group dynamics and face-to-face sessions) seem to have become accepted, questions arose: What now? What are some current 2014 aviation issues (as well as prior but unresolved ones) which are both important and amenable to some form of the SGDP? What can modern technolgy offer in 2014 and beyond to the SGDP and, vice-versa? Some current issues,as well as some in the past that seem to re-emerge, are as follows:
Aircarrier upset training, training that the Colgan Air accident brought to the fore. In direct response to the Colgan crash, Congress passed the Airline Safety and FAA Extension Act of 2010, which mandated that the Federal Aviation Administration require pilots to complete 1,500 flight hours before they're allowed to fly commercially, up from just 250 hours before the act. While this new rule may do little to improve safety, it is exacerbating an already severe pilot shortage. Too few pilots are now available to replace the ones who are retiring. The pilot shortage is beginning even faster than expected. In that context, the new 1,500-flight-hour requirement is a particular problem. Both pilots involved in the Colgan crash had far surpassed 1,500 hours of flight time, so that requirment probably had little to no impact on the accident.
A historically low number of people are training to become pilots and, of those, only half are seeking a career with commercial airlines. For many would-be pilots, a main consideration is financial: while flight training costs between $60,000 and $70,000, entry-level pilot positions typically pay $25,000 a year or less. Furthermore, the financial turbulence that has plagued the airline industry since September 11, 2001, makes the profession somewhat less attractive to aspiring aviators. The existing workforce has been stretched even thinner by new anti-fatigue rules. Pilots were once required to have eight hours of time off between shifts; but now they must be given no less than ten hours. This particular anti-fatigue rule (see below) was empirically justifiable and it may well improve safety, but it also results in airlines' needing between 3 and 7 percent more pilots available ("on the clock") at any given time.
The FAA, while not yet issuing an Advisory Circular (AC) or a federal aviation regulation (FAR), has issued a document called Airline Upset Recovery Training Aid, version 2. The issues seem to be use of a full motion flight simulator (FS) that will be part of an expected FAA pilot training rule by 2018 (Croft, John. 2014a); in-aircraft training and, swept wing jet aircraft specialized training . The American Airlines UPRT ground school with FS training, called advance aircraft manuevering program (AAMP), was seen by The National Transportation Board (NTSB) as possibly a contributing factor in the American Airlines flight 587/A300-600 crash in November, 2001 (Croft, John. 2014b).
We now return to that long-time and often researched area: crew fatigue. It surfaced again with the United Parcel Service (UPS) flight 1354 crash in Birmingham, AL in 2013. At this time, it seems that the UPS pilots, NTSB and Airbus (the aircraft involved was an Airbus A300-600) are in "disagreement." Remember that UPS has an FAA-managed fatigue risk management program (Croft, John. 2014c).

If memory serves (author was with FAA from 1989 into 2004), the FAA was involved in a NASA/United AirLines study about long-haul/TransPac flight and sleep/rest. As one result, in 1991, the FAA proposed a draft AC called Controlled Rest on the Flight Deck, which was opposed by industry. Here we are in 2014 and aviation is still working this issue while still more lives have been lost. Admittedly, the issues cited above all come from a small sampling of Aviation Week & Space Technology magazines (AW&ST), but the attempt has been made to select both current and somewhat safety oriented problems. (*Full disclosure*: while writing this paper, the author had plans to show the "how" of a revised SGDP in dealing with two (2) of the above aviation problems. He soon discovered that the page limitation made this an impossibility. He will submit a second paper with more detail on the structure of the SGDP, possible structures for a revised SGDP that incorporates technological advances and, the procedures for addressing at least two of the current aviation problems indicated in this paper. It is hoped that the second paper will, as well as this one, be accepted and possibly form a basis for a 2015 ISAP Symposium session. However, the second paper will be self-contained and will not rely, for comprehension, on a reading of this paper.)

SGDP: Its Time Has Come Again

The Delphi is based on the principle that forecasts (or decisions) from a structured group of individuals are more accurate than those from unstructured groups. As has been said, the use of face-to-face Delphi techniques has been re-discovered. New technologies have resulted in what are generically referred to as mini-Delphi or Estimate-Talk-Estimate (ETE). Other innovations come from the use of computer-based (and later web-based) Delphi conferences. One example of a difference in a type of ETE (a computer-based Delphi) versus either a tradtional or SGDP Delphi is the iteration structure used in the tradtional or SGDP Delphis, which is divided into three or more discrete rounds, can be replaced by a process of continuous (roundless) interaction, enabling SMEs to change their evaluations at any time. In view of technological advances, it is posited that the SGDP structure and processes are still relevant but need integration with ECE. It is further posited that this revision of the SGDP will produce the same level, if not a higher level, of accurate information and products in the aviation arena.

Integrating SGDP With ETE

Here is a brief review of the core structure of a SGDP with indications of where aspects of an ETE can be used. The core on a SGDP is: careful selection of a limited number of SME; the use of an extensive read-ahead package for the SMEs; the use of some facilitation and group dynamics instruction, combined with some type face-to-face sessions. A new ETE/SGDP model would be computer-based; the reader is referred to the work of Turoff and Hiltz (1996) on computer-based Delphis. Integration of the SGDP with a ETE approach can be achieved thusly: all participants can be logged on simultaneously, each participant can briefly state their name and credentials, the group dynamics instruction can be done by the facititator to all simultaneously (aside: it would seem that a linked network of all SMEs is possible and even *de rigueur*. This will allow for instanteous feedback by any SME during a session, as well as discussions). The iteration structure used in SGDP, which is divided into as many discrete rounds as needed for consensus, can be replaced by a process of continuous (roundless) interaction. This will enable participants/SMEs to change their evaluations at any time and give a rationale with ensuing discussion in real-time. Finally, the statistical group response can be updated in real-time and shown whenever a SME or a group provides a new evaluation.

