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Final Report: Mathematical Method for Quantifying the Effectiveness of Management Strategies

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Final Report: Mathematical Method for Quantifying the Effectiveness of Management Strategies

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ABSTRACT

Large complex teams (e.g., DOE labs) must achieve sustained productivity in critical operations (e.g., weapons and reactor development) while maintaining safety for involved personnel, the public, and physical assets, as well as security for property and information. This requires informed management decisions that depend on tradeoffs of factors such as the mode and extent of personnel protection, potential accident consequences, the extent of information and physical asset protection, and communication with and motivation of involved personnel. All of these interact (and potentially interfere) with each other and must be weighed against financial resources and implementation time. Existing risk analysis tools can successfully treat physical response, component failure, and routine human actions. However, many "soft" factors involving human motivation and interaction among weakly related factors have proved analytically problematic. There has been a need for an effective software tool capable of quantifying these tradeoffs and helping make rational choices. This type of tool, developed during this project, facilitates improvements in safety, security, and productivity, and enables measurement of improvements as a function of resources expended. Operational safety, security, and motivation are significantly influenced by "latent effects," which are pre-occurring influences. One example of these is that an atmosphere of excessive fear can suppress open and frank disclosures, which can in turn hide problems, impede correction, and prevent lessons learned. Another is that a cultural mind-set of commitment, self-responsibility, and passion for an activity is a significant contributor to the activity's success. This project pursued an innovative approach for quantitatively analyzing latent effects in order to link the above types of factors, aggregating available information into quantitative metrics that can contribute to strategic management decisions, and measuring the results. The approach also evaluates the inherent uncertainties, and allows for tracking dynamics for early response and assessing developing trends. The model development is based on how factors combine and influence other factors in real time and over extended time periods. Potential strategies for improvement can be simulated and measured. Input information can be determined by quantification of qualitative information in a structured derivation process. This has proved to be a promising new approach for research and development applied to personnel performance and risk management.

Acknowledgment

The work documented in this report was supported by the NNSA/SNL LDRD program. Other key supporters of the work were Bob Eagan, Les Shephard, Margie Tatro, Dick Perry, and Renae Perrine. The mathematically oriented exchanges during meetings of the core group of researchers had a synergistic benefit. Assisting the authors of this report in these meetings and in private consultation were Paul Werner, Ron Pedersen, and Susan Camp, all of Sandia National Laboratories, as well as Lisa Brown (former Sandian), and Marisa Sleeter (Sandia summer employee, now at Texas Christian University).

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1. Introduction

Problem and Needs: Modern organizations that must be productive in critical operations (e.g., weapons and reactors) while maintaining safety (for personnel, the environment, and security of assets) are faced with complex decisions and tradeoffs. It is important to enhance productivity, and to identify and efficiently address weaknesses and potential for accidents, while adhering to financial and time constraints and maintaining the morale of personnel. It is also required to remain in or come into compliance with laws, regulations, and rules. Degrading effects can be physical or can involve personnel. Physical effects are usually satisfactorily addressed by conventional analysis. Personnel effects (including design, establishing infrastructure, management, and operational performance) need to be analyzed differently [Ref. 1]. Neither physical nor personnel systems can be simply dichotomized into subsystems, because there are interrelations that affect functionality and "interferences" that create sometimes-unexpected overall degradation [Ref. 2]. Personnel actions are especially difficult to control and predict. Decisions that must be made under these conditions involve complex factors that are not always clearly tractable. An analysis methodology and a quantitative analysis tool that can account for these factors and can be used as a decision aid is an important contribution derived from this project.

Technical Challenges: There were several technical problems that were encountered in constructing the approach used in the project.

1. Many factors are subjective, but must be measured quantitatively. However, there is a large body of research in the area of providing guidance for such metrics. Our approach involved relating observed factors to reference values that help establish a consistent and easily followed protocol.
2. Some tradeoffs required measuring weakly related quantities, such as financial cost vs. non-monetary impact. Methods have been previously proposed (e.g., Analytic Hierarchy Process [Ref. 3]) that help provide effective but tedious comparisons. We considered similar, but less complex, and possibly more effective approaches that were weighed for reference against known approaches as part of our validation effort.
3. Human decisions are influenced by "soft aggregation" (nonlinear accumulation) of information. These aggregations are weighed against "soft" (non-abrupt) thresholds. Any representative mathematical model should reflect the nonlinearity of these processes, so we used exponential accumulation and comparison.

Technical Issues and Risk: Although we had confidence in the proposed approach, because similar methods had been tested in some limited environments and situations, we had not yet fully validated the proposed technique, and so its success was not risk-free. However, a substantial degree of validation has now been provided.

Impact: The work provided contributions in the following areas.

1. Technical soundness. Decomposition by latent effects was shown capable of incorporating and measuring factors such as fear, culture, and motivation; the assessment also included the dynamics of subsystem relations in a systemic decision-aid model.
2. Aggregation. Financial, environmental, security, personnel and team-based data were combined using soft aggregation mathematics, accounting for dependence, and were used to compare to soft sigmoid thresholds.
3. Uncertainty. Uncertainty concerning productivity, cost, time, and long-term effects was quantified, using possibilistic mathematics.
4. Rankings. Decisions and resource allocation were shown capable of being guided by rankings of potential input values and strategies.
5. Early alerts. Propositional-logic-based real-time alarms and pro-active trend-based indicators were derived.
6. Importance and Sensitivity. The contribution of input data to overall assessment was measured as a means of information filtering and resource allocation.
7. Simulations. Dynamic scenarios were utilized to evaluate tradeoffs, and were also shown to be useful for personnel awareness.
8. Forensics. Lessons were derived from history and postulated scenarios.

Technical Approach and Results: This project was intended to help manage risk and improve personnel performance. It followed a top-down system-analysis strategy, recognizing that the particular project thrust was part of a more general problem. Fig. 1 shows the overarching structure, with risk management indicated on the left and risk analysis on the right.

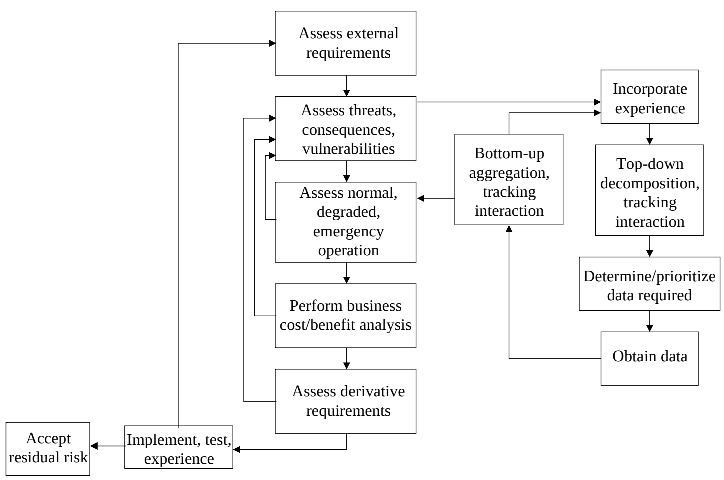

Figure 1. Overarching Approach Structure

This approach includes requirements, many of which are dynamic, under expectations for normal, degraded, and emergency operation, and takes into account the results of the threat analysis and resource limits. The basic structure for analysis, the "Markov latent effects" contribution to that analysis, the role of expert elicitation in gathering input data, the requirements for software processing, and expected results are addressed below.

Decomposition is useful in analyzing complex problems, providing that interactions among the subsystems are included [Ref. 4], e.g., for latent effects. The information necessary for the variable inputs to the proposed analysis is derived from a latent effects system decomposition. This approach is taken because many forensic investigations of our own and of others [Ref. 5] have indicated that root causes are frequently not the most immediately obvious ones, but often lie relatively hidden in factors such as culture, commitment, and regulatory and financial constraints. For example, many activities follow a build-up of latent influences (from lower left to upper right) as shown at a high level in Fig. 2.

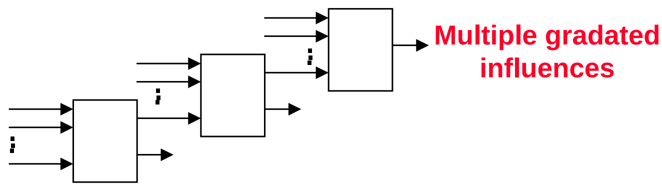

Figure 2. Latent Effects Structure

Decomposition modules are constructed by first introducing the most fundamental "fixed" factors (financial limits, legal requirements), using these to develop a "culture" of behavior, then considering how an activity is organized, addressing the activity itself, and examining "lessons learned" in a cyclic structure that feeds back into the original environment. Inputs to decomposition modules are "weighted" (values are multiplied by the weights). This is similar to a weighted sum, but we used "soft aggregation", complete with possibilistic uncertainty functions [Ref. 6]. An example soft aggregation weighted sum is given in Eq. 1.

$$y = \frac{1}{1 + e^{-5.5\left(\sum_{i=1}^{n} w_i x_i + \sum_{j=1}^{m} v_j y_j - 0.5\right)}} \qquad (1)$$

where the x_i are the individual inputs to each module, the y_j are the latent effects inputs from prior modules, the w_i and v_j are the corresponding weights, and y is the module result. The form of soft aggregation described by Eq. 1 and its inverse can be positive or negative, as shown in Fig. 3.

Some of the terms in the mathematics require non-latent (conventional) decomposition; for others, a hybrid decomposition is appropriate. All of these types of decompositions have appropriate mathematical properties (e.g., the result is the same as each input if all inputs are equal, regardless of weights, and it is no greater than the maximum input and no less than the minimum input, regardless of weights). An important feature of soft aggregation is that all results are guaranteed to be greater than zero and less than one.

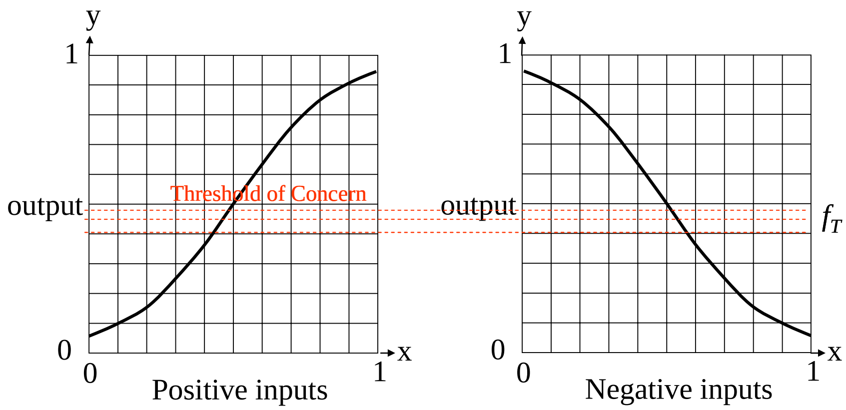

Figure 3. Depiction of Soft Aggregation

The results obtained as module outputs are an aggregate measure of the combined influence of all of the variables. For example, a company's "productivity" could be measured by its scientific accomplishments, its personnel morale, its operating safety, its environmental impacts, its asset security, and its future projections. In order to consider changes in the safety and security environment, scenarios can be simulated prior to their occurrence. In order to do this, several metrics are helpful. Trends-tracking helps identify subtle changes and projected effects. Importance metrics help rank variables by their contribution to success. Sensitivity metrics help rank variables according to the cost-effectiveness of overall improvements expected due to improvements in individual variables. Early alerts are logic-based indicators that call attention to combinations of effects that may have otherwise unexpected impact.

In order to be useful in analysis, the qualitative metrics must be accompanied by guidance criteria. These must be derived in such a way as to specify relevant data that are feasible to obtain. The process must also be repeatable; it must be assured that similarly knowledgeable people seeing the same situation would record similar (not necessarily exactly the same) results. All of this (including work process guidance and derivation strategy) is part of a data-availability analysis, which was provided during this project.

<u>Creativity and Innovation</u>. Several features of the project approach are unique and yet based on a firm foundation. These include:

1. The analysis structure helps understand the human process, including latent factors such as fear, lack of full disclosure, "brainwashing", and dedicated motivation. This is a promising approach to the previously unsolved problem of estimating likelihood of types of performance, safety, and security failures.
2. The latent effects decomposition tied to a mathematical analysis helps in understanding processes, interrelating factors, accounting for dependence, and aggregating inputs into meaningful decision aids.
3. The expert elicitation process blends inputs from operations "owners" with more global information of which they may not be aware.

4. Possibilistic uncertainty processing allows appropriate representations of subjective uncertainty and aggregation of that uncertainty in the latent effects structure. This processing also blends through hybrid analysis with objective data, where they are available.
5. The combination of "scoring" risk of various types of problems, along with trends and early alerts allows for a realistic global view of productivity, safety, and security impact.
6. The business-oriented top-down system process for subjecting requirements and responses to cost-benefit processing under normal, degraded, and emergency conditions also is unique.
7. The method addresses problems of varying scale, e.g., a single operation or an entire organization.

<u>Milestone Summary:</u> The planned milestones were all met:

1. Construct mathematical models applicable to safety- and security-critical operations, including the involved personnel, organizations, and management.

   The activity was focused on five main thrusts along with some less intense treatment in one or two other areas. The choices for emphasis were: personnel performance and evaluation, management performance and evaluation, organization performance, team performance, and organization safety posture.

2. Decompose the operation factors into analyzable latent effects structures, chained to show salient effects.

   In doing this, consideration was given to game theory, dissipative sustainability analysis, Unique Signal communication, and various forms of entropy theory.

3. Acquire a preliminary information base on the current status of the selected critical SNL projects.

   The selections were filtered down to three that were the most pertinent to the project and also feasible under the time and resource constraints.

4. Develop and test expert elicitation methods for potential information needs and for the consequences of changes.

   This part of the project focused on how mathematical inputs could be derived from objective data and expert elicitation. Consideration was also given to how outputs could be effectively portrayed.

5. Develop criteria for judging degree of success of the project, so its value can be assessed based on test cases.

    This effort required validation metrics, since we had to show if the methods developed were effective and useful.

6. Develop prototype software for processing the data gathered in a Markov chained latent effects structure with soft aggregation information processing.

    Bob Roginski, retired Sandian, was placed under contract for software development. His experience was valuable in implementing the software routines necessary for this approach.

7. Construct several test cases that could be used to test model validity.

    In construction of the test cases, we showed value added, first to Division 6000, second to Sandia National Laboratories, third to DOE, and fourth to the scientific community in general.

8. Assess results of the test cases against the criteria for success.

    To do this, we demonstrated the value of the project in a variety of ways falling into three types of tests: exercising the methods in job-related functions, testing three types of organizational applications, and conducting wide peer evaluation. Based on these approaches, a decision was made that the work achieved its objectives.

9. Demonstrate validation of the concepts and usefulness for key applications.

    The validation is demonstrated in Sections 3-5. This validation included peer assessment, user feedback and comments, and demonstrated operational improvements.

10. Write a report summarizing the results obtained.

    Th**is** report meet**s** the requirements for an LDRD report, and is intended to document the work in a way that will make future duplication unnecessary. Various interim papers were also written (see Section 3).

<u>Summary of Accomplishments</u>

In summary, high level mathematical models were constructed for personnel, management, organization, and team performance and assessment, for organization safety and environment posture, and for specific application to personnel performance research. The operational factors were decomposed into analyzable latent effects structures, chained to show the specific contribution of latent effects to the overall operation. Input categories for these structures were determined, and a structured expert elicitation guideline was developed to help obtain particular input values. These values were combined using soft aggregation analysis in order to obtain scores for each module. Importance and sensitivity metrics were determined in order to rank the inputs in terms of contribution to overall value and overall payoff for improvements to particular inputs. Various demonstrations were developed in order to simulate the effects of human motivation on overall results. Computer simulations were run and the results were compared to a Markov latent effects analysis in order to help validate the latent effects approach.

A particular line of research on personnel and team performance was undertaken. This resulted in the production of five related papers (see Appendices A.1 through A.5). One of these papers has been published; the other four companion papers are under consideration for completing the publication of the five-paper sequence (in the Journal of System Safety).

2. Related Research Papers

Five papers were written following a sequence of productive research goals. The motivation for each of the papers and a short summary of each is given here; the complete papers are reproduced in Appendices A.1 through A.5.

The motivation for the papers was derived from some of the concepts being explored in a book under preparation by Rush Robinett III [Ref. 7]. The basic concepts that had to be combined are illustrated in Fig. 4.

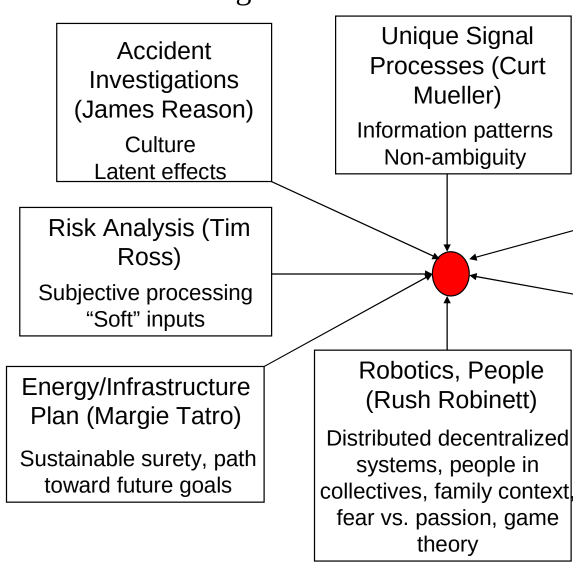

Figure 4. Contributing Constituents to Project

The constituents included results of accident investigations (e.g., [Ref. 8]), Unique Signal methods derived from the nuclear weapons program (e.g., [Ref. 9]), work in error-correcting codes (e.g., [Ref. 10]), top-down system decomposition (e.g., [Ref. 11]), subjective risk analysis concepts (e.g., [Ref. 12]), organization mission planning (e.g., [Ref. 13]), in addition to the synergistic teaming concepts in Ref. 7. The general developmental strategy used is illustrated in Fig. 5.

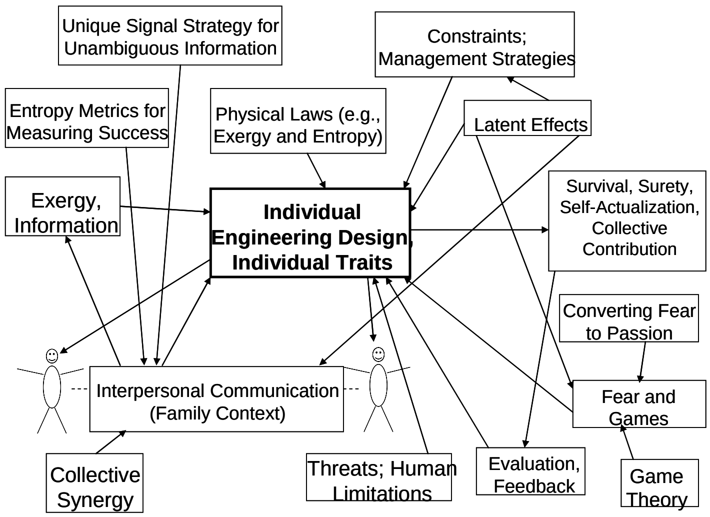

Figure 5. Illustration of the Strategy for Developmental Research

The strategy was aimed at working with individuals to improve their productivity, morale, and teaming contributions. This required a focus on communication (lower left of Figure 5), where contributions were required in synergistic combination, with contributions from strategic communication effects (utilizing Unique Signal concepts), along with recognition and utilization of latent effects. Since performance metrics were desired, entropy concepts were used to provide a basis for measuring degree of success. Fear and game-playing were identified in Ref. 14 as specific effects that could be detrimental, so these were introduced (lower right of Fig. 5). It had been found that these could be overcome by latent effects derived from training, so game theory and latent effects were applied and a strategy was derived for dealing with and altering the detrimental effects. It was obvious that management strategies were a necessary contributor to influencing changes, so this was included (upper right part of Fig. 5), including the influence of latent effects and systems of rewards and redirection. The focus was on what could be called the "engineering design" of optimum individuals, along with utilization strategies for non-optimum individuals (center of Fig. 5). All of the factors studied were dichotomies, in that balancing factors that would serve good or detrimental purposes was required. Since synergy was also identified in the balancing process, resolution of these dichotomies was necessary in order to tie the concepts together. Based on the illustrated strategy, development of five papers on the five general concepts brought out by the above discussion was pursued.

<u>Structured Communication and Collective Cohesion Measured by Entropy</u> [Ref. 15]. Since interpersonal communication is one of the most essential contributors to company productivity, quality, and operational safety and security, this was identified as an important research topic. The paper outlines a structured approach that has the potential

to improve communication and which is mathematically analyzable. The strategic approach is based on contributions of latent effects modeling and Unique Signal principles. An important contribution is a method for identifying quantifiable units of interpersonal information along with their specific benefits to each concerned party and to the collective aggregation of communicating parties. The measurement of the processes' quality is facilitated by the use of entropy-based metrics.

Analyzing and Overcoming Fear in Personnel Performance and Interpersonal Interactions [Ref. 14]. There have been many indications that "fear" is an important impediment to personnel performance and the interpersonal interactions that are essential to teams, organizations, and other collective efforts. This paper addresses methods for overcoming detrimental fear. First, the "latent effects" that can encourage counterproductive tendencies are described. Then, some of the salient effects are noted, identification of fear is considered, and fear is established as a "root cause" of performance shortcomings. Corrective measures are addressed through identifying how humans process stored and real-time information and by applying "game theory" for helping to understand interactive effects. Additional understanding and validation of the subject is facilitated by description of a processing and an analysis structure.

Managing Safety into High Consequence Organizations (with Supporting Analysis) [Ref. 16]. One of the primary interests of the research was to describe demonstrated safety-relevant weaknesses and successes (some potential) in the management of high consequence organizations, and to derive an analysis approach that helps assess and guide improvement of organizational performance and management. Management of personnel requires detailed knowledge of competitive and cooperative motivations. The modes used by management to reward personnel can have a significant effect on productivity. We developed a game that illustrates the potential effects of rewards. Analysis of the results adds validation to the results of the game.

Engineering Optimum Individuals [Ref. 17]. This paper demonstrates methods for assessing and improving personnel productivity through focus on the desirable (and inherent) characteristics of individuals. Although skilled management, facilitated communication, and structured strategies are essential to productivity, the most important factor is shown in this paper to be individual behavior. Characteristics of optimum individuals are examined, the contribution of individuals to collectives is addressed, methods for enhancing the contribution of individual performance to collective goals are proposed, strategies for improving the utilization of sub-optimal individuals are developed, and a quantitative analytical structure is derived.

Deriving Sustainable Ordered Surety by Overcoming Persistent Disorder Pressures [Ref. 18]. The fifth paper was the most global of the series of five. A large number of interrelated factors in our daily lives involve surety (safety, security, and functionality, all with sustainability). However, there are opposing (threat) factors. Strategies for dealing with the evolving and diverse factors that can contribute to surety and can detract from it are important in a variety of enterprises, such as national energy policy, national defense, homeland security, business operations, and personal collectives, such as families. This paper derives an innovative risk analysis structure for surety by considering technical and social factors that create diverse pressures and dichotomies. Based on the derived structure, a strategic surety approach involving a variety of effects is developed. An analytic treatment helps quantify the potential success of the approach.

3. Personnel Performance in Various Contexts

Personnel performance was a particular focus of the overall project. The contexts involved were performance as an individual entity, execution of management expectations, participating in team activities, helping to carry out specific operations, and general organizational contributions. We investigated individual personnel performance factors, examined interactions between individuals and their peers, between individuals and their management, inter-management interactions, team synergy, and overall organization performance based on individual contributions. The basic key to all of these was the latent effects structure discussed earlier and shown at a high level in Fig. 2. A more detailed basis is shown in Fig. 6.

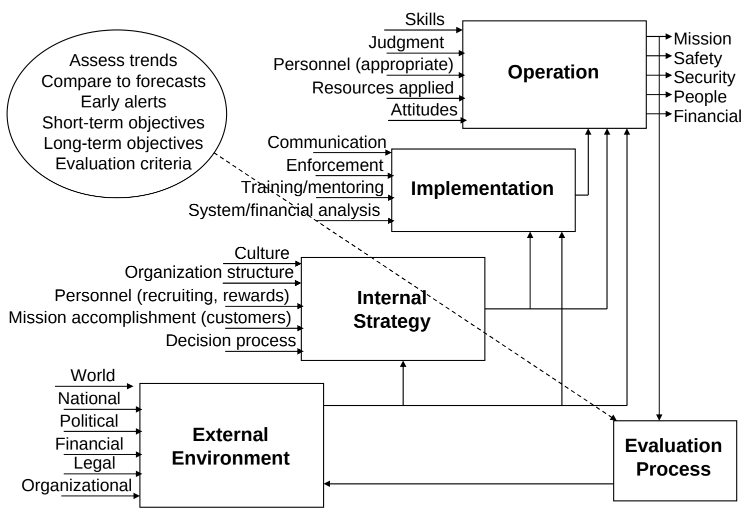

Figure 6. Global Latent Effects Strategy

In this diagram, some of the conditions that are difficult to change (termed part of the external environment) are shown at the lower left. Within these, an internal strategy is developed, based on both of these, implementation is undertaken, and from these, operation is undertaken. Various operational missions can be assessed, individually, or in combination. All of this is subject to evaluation and feedback.

<u>High Level Markov Latent Effects Model for Personnel Performance and Assessment:</u> The intent of the model developed for personnel performance and assessment was to test a vehicle for communication between management and personnel regarding personnel performance and assessment. The model used was a Markov Latent Effects Model [Ref. 12], diagramed in Fig. 7. There are five modules shown, beginning with “Self awareness,” continuing to “Personal culture,” then to Team interaction,” all of which

contribute to “Execution,” which results in a “Performance” metric. Feedback is derived through “Lessons learned,” which also provides a measure of “Prognosis.”

The aggregation of input values is similar to a weighted sum, but we use “soft aggregation”, complete with possibilistic uncertainty functions [Ref. 6]. An example soft aggregation weighted sum was given in Eq. 1.

Guidance on the meaning of the numeric values and space for numeric entries was developed, and a summary is provided in Table 1.

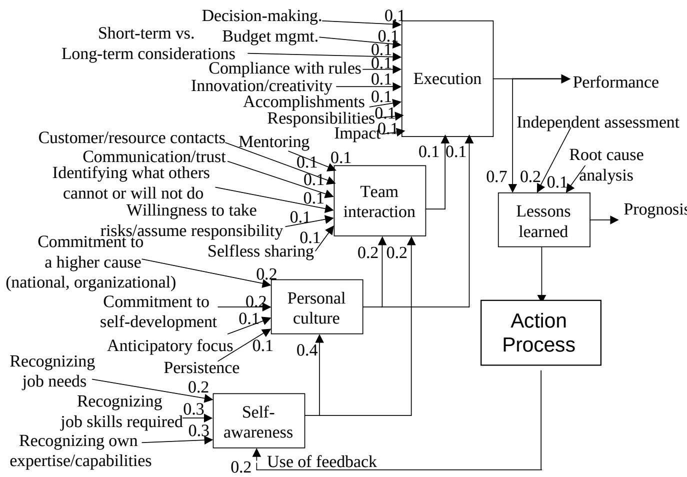

Figure 7. Markov Latent Effects Model for Personnel Performance Assessment

Table 1. Input Guidance

The general guidance for all inputs is:

- If there is no apparent recognition of the attribute, or if the person appears to attach no importance to it, an appropriate entry is in the range of 0 to 0.1.
- If there is minor recognition of the attribute, or if the person appears to attach minor importance to it, an appropriate entry is in the range of 0.1 to 0.3.
- If the recognition of the attribute is about average, and if the person appears to achieve the attribute with average success, an appropriate entry is in the range of 0.3 to 0.7.
- If the recognition of the attribute is somewhat above average, or if the person appears to achieve the attribute with somewhat above average success, an appropriate entry is in the range of 0.7 to 0.9.
- If the recognition of the attribute is outstanding, and if the person appears to achieve the attribute with outstanding success, an appropriate entry is in the range of 0.9 to 1.0.

This model was tested on a selection of Management and staff member personnel, where each entered their view of what the scores should be. This provided an opportunity for discussing differences, which generally helped each better understand the other's views. The software was also used to rank all inputs (based on the values entered by each individual) on the basis of "Importance" (contribution to the overall result) and "Sensitivity" (most effective impact if improved). These rankings provided further opportunities for discussion.

Another model was constructed as an assessment tool for management performance. This is shown in Fig. 8.

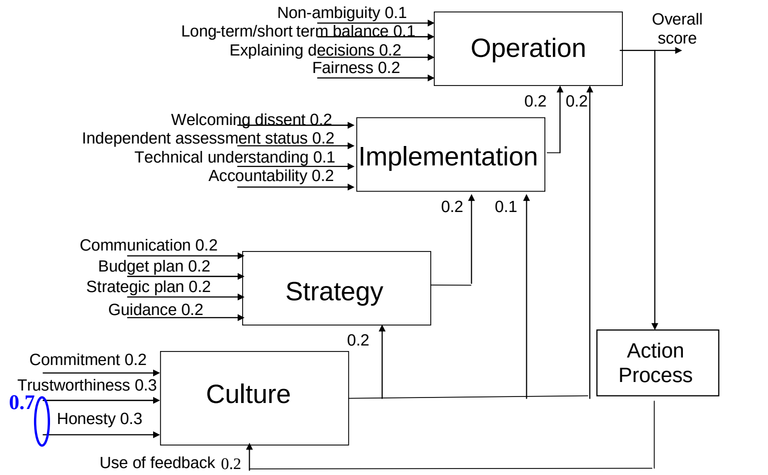

Figure 8. Model for Management Performance Assessment

The management model was also exercised in various applications, including management assessment by staff, and management assessment by various levels of management personnel.

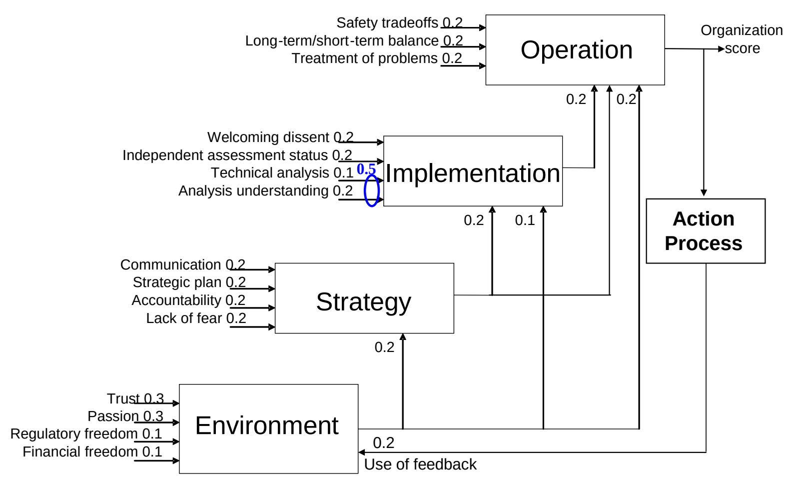

Figure 9. Organization Latent Effects Model

Several organization models were also constructed. One of these is shown in Fig. 9.

This organization model was used to assess the operation of a particular organization. Other models were used in the three test cases described in Section 5.

Various team latent effects models were developed for application to some teams that operated differently from most organizations. An illustration of one of the team models is shown in Fig. 10.

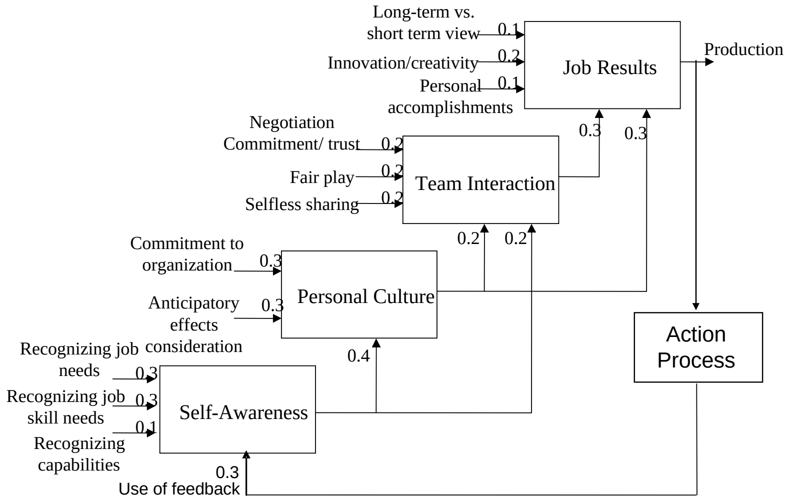

Figure 10. Example of a Team Latent Effects Model

Personal, public, and environmental safety was also addressed by a latent effects model, shown in Fig. 11. This was similar to ES&H assessment, but was more comprehensive. This was also part of the modeling done for the three operations described in Section 5.

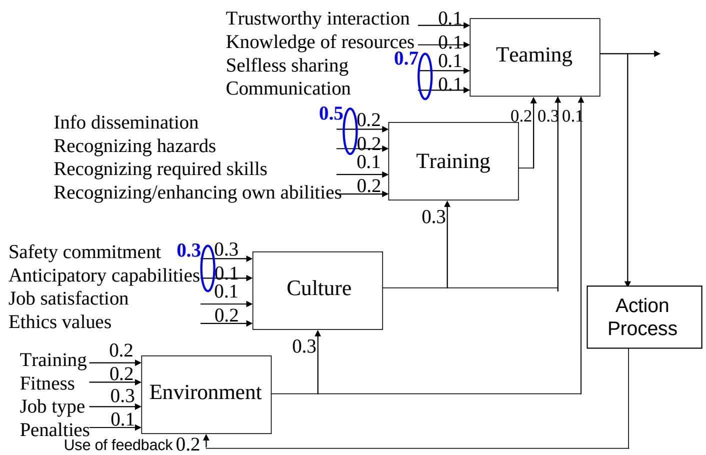

Figure 11. Latent Effects Model for Personal, Public, and Environmental Safety

A combination model was also designed and exercised. A high level indication of the model is shown in Fig. 12.

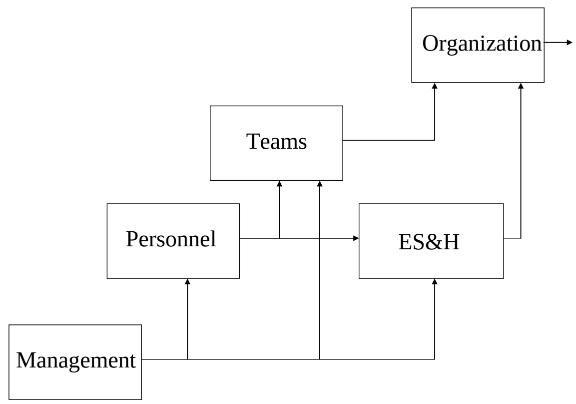

Figure 12. Structure of Combination Latent Effects Model

All of the models developed were implemented in software, and user manuals were prepared. Two of the user manuals are in Appendix B.1-2.

4. Publications and Presentations

Validation of the effectiveness of the research approach and results was obtained in three major ways. The first contribution to validation was the verbal endorsements obtained from the participants in the personnel evaluation exercises described in the previous section. The second contribution was the results of the test cases described in the next section. The third contribution to validation is the peer acceptance of the research concepts as expressed through peer-reviewed publications, a patent, and invited presentations. These are documented in this section.

<u>Publications of Papers in Journals</u>

1. Cooper, J. A., "Soft Markov Chain Relations for Modeling Organization Behavior," *Risk Decision and Policy Journal*, Cambridge University Press, Vol. 9.1-12 (2004).
2. Tidwell, Vince, J. A. Cooper, and Consuelo Silva, "Threat Assessment of Water Supply Systems Using Markov Latent Effects Modeling," *American Society of Civil Engineers Journal of Water Resources Planning and Management*, June 2005.
3. Cooper, J. A., and Rush Robinett III, "Structured Communication and Collective Cohesion Measured by Entropy," *Journal of System Safety*, July-August 2005.

[Four other papers have been submitted for publication and are under review by journal-selected peers.]

<u>Patent</u>

1. Cooper, J. A., and Paul Werner, "Latent Effects Decision Analysis," U.S. Patent No. 6,782,372 B1, August 24, 2004.

Invited Presentations

1. Cooper, J. A., “A Method of Enhanced Estimation of Extreme Hazards,” Warhead Hazardous Environment Protection U.S.-Russian Workshop, September 30, 2004.
2. Cooper, J. A., “Management Strategies and Analyses for Safety in High Consequence Operations,” NASA Contractors Safety Forum, February 22, 2005.
3. Cooper, J. A., “Extensions to Conventional Safety Analysis,” Sixth Annual Tri-Lab (LLNL, SNL, and LANL) Engineering Conference, September 13, 2005.

Peer-Reviewed Conference Presentations and Proceedings Publications

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2. Cooper, J. A., and Rush Robinett III, “Productivity/Reward Game Demonstration,” International System Safety Conference, Providence, RI, August 2004.
3. Cooper, J. A., “Soft Markov Chain Relations for Modeling Safety Management,” Probabilistic Safety Assessment and Management and European Safety and Reliability Association Joint Conference, Berlin, Germany, June 2004.
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4. Cooper, J. A., “A Mathematically Guided Strategy for Risk Assessment and Management,” SAFE [Safety Analysis] Conference, Rome, Italy, June 2005.
5. Cooper, J. A., and Rush Robinett III, “Safety-Relevant Interpersonal Communication Strategy and Metrics,” International System Safety Conference, San Diego, CA, August 2005.

[One other conference paper has been submitted and is under peer review.]

5. Test Cases

This section describes applications of the analysis methods developed or refined as part of this project. These test cases were performed to gather “real world” experience to critique the methods and intents of the techniques used. Because the analysis was attempted on ongoing projects, detailed reports are being supplied only to the involved organizations. This section describes the projects more generally, with the intent to contrast their individual aims and differences.

We chose three distinct projects for analysis; we shall call them “Facility Operations,” “Safety Planning Documentation Development,” and “Contractor Operations Control.” We describe each separately before contrasting them.

The Contractor Operations Control project is for a group overseeing a major contractor activity at Sandia National Laboratories. Each of several activities has a prime contractor and several subcontractors. Some of the subcontractors are “8A” contractors, meaning that they receive some amount of favoritism intended to encourage minority persons to enter into, and succeed in business. Because of their relative inexperience, some of these workers are at greater risk of injury to themselves or others. All in all there are thousands of non-Sandians doing every type of work ranging from foundation work to structural work to electrical, plumbing, and many other trades necessary (for example) for laboratory or office building construction. During mid- or late stages of such projects, many trades are working in proximity to one another. These projects present special risks tracing to cultural, procedural, and temporal factors. The overseers must allocate limited funds to control these risks in a manner that does not unduly impact overall cost and schedule for a product that is key to the future of the laboratories. It is important that both real-time and latent risks are controlled: real-time risks can impact workers or bystanders during construction; latent risks can impact future occupants and others after construction and during occupation and residency. Accurate records of “as-built” construction are important for controlling latent risks.

The Facility Operations project is for a group having more of an R&D focus. This group works simultaneously on numerous distinct projects that are more often of a developmental nature but occasionally test-result oriented. As is the case with many R&D groups, the typical worker may labor not only in his/her specialty, but temporarily in other capacities as may be called for in the midst of a project. Priority demands for various projects may be shifted by accidents occurring within the funding industry. Most projects are pursued concurrently within one large, interconnected work area. Most projects receive guidance or advice from persons outside the core group—either other Sandians, contractors, or government entities—all associated with the funding industry. Latencies may occur within a single project or result from interferences with other collocated and concurrent projects.

The Safety Planning Documentation Development project supports mission success for several local and remote high consequence Sandia facilities. This is accomplished by helping to demonstrate their continued readiness for safe operation to both the Laboratories and regulators. Continued readiness is demonstrated in a number of ways including identification of hazards and their control through positive measures, formal documentation of these efforts, and independent assessment of the documentation and physical preparedness to operate safely.

Demonstration of preparedness is repeated periodically but takes on extra importance during significant facility modification and before its return to operation. Consistency is assured by using a single clearinghouse for these activities; such disparate facilities as radiation chambers, rocket launchers, centrifuges, and microcircuit fabs must interact with a common set of project representatives.

Long-standing latencies have hindered attempts to improve preparedness. These include:

- a history of outdated management and worker culture “stuck” in a loosely-regulated past
- poor records of infrastructure
- loss of corporate memory (retirement or other turnover of knowledgeable workers)
- latent design error
- latent construction error
- lack of change control

Each individual report to the involved organizations will be structured in a top-down fashion to be maximally useful to the project owner. The structure will clarify what we knew—or assumed about—the project so as to better describe the model structure, parameters chosen, and lessons learned from running the model. Each report will begin with the following topical discussions to help clarify our understanding of the project:

- Project Mission—includes statement of the required function as well as description of positive measures to assure success and discourage failure.

- Upsides of Project Success—hard and soft benefits of getting it right, including benefits to the nation, the NWC or Sandia.

- Downsides of Project Failure— hard and soft negative consequences of getting it wrong, including heads rolling, increased laboratory oversight, loss of public confidence, increased lawsuits, lost funding, etc.

- Stress Environments(soft focus)—includes management pressure, game-playing, information-filtering, brainwashing, public sentiment, schedule and cost pressure

- Latencies—includes mostly soft factors that influence a project positively or negatively. For example the latency can act currently, as something that occurred years ago but is now hindering a project. Or the latency might act in the future, as a well-planned or well-formed current act that can enable a more positive outcome in the future.

6. Conclusions

This project resulted in compelling evidence that the subtleties of personnel, team, and organization performance were amenable to quantifiable mathematical analysis. The innovative blend of top-down business-oriented decomposition, latent effects, Unique Signal strategy, game theory, fear redirection, and dichotomy resolution were keys to the validated success of the project.

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Appendix A.1

Structured Communication and Collective Cohesion Measured by Entropy

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Key words: entropy, interpersonal communication, latent effects, Unique Signals, metrics

Abstract

Interpersonal communication is an essential contributor to company productivity, quality, and operational safety and security. This paper outlines a structured approach that has the potential to improve communication and which is mathematically analyzable. The strategic approach is based on contributions of latent effects modeling and Unique Signal principles. An important contribution is a method for identifying quantifiable units of interpersonal information along with their specific benefits to each concerned party and to the collective aggregation of communicating parties. The measurement of the processes' quality is facilitated by the use of entropy-based metrics. A latent effects structure relating various forms of entropy is developed in order to derive an overall interpersonal communication analysis. An example is shown to demonstrate the concepts.

Introduction

Interpersonal communication is essential for the success of large organizations and as a way to motivate personnel toward continuously improving performance. The implications are direct for company productivity, safety, security, and quality. This paper addresses strategic methods that can be used to improve communication and metrics that can measure success or failure.

An example scenario will be used to help lay a foundation. Consider two people who contemplate going into business together, for example to purchase and operate an almond orchard. In order to succeed in the face of uncertain potential threats and risks, the two people should be well matched in that their business interests, business philosophy, business skill, management philosophy, and amount of passion and drive are compatible and/or complementary. They should have similar levels of risk aversion and respond similarly to business-related stress. They should be mutually supportive and neither can have a tendency to deceive the other or to let the other down. They should have similar short-term and long-term expectations. They should be willing to respond similarly to external effects (e.g., damaging weather, water shortages, crop diseases, market downturns). They should be able to build trust in each other. They should have similar expectations of business exit strategies, should that become necessary.

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Such matches are not likely to occur by accident, but they can be made much more likely by a strategic directed effort over a period of time. Planting early seeds that can result in later productive results is a manifestation of *latent effects*.[3] Information-gathering effort over time can help build a common basis or reveal if this is not possible.

As a common context for communication is developed, essential information can be exchanged. Each person needs to derive supporting information about the other. It is important for each to understand the other's basic views and approaches, to know that there will not be devastating surprises brought to light, and to know how the other responds to stress. Obtaining these sorts of data is not often as direct as asking a question and listening to the answer, although that can be a contributor. Some information can come by strategic application of various forms of discussion, some information can come from other people, and some can come from observation of responses to planned or unplanned situations. These forms of information may appear unpredictable, but they can be part of an overarching strategy. As the information aggregates, each piece of information is treated as new and useful (memory of previous data is not used to suppress importance). This form of information sending and receiving is termed *Unique Signals*.

As the latent effects and Unique Signal information exchanges take place, interpersonal communication effectiveness generally improves. When crucial business decisions must be made, often quickly and under off-normal stress, there is more likely to be effective communication between the partners with minimal chance of obfuscation or misunderstanding. This can be termed a low *entropy* communication, which opens the door to quantifiable metrics.

The concept of "entropy" serves as a basis for measuring interpersonal communication problems. Entropy is familiar to most technical personnel who have studied thermodynamic and/or electronic communication processes. Thermodynamic entropy generally increases as the available energy and organization in the known Universe dissipate. This form of entropy becomes a measure of dispersion, or disorder. The Second Law of Thermodynamics states that the entropy of the Universe will continue to increase. However, the presence of life, with its attendant cellular organization, information accumulation, and skills development, is in temporary opposition to the overall order decrease. For each individual, beginning with apparent disorganization of basic cells and DNA, entropy decreases to a virtual minimum during the prime of life, until aging begins to relentlessly increase entropy, finally resulting in death. A general plot of the development and degradation of a living organism's cellular (and in some ways intellectual) "order" is shown in Fig. 1. Individuals, collective teams, and civilizations can counter entropy by producing exergy [Ref. 1] (a measure of the ability of an entity to do work), information, learning, skills, and strategies. All of these are ways in which the tendency of entropy to increase can be at least temporarily reversed.

[3] Italicized terms will be further explained later in the paper.

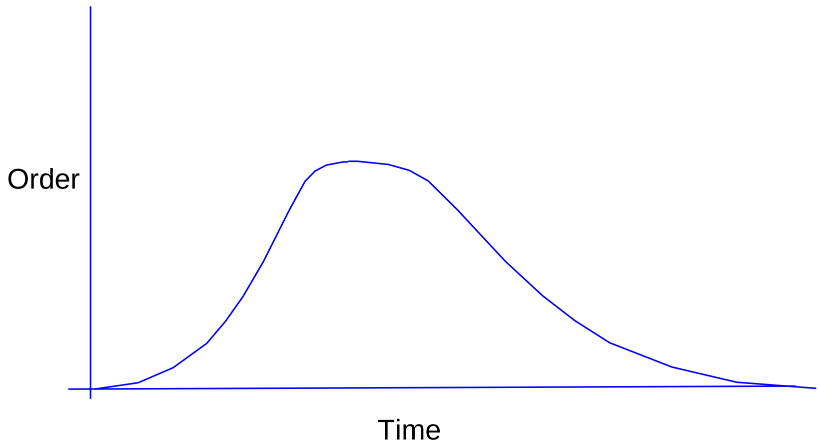

Figure 1. Depiction of Human Cellular Order

"Communication entropy" was developed by Claude Shannon [Ref. 2] to relate the probabilities of communication entities sent over a communication channel to "uncertainty," with higher entropy measuring higher uncertainty about what entities might appear on the channel. Weaver [Ref. 3] equated high entropy with high "information." This viewpoint has caused some confusion in the literature [e.g., Ref. 4], because it appears that information requires "organization," which should relate to low entropy. We claim to have unraveled this confusion by noting that Weaver's assertion was based on the transmitter's (originator's) viewpoint, which is different from the receiver's. The transmitter has a high measure of information available if it has complete freedom of choice (no restrictions) among information entities (high entropy). The receiver has a high measure of entropy if any received information entity is equally likely (i.e., there is nothing noteworthy about the reception). This means that high entropy is an attribute for a transmitter, and low entropy is an attribute for a receiver (an apparent "zero-sum" situation). These concepts are a basis for the development in the paper.

Because thermodynamic entropy and communication entropy both measure a quantity associated with disorganization, it is apparent that the two can be related. Reif [Ref. 5] and Frieden [Ref. 6] are authors who have demonstrated the basic relationship between thermodynamic entropy and communication entropy mathematically. The basis for this development was the exponentially distributed probabilistic nature of available thermodynamic states available for a system containing particular energy levels. The result shows that:

$$S = k \ln \Omega = -k \sum_r P_r \ln P_r \tag{1}$$

where Ω is the number of system states containing particular levels of energy, k is a constant, and P_r is the probability of states at the rth energy level. The r probabilities, (which can analogously represent communication entities) must sum to one. The natural logarithm results from the exponential distribution. A logarithmic relationship is essential to all expressions of entropy.

Entropy changes have a reversible and an irreversible component, as shown in Eq. 2.

$$dS = d_e S + d_i S \tag{2}$$

In a system such as that shown in Fig. 1, there can be energy derived from matter, such that the entropy change represented by the first term is negative, and there can be non-equilibrium over a period of time. However, the change represented by the irreversible entropy term is positive, so that entropy will eventually increase. It is the time dynamics that allow human ordering to be achieved. The implications of the above associations will be addressed subsequently.

Another nuance of communication involves social interaction as a potential basis for later communication. Consider two[4] people who participate in various activities together, such as playing sports, attending school or church, dining, discussing weather, health, family, etc. The communication efficiency in such situations does not appear high, because considerable time is expended and a relatively small amount of focus is generally placed on information exchange. The amount of immediately meaningful information is low, so this would be measured as relatively high communication entropy. However, these types of interactions tend to build a common context for future communication and understanding. There is also enhancement of the synchronization between the transmitters and the receivers. For these reasons, the long-term impact of the exchanges can be significant. From this overarching viewpoint, the communication entropy can be low.

From these foundations, entropy concepts can be developed as a communication analysis approach that can assist in measuring the details of and the overall effects of interpersonal communication. In the following sections, the general concepts of entropy are first reviewed, then specific applications of various forms of entropy to interpersonal communication are addressed, and lastly the concepts are tied together in an analysis approach that can be used to measure the success of interpersonal communication strategies.

Thermodynamic Entropy

An important basis for the properties of entropy that apply to the measurement of interpersonal communication is thermodynamic entropy. Thermodynamic entropy is associated with energy, heat, and temperature [Ref. 7]. Thermodynamic entropy is limited by definition to values no lower than zero at absolute zero degrees Kelvin. Its

[4] This could apply to any number of communicators, but two simplifies the description.

maximum value is not specifically limited. The basic relation can be expressed by the "Gibbs" equation [Ref. 4] as:

$$\Delta G = \Delta H - T\Delta S \tag{3}$$

where ΔS is the increase in entropy as ability to do useful work is lost, T is absolute temperature, ΔG is change in free energy, and ΔH is the change in enthalpy (heat content).

The Boltzman/Schröedinger equation [Ref. 4] relates entropy to "atomistic disorder" introducing a symbol D (disorder, or ratio of final microstates to initial microstates). This form of entropy can take on values ranging from zero (unity order) to infinity.

$$S = k \ln D \tag{4}$$

In Eq. 4, k is the Boltzmann constant, 1.38×10^{-23}J/K. The Second Law of Thermodynamics assures that "order" in the universe will ultimately be lost. However, the existence of entities such as life and the generation of information show that order within subsystems can temporarily increase. In fact, the existence of human life coupled with learning and information is the most important example of entropy decrease and exergy increase we know of. This means that utilizing the theory of entropy can contribute to measured increases in the exergy-based quality of life (e.g., energy infrastructures) in the relative short term of human existence.

Communication Entropy

A similar concept to the above is communication entropy. Communication entropy, developed from earlier concepts by Claude Shannon [Ref. 2], is a metric that relates communication channel efficiency to the likelihood of communication entities. It can be normalized between 0 and 1 with highest entropy for optimally efficient systems. Shannon called this form of entropy a measure of uncertainty. For ordinary block coding (e.g., ASCII), high-entropy systems are most uncertain, the most efficient, and the most disassociated with meaningful information transfer. This is because maximum-entropy systems place minimal constraints on the transmitter, i.e., "random" information is available. Nonrandom information is an important potential means of decreasing entropy. The mathematical measure of Shannon communication entropy is:

$$H = -\sum_{i=i}^{j} p_i \log_j p_i \tag{5}$$

where there are j potential "messages" (units of information), the i^{th} having a probability p_i of occurring. Note that a natural logarithm is not used, nor is it necessary to be compatible with Eq. 1. A common approach in the literature is to use a base-two logarithm and measure multi-symbol entropy in terms of the number of equivalent "bits."

For our development, the form of the logarithm in Eq. 5 (more general than base two) is chosen so that the entropy can be normalized between zero and one.

From a transmitter's viewpoint, highest entropy systems are advantageous because they are most efficient and the transmitter can more freely choose information symbols. For example, the maximum solution to Eq. 5 occurs for equally likely (random) inputs. From a receiver's viewpoint, highest entropy randomness is associated with less noteworthiness, which reduces the most useful amount of received information (equal likelihood occurrences minimize noteworthy information). This is what is known in "game theory" [Ref. 8] as a zero-sum game (benefiting one entity is detrimental to another). However, we will show how to use particular strategies and the important lever of time to create mutual advantage and a beneficial non-zero-sum game.

As an example application of entropy metrics, "Unique Signals" [Ref. 9] are used in the U.S. weapons program for signifying an unambiguous intent to use a weapon. Unique Signals are carefully engineered to have high entropy for all subset bit lengths so that an unintended reception has minimal useful information. Conversely, transmission of intended Unique Signals conveys unambiguous low-entropy information. This property provides important insight into the enhancement of long-term interpersonal communication and into the different bases associated with transmission and reception.

As an illustration of Unique Signal entropy metrics, a communication channel that carries information in bits and has the same number of zeros and ones has unity entropy ($-\frac{1}{2}\log_2\frac{1}{2}-\frac{1}{2}\log_2\frac{1}{2}$). However, for a communication channel that carries three times as many zeros as ones (or vice versa), the communication entropy of the channel is $-\frac{1}{4}\log_2\frac{1}{4}-\frac{3}{4}\log_2\frac{3}{4}$ = 0.81. This maps to a trivial requirement on Unique Signals that the numbers of zeros and ones must be equal. Extending this concept to binary patterns requires defining a number of *n*-character "entities," indexed by *i*, that can be single bits or groups of bits. The probability of each of these entities (which can overlap) is derived from the maximum potential probability, corresponding to matching the frequency of appearance of the entities. For example, consider the 24-bit pattern given by Eq. 6:

$$\mathrm{P} = 0,1,0,0,0,1,1,0,0,0,1,1,1,1,0,1,0,0,1,0,1,1,1,0 \qquad (6)$$

The pattern has 12 *0*s and 12 *1*s, so $p_1 = p_2 = ½$, resulting in unit bit entropy rate. There are 6, 6, 6, and 5 transition pairs (i.e., 0 followed by 0, 0 followed by 1, 1 followed by 0, and 1 followed by 1), so there are four possible entities, and they have a bit-pair entropy metric of $-3\times\frac{6}{23}\log_4\frac{6}{23}-\frac{5}{23}\log_4\frac{5}{23}=0.998$. Note that this also minimizes statistical dependence of one bit on the next (first-order dependence). Since there are eight transition trios (two occurrences of 00 followed by 0, three occurrences of 00 followed by 1, etc, resulting in trio counts of 2, 3, 3, 3, 3, 2, 3, and 3) in the example pattern, the bit-trio entropy metric is 0.994. This minimizes second-order dependence. The above metrics are the highest that can be achieved, which contributes toward a near-optimum 24-"event" Unique Signal pattern. This concept can be extended to the remaining bit lengths and can be extended to non-uniform bit lengths, but there are many other considerations in choosing effective Unique Signal patterns [Ref. 10].[5] An interesting aspect of the relations of Unique Signals to interpersonal communication is that apparent communication isn't always representative of the real thinking of one or more of the communicators. Frequently, an improved picture is obtained over a period of time by asking questions in different ways and observing responses to other verbal and non-verbal stimuli. A high-entropy pattern can be established over time that comes closer to a true picture by combining random-appearing information in the same manner that a high-entropy sequential Unique Signal pattern can be used to distinguish random inputs from an unambiguous "intent" input. From an interpersonal communication standpoint, this means for example that communication should not be one-sided (it is helpful to avoid transmission dominating reception, or vice-versa), queries should not encourage unipolar responses (it is helpful to avoid multiple questions where the most "acceptable" response is always the same, e.g., "Yes"), and information should be transmitted and received in ways that appear near-random (using various approaches such as probing for responses, observing situational responses, adapting to the communication target, and all the while maintaining the goal of random-appearing communication mode).

Communication Entropy Encoding

In establishing the entities for communication, a "coding" strategy must be derived in order to represent the entities through the most effective expression possible. This can also be measured using entropy. There has been considerable work on data compression as a communication entropy-enhancing encoding technique. Shannon-Fano coding (now obsolete, but providing important foundations) was developed by Shannon and Robert Fano [Ref. 11]. This was essentially a "top-down" approach, which assigned ranked (high to low) probabilities to sets of symbols. For binary coding, the set was divided into an equally probable high group and low group. The first set was assigned the first bit value (e.g., *0*) and the second set was assigned the other bit value. Then the process continued until all bit assignments had been made. This procedure offered an important development impetus and was useful for a while, but was provably non-optimum.

In 1951, A Fano student at MIT, David Huffman, developed a bottom-up technique that was provably optimum for integer numbers of encoding bits [Ref. 12]. An example of Huffman coding is shown in the Appendix.

Huffman coding gives minimum information entropy (maximum information transfer) consistent with maximum efficiency (maximum communication entropy). The message for interpersonal communication is that the most immediately important messages should be expressed the most efficiently.

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[5] Higher-order Unique Signal independence is maximized using non-entropy metrics for reasons given in Ref. 9.

Subjective Entropy

Probability metrics imply objective information. For example, Shannon entropy and Huffman coding are based on the assumption that the information statistics are measurable and stationary. When use frequencies can only be estimated subjectively, modifications to the objective entropy measures are necessary [Ref. 13]. One reason for this is that probabilities are objective measures. Subjective estimates are more appropriately handled through possibilistic concepts, such as fuzzy mathematics [Ref. 14]. The most basic description of the difference between probability and possibility is that the probabilities of all possible outcomes must sum to one. Possibilistic numbers are uncertain, forcing a weaker condition: the ranges of possibilistic uncertainty can sum to less than or more than one, although the probabilistically objective outcomes within the ranges (when and if known) would precisely sum to one.

Semantic Information Entropy

Some communication is intended to transmit information, some to receive information, and some to exchange information. Semantics are important, because the information needs to be meaningful. But indirect communication may be optimal. Subtle messages can sometimes better avoid causing hurt and can discourage the establishment of defensive barriers. Effectiveness is an issue, where influence or action is desired. The time frame is a consideration, since some effects are intended to be immediate, and some must be established over a long-term. Latent effects (influence of previous background on current communication effects) show that information conveyed is dependent on history and context. The mode can be detached or in close proximity. The participants can be two or more peers, or can be in the "leader/follower" context. Once the actual "entities" of a potential communication and the likelihood of each entity have been established, semantic information entropy (henceforth termed in this paper simply "entropy") can provide a metric that helps determine whether the information is near random (high entropy) or contains real contribution (low entropy). Entropy metrics can also be used to track trends and illuminate interpersonal response dynamics. A core of these nuances is selected for development in the remainder of this paper.

In addition to transmitted information and communicated information, received information is important. In other words, information intended to be transmitted must be understood by the recipient. When one sends information that is not understood or is understood to lack meaning, the semantic content is low and the entropy metric should be high. An example of the former is words spoken in a language that is not understood by the listener. An example of the latter is a vacuous greeting such as "Hi, how are you?" From a communication entropy viewpoint, the channel is mostly wasted. However, when people communicate, the prior establishment of a common context can facilitate semantic understanding. This illustrates that there are compelling social and bonding values to preliminary exchanges, as a common basis for understanding is built. When a semantically important message is to be sent, following establishment of a common context, it should be expressed concisely so it will receive high attention and there will be no misunderstanding due to obfuscation. Examples are “Listen!” and “You’re fired!” If prior context has been established, the meaning is not likely to be missed.

Where messages are intended mostly for establishing a common social context, conventional entropy appears high, when viewed in the short term. However, this type of entropy must be measured with the objective over time in mind, also recognizing that an up-front investment is made with the expectation of a long-term payoff. With these considerations, the eventual value of context-oriented exchanges can be consistent with low entropy. This is because social entropy effort can form a basis over time for more efficient conveyance of low entropy messages that are basic to semantic communication. For example, carefully constructed social relations in a marriage can lay a foundation for unmistakable information through something as simple as an arched eyebrow. Measuring the intent of such targeted exchanges requires a low-entropy metric.

Stimulus/Response Strategies

There are various forms of stimulus/response interactions. When one person questions another and listens to the answer, this is straightforward. But the information obtained may not be optimum. For example, a manager might ask an employee, “What do you really want to do in your job?” If the answer is “Whatever you want me to do,” or “Anything,” the interchange is not particularly productive. These types of responses are likely caused by fear about how the information might be used (lack of trust). Similar to the concepts outlined in the previous section, high-social-entropy communication can be used to create a trust background for a communication stimulus for which the response has a high semantic value when associated with the stimulus.

Another type of stimulus/response is to observe the response to an external stimulus. A situation might force a response from an individual that is more informative than a question might be. For example, one person might ask another “Do you trust me?” and receive “Yes” as an answer. Alternatively, the respondent might be discovered trying to hide information from the questioner, which would display lack of trust. In the latter case, the stimulus might have been inadvertent, but the action can be more informative and honest than the response “Yes.” This is an illustration of “Actions speak louder than words.”

Latent Effects Entropy Relations

The actual interpersonal communication experience is generally a combination of the previously discussed modes. Combining these in a way amenable to quantitative analysis requires use of a modeling decomposition. A latent effects decomposition [Ref. 15] is of particular interest, because it demonstrates a cascading series of effects. An example is indicated in Figure 2 below. This is a simplified structure with a single feedback path and no time dynamics, but it illustrates some important points. Working from lower left to upper right, the first module represents groundwork in establishing a long-term relationship, establishing a common context, and building trust. The second module represents information gathered that helps establish a background portrait. The third module represents information and guidance that is to be conveyed. The fourth module represents imperatives of importance to be unambiguously given, where there are latent effects influences from the three earlier modules. The feedback path accounts for learning, adaptation, and strategy changes.

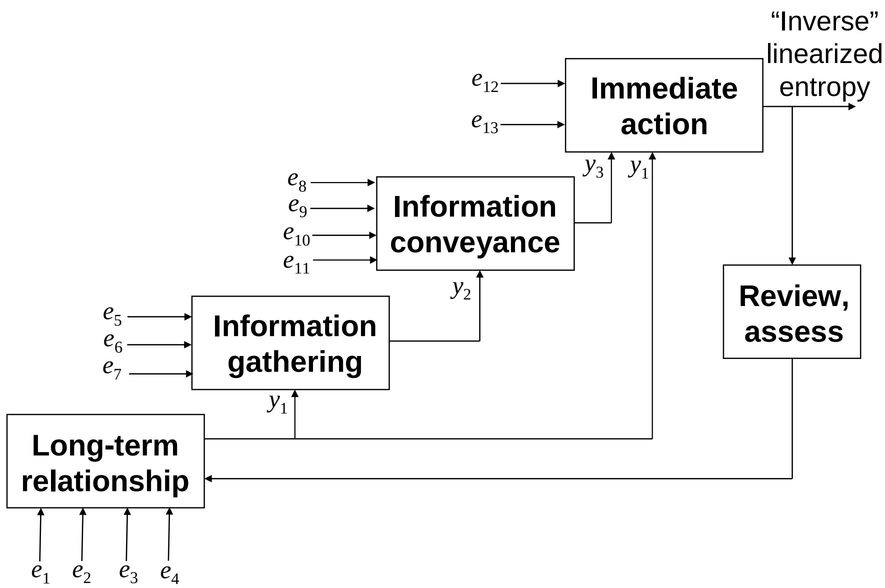

Figure 2. Example Latent Effects Entropy Structure

There are "primary" inputs to each module and "secondary" inputs from one module to the next. In the Figure 2 example, there are shown four modules, 13 primary inputs, and four secondary inputs (y_1 used twice). Not shown are mirror-image negative inputs corresponding to each of the inputs in Fig. 2. This is necessary to establish a computational balance, as will be shown below. The inputs are denoted as e_i. The primary input values (range [0, 1]) represent effectiveness for the specific information entity used. The primary inputs are proportional to enhanced communication. Values for all inputs can have uncertainty (e.g., possibilistic).

Module outputs (the y_{i}) represent the entropy-related result of the process indicated by each module. It is desirable for both these outputs and the secondary inputs to represent the module contribution to the interpersonal communication process, with higher values representing greater contribution. Since this is the additive inverse sense of the entropy (greater entropy is less valuable), the conversion from inputs to outputs requires intermediate representations for the possibilistic entities. The first intermediate step is to derive quality-related entities that are analogous to probabilities, but which are possibilistic. We term these entities "qualitivities" here. These must sum to one for an entropy-related calculation, just as the probabilities in objective entropy sum to one. Since there are $2n$ inputs (including the mirror-image inputs), the maximum-entropy value for each would be $1/2n$. This corresponds to an entropy metric of one. Increasing effectiveness of communication reduces entropy by forcing the inputs away from the equally likely value, while assuring that they still sum to one. We choose to let positive input e_is increase the numerator of the qualitivity linearly from 1 toward n. The mirror-image balancing negative inputs decreases the numerator of the qualitivity linearly from 1 toward zero. In order to assure that the sum of the qualitivities (which are analogous to uncertain possibilities) must be one, and in order to associate outputs with the quality of communication, there are two basic steps (Eqs. 7 and 8). The first step accounts for deviations (positive or negative) from equi-possible reference points. The structure in Eq. 7 assures that the sum will be one. Calculations for the example will use an interval limit of the possibilistic functions, meaning that only a lower and upper bound will be indicated, although the extension to more general possibilistic functions is straightforward [Ref. 14].

The first step in normalizing the deviation from the equi-possible reference value ($1/2n$) at each module is to convert these inputs into qualitivity, q. Each positive input is converted by the first of the following equations; each negative is converted by the second.

$$q_{l_i}{}^{+} = \frac{2e_{l_i}{}^{+} n_l - e_{l_i}{}^{+} + 1}{\sum_{i=k+1}^{n+k} (2e_{l_i}{}^{+} n_l - e_{l_i}{}^{+}) - \sum_{i=n+k+1}^{2n+k} e_{l_i}{}^{-} + 2n_l}$$
$$q_{l_i}{}^{-} = \frac{1 - e_{l_i}{}^{-}}{\sum_{i=k+1}^{n+k} (2e_{l_i}{}^{+} n_l - e_{l_i}{}^{+}) - \sum_{i=n+k+1}^{2n+k} e_{l_i}{}^{-} + 2n_l} \quad (7)$$

Here, $2n_l$ is the number of inputs to module l, and k is the total number of inputs in modules numbered less than l. This derives qualitivity for each primary input, e_i, to each module, l.

In interval analysis, each equation has to be solved twice for interval numbers, once for the lower bound, and once for the upper bound. The upper bounds of the positive qualitivities are derived from the upper bounds of the positive inputs and the upper bounds of the negative inputs. The lower bounds of the positive qualitivities are derived from the lower bounds of the positive inputs and the lower bounds of the negative inputs. The upper bounds of the negative qualitivities are derived from the lower bounds of the positive inputs and the lower bounds of the negative inputs. The lower bounds of the negative qualitivities are derived from the upper bounds of the positive inputs and the upper bounds of the negative inputs.

The second step provides for the calculation of entropy, additive inversion to match the polarity of the inputs (and be compatible with quality), and linearization to compensate for the logarithmic function in the entropy calculation. The additive inversion is accomplished by subtracting the entropy from one. The linearization uses a quantity a_l, which is the average of all positive inputs to module l. Additive inversion is required in Eq. 8, because each input represents a mode of communication with a particular entropy-reducing aim. The better this mode is, and the better it can be done, the higher the input value. In this step, the output of each module is calculated as:

$$y_l = (1 + \sum_{i=k+1}^{2n_l+k} q_{l_i} \log_{2n_l} q_{l_i})^{\frac{1}{10a_l^2}} \quad (8)$$

The upper bound of each y output comes from the lower bound negative qualitivities and upper bound positive qualitivities. The lower bound of each output comes from the upper bound negative qualitivities and lower bound positive qualitivities.

The module outputs are the desired linearized inversed entropy. Importance (rank of contributors to the final result) and sensitivity (rank of most potential for improvement) can be derived by first using the mean value of each input in deriving a reference output. For importance, the mean value of each input is reduced by a fixed amount (the mean value), and the difference from the reference is computed. Then all inputs are ranked, normalized to one. For sensitivity, the mean value of each input is increased a fixed amount (to one), and the difference is computed. Then all inputs are ranked, normalized to one. Importance and sensitivity can be calculated at any point in the latent effects structure. For the example problem, we chose the final output for these computations in order to assess the ultimate effect of an important directive.

The inputs for this example structure are:

e_1 = lack of deceit (conveying that the initiator will not give dishonest information to the recipient).
e_2 = openness (conveying that the initiator will not hide information from the recipient).
e_3 = goals (determining from the recipient what they would like to be doing professionally)
e_4 = support (offering to find ways to help the recipient toward those goals).
e_5 = dislike (aimed at finding what things about the job are most disliked).
e_6 = like (aimed at finding what things about the job are most liked).
e_7 = indirect (information about the person received from other sources).
e_8 = skills (in order to improve job performance, recipient must develop new skills). The intent for this example is that the employee needs to improve job performance or leave.
e_9 = jobs (in order to be successful, recipient should consider changing jobs).
e_{10} = example (offering example of what another successful person is doing).
e_{11} = salary (salary treatment corresponds to job performance).
e_{12} = order (direct command).
e_{13} = demeanor (body language where it is sensed necessary in reinforcing order, e.g., stern expression).

Here are trial inputs for the example:

Table 1. Example Inputs

e_1 = 0.2, 0.4	e_2 = 0.3, 0.5	e_3 = 0.7, 0.8
e_4 = 0.3, 0.4	e_5 = 0.3, 0.5	e_6 = 0.7, 0.9
e_7 = 0.6, 0.8	e_8 = 0.5, 0.7	e_9 = 0.5, 0.6
e_{10} = 0.6, 0.7	e_{11} = 0.4, 0.6	e_{12} = 0.8, 0.9
e_{13} = 0.7, 0.8		

The outputs for the four modules are shown in Fig. 3 as displayed through a demonstration software program.

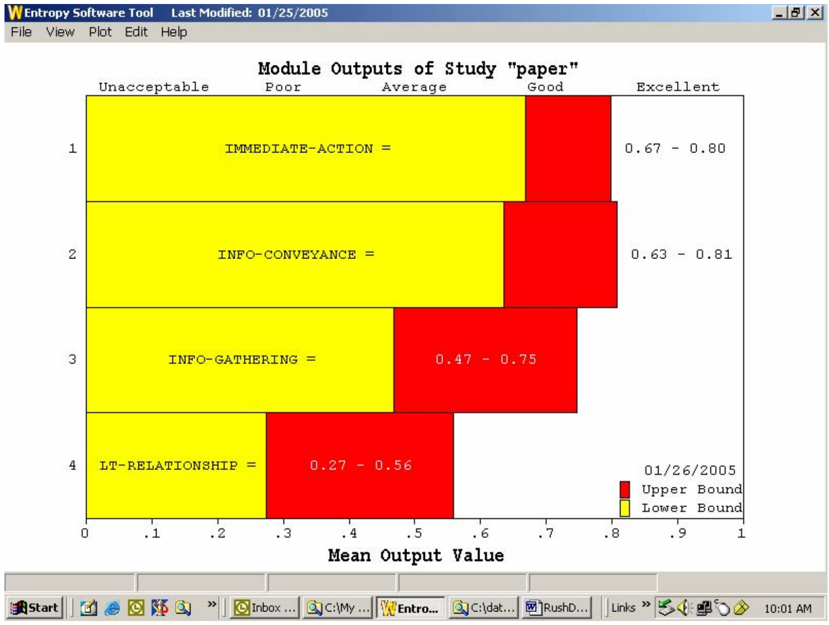

Figure 3. Module Output Values for Example Problem

The importance and sensitivity are shown in Figs. 4 and 5.

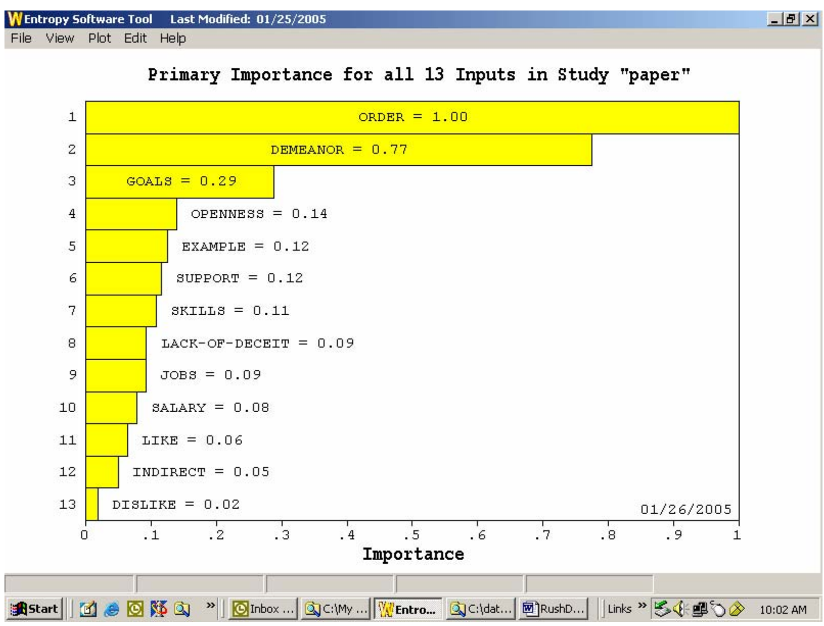

Figure 4. Importance Ranks for Example Inputs

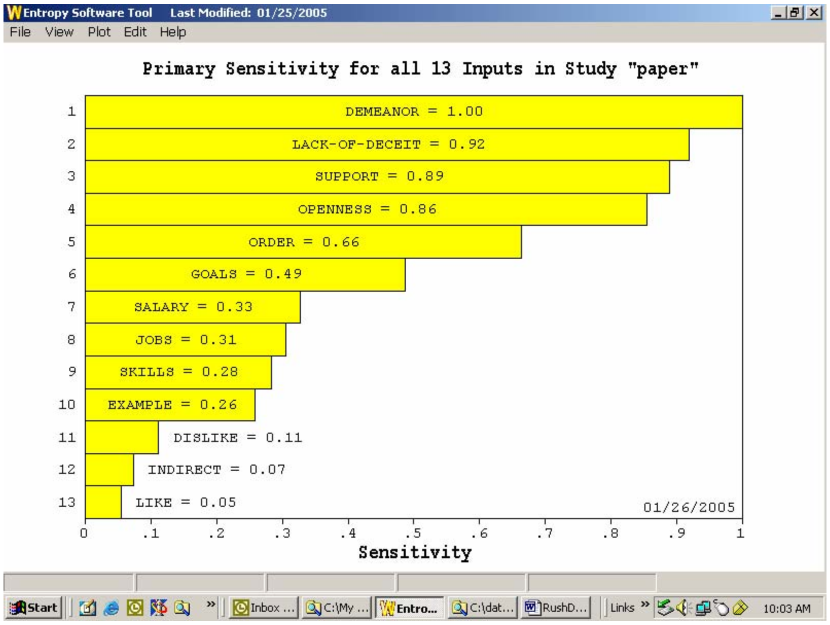

Figure 5. Sensitivity Ranks for Example Problem

Conclusions

Interpersonal communication can temporarily reverse the ravages of entropy, and entropy can be used to develop a metric of the degree of success. Interpersonal communication is so human-dependent that it is difficult to develop prescriptive communication methodology, and it is even more difficult to quantitatively analyze the process and measure its success. However, the work described in this paper, based on entropy analysis, Unique Signal properties, and latent effects relations, is a promising approach to improved communication strategy and success metrics. The work shows the importance of latent effects in establishing understanding through a common context and accumulated information, and the conveyance of information as background and as clear imperatives. Additional work could prove valuable. For example, we addressed only a subset of the interpersonal communication spectrum, and we have not yet completely validated the analytical approach. This additional work is planned as a follow-on effort.

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Appendix: Example of Huffman Coding

In order to demonstrate Huffman coding, first assume six letters used in a message with the frequencies shown below, where they have been ordered from the lowest frequency at the top to the highest frequency at the bottom:

Letter	**Frequency**
S	4/65
I	1/13
N	7/65
T	8/65
P	12/65
E	29/65

The first two letters are given opposite values of the first encoding bit (e.g., *1* for S and *0* for I) and their frequencies are added for re-ranking and re-tabulation:

Letter	Frequency
N	7/65
T	8/65
S = *1*, I = *0*	9/65
P	12/65
E	29/65

The process continues:

Letter	Frequency
S = *1*, I = *0*	9/65
P	12/65
N = *0*, T = *1*	3/13
E	29/65

Letter	Frequency
N = *0*, T = *1*	3/13
S = *11*, I = *10*, P = *0*	21/65
E	29/65

Letter	Frequency
E	29/65
N = *00*, T = *01*, S = *111*, I = *110*, P = *10*	36/65

Letter	Frequency
N = *000*, T = *001*, S = *0111*, I = *0110*, P = *010*, E = *1*	1

Reading a coded word (e.g., TEST) from this encoding requires processing exactly the required number of bits for each character to get a match. For decoding, bits are considered sequentially until each coded character is identified unambiguously. For example there are five characters whose code begins with *0*, but beginning with *1* is unique to E. Therefore *00110111001* cannot begin with E, but the other five letters are possible. Two letters begin with *00*, so T is not decoded until the third digit. After this, the fourth bit must be E, since the other five characters start with *0*. Then it takes four bits to distinguish S, and the last three bits are again decoded as T.

Appendix A.2

A Strategic Technology for Risk Management

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Key words: technology of management, productivity, personnel, mathematical analysis, metrics

Abstract

We are developing innovative technology for enhancing risk management and personnel performance. The intent is to improve management and leadership contributing to sustained productivity and safety in critical operations through a combination of strategies, mathematical analysis metrics and decision aids, and morale improvements for involved personnel. The resource base utilized includes research on team-oriented interpersonal interactions, post-accident corrective recommendations, and new analysis development. The metrics contributing to decision-aid analysis must be weighed against financial resources and implementation time. Although mathematical descriptions are obviously useful, many “soft” factors involving human motivation and interaction among weakly related factors are analytically challenging. In addition, motivation is significantly influenced by “latent effects,” which are pre-occurring influences. One example of these is that an atmosphere of excessive fear can suppress open and frank disclosures, which can in turn hide problems, impede correction, and prevent lessons learned. Another example is that a cultural mind-set of commitment, self-responsibility, and passion for an activity is a significant contributor to the activity’s success. Strategies for rewarding personnel performance can contribute to enhanced morale, so insight into the rewards evaluation process is an important contribution. We also describe an approach for quantitatively analyzing latent effects in order to link the above types of factors, aggregate available information into quantitative metrics that contribute to strategic management decisions, and measure the results, using a software tool. The approach also portrays the inherent uncertainties, and allows for tracking dynamics for early response and assessing developing trends. The analytical model development is based on how factors combine and influence other factors in real time and over extended time periods (latent effects). Potential strategies for improvement can be tested and measured using analytical simulation. Input information can be determined by quantification of qualitative information in a structured derivation process. The result is a strategic technology that can potentially contribute to improved management, leadership, and personnel performance.

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Introduction

Modern organizations that must be productive and maintain safety in critical operations are faced with complex decisions and tradeoffs for managing personnel[9]. It is important to strategically influence their performance through leadership and to maintain their morale. However, personnel actions are difficult to control and predict. Decisions that must be made under these conditions involve complex factors that are not always clearly tractable. A strategic plan and analytical validation that can account for these factors and can be used as a decision aid could be an important contribution to productivity and safety.

Organization missions are facilitated through management (e.g., decisions, resource allocation, personnel assignment), leadership (setting examples and motivating personnel), and personnel effort (using technical skills and effective performance). Accomplishing missions while ensuring safe and productive operation can be made more likely through management and leadership that results in effective teamwork, synergistic performance, and personnel morale. These three aspects are emphasized in the following three sections. Combining personnel into teams with common goals is presented in the following section. The intent is to describe developments involving interpersonal communication, including factors that facilitate meaningful information, personal motivations, interactive feedback, pattern-based intuition, collective aggregation effects, self-actualized passion, and conflict resolution. The next section identifies attributes such as organizational strategic vision and goals, independent assessment, fear of problems, judicious risk-taking, bureaucracy, communication venues, culture, and analytical capabilities. The last of the three sections demonstrates the effects of rewards management on performance. The concluding section ties these three sections together, assesses the status of the work, and suggests future directions.

Some salient results that contribute to the overall strategy are:

8. The strategic and the analytical structures help illuminate the human process, including latent factors such as fear, lack of full disclosure, "brainwashing", and dedicated motivation. This is a promising approach to the relatively unsolved problem of estimating likelihood of types of performance and safety failures.
9. The decomposition is tied to a mathematical analysis to help understand processes, interrelated factors, effects of dependence, and aggregation of inputs into meaningful decision aids.

[9] The term "personnel" is used herein to denote "staff" or managed personnel.

10. The expert elicitation process blends inputs from operations “owners” with more global information.
11. Possibilistic uncertainty processing allows appropriate representations of subjective uncertainty and aggregation of that uncertainty in the latent effects structure. This processing also blends (through hybrid analysis) with objective data, where available.
12. The combination of “scoring” risk of various types of problems, along with trends and early alerts allows for a realistic global view of productivity and safety impact.
13. The business-oriented top-down system process for subjecting requirements and responses to cost-benefit processing under normal, degraded, and emergency conditions is useful as a decision-aid.

These results will be shown to be part of an overarching structure for establishing a strategic approach along with a corresponding analytical basis.

Basic Team Relationships

Interpersonal relations are basic in establishing team management strategies and in influencing