It is clear that "face-to-face" discussion will be virtual. This is both a real and significant loss. However, the speed, multiple iterations, real-time and other aspects to be gained cannot be ignored. Another possible modification is a multi-tiered SGDP/ETE in which the use of two or more SGDP/ETE groups with different issues/expertise can be convened and given objectives based on these issues/expertise. As these groups come to consensus on their objectives, these new data can be integrated, built into a new re-ahead package and made available to a new SGDP/ETE set with new or prior SMEs.

What Is Next?

Future research can revolve around comparison of the accuracy of results using a traditional Delphi, the SGDP, various ETE Delphis (computer and/or web-based). A recent Delphi technique is a web-based communication structure involving a large number of participants.These web-based variable communication structures are designed to make Delphi efforts more fluid and adapted to the hypertextual and interactive nature of digital communication. As above, comparisons can be made among various ECE results and those of other Delphi techniques. Finally, new and perhaps blended Delphi techniques may emerge from such research and comparisions.

References

Brown, B.B. (1968). Delphi Process: A Methodology for the Elicitation of Opinions of Experts. Santa Monica, CA: The Rand Corporation.(possible:ASMTE Vectors, February, 1968).

Croft, John. (2014a). Unambigous Upset. *Aviation Week & Space Technology*, Vol.176, No.20, 52.

Croft, John. (2014b). Unambigous Upset. *Aviation Week & Space Technology*, Vol.176, No.20, 53.

Croft, John. (2014c). Rest Assured. *Aviation Week & Space Technology*, Vol.176, No.18, 38.

Feigenbaum, Edward A, McCorduck, Pamela (1983). *The Fifth Generation (1st ed.).* Reading, MA: Addison-Wesley.

Fleishman, Edwin A. and Quaintance, Marilyn K. (1984, reissued 2000). *Taxonomies of human performance: The description of human tasks.* Management Research Institute, Inc.: Potomac, Maryland.

Gibb, G.D., Lofaro, R.J. et al. (1993). Computer-based Assessment of Air Traffic Controller Abilities: Experimental Selection Tasks in *Proceedings of 1993 Aerospace Medical Association Annual Symposium.* Alexandria, VA.

Gibb, G.M., Lofaro, R.J. (1994). Airport Security Screener and Checkpoint Security Supervisor Training Workshop. DOT/FAA/CT-94/109. National Technical Information Service. Springfield, VA.

Intano, G.P., Howse, W.R., and Lofaro, R.J. (1991). The Selection of an Experimental Test Battery for Aviator Cognitive, Psychomotor Abilities and Personal Traits. U.S. Army Institute for the Behavioral and Social Sciences RN 91-21: Alexandria, VA.

Judd, R.L. (1972). Use of Delphi Methods in *Higher Education in Technological Forecasting and Social Change, 4.* NV: Reed Elsevier

Lofaro, R.J., Gibb, G.M., and Garland, D.(1994). A Protocol for Selecting Airline Passenger Baggage Screeners. DOT/FAA/CT-94/110. Springfield, VA: National Technical Information Service.

Lofaro, R.J. and Intano, G.P. (1989). Exploratory Research and Development: Army Aviator Candidate Classification By Specific Helicopter in *Proceedings of 5th International Symposium of Aviation Psychologists.* ISAP: Colunbus, OH.

Lofaro, R.J., Intano, G.P., and Howse, W.R. (1990). Final Validation of the Army Aviator Multitrack Algorithm in *Proceedings of the 1990 Annual Military Testing Association Conference.*

Lofaro, R.J. and Maliko-Abraham, Helene, (2002). Techniques for Developing High Predictive Validity Selection and Screening Test Batteries in *Proceedings* of the 2002 World Aviation Congress; Phoenix, AZ.

Lofaro, R.J. (1992a). A Small Group Delphi Paradigm in *The Human Factors Society Bulletin, 35 (2),* 1-4. Santa Monica, CA.

Lofaro, R.J. (1992b). Workshop on Integrated Crew Resource Management (CRM). DOT/FAA/RD-95/5. National Technical Information Service: Springfield, VA.

Lofaro, R.J., (1998). Identifying and Developing Managerial and Technical Competencies: Differing Methods and Differing Results in *Proceedings of 42nd annual Human Factors and Ergonomics Society:*

Santa Monica, CA.

Lofaro, R.J.,(1999). Core Competencies and Individual Differences: Chasm or Linkage? in *Human Factors and Ergonomics Society/HF&ES Individual Differences in Performance News, 12 (2).* Santa Monica, CA.

Meister, David (1985). *Behavioral Analysis and Measurement.* NYC: Wiley Press.

Murray Turoff, Starr Roxanne Hiltz (1996). Computer-based Delphi processes in Michael Adler, Erio Ziglio (eds.). *Gazing Into the Oracle: The Delphi Method and Its Application to Social Policy and Public Health,* 56-88. London: Kingsley Publishers.

Pill, J. (1970) The Delphi Method: Substance, Context: Critique and an Annotated Bibliography. *Case Western Reserve University Technical Memorandum 183*: Cleveland, OH.

Studer, Rudi, Benjamins, V. and Fensel, Dieter (1993). Knowledge Engineering, Principles and Methods in *Data & Knowledge Engineering 25*, 161-197. North Holland: Elsevier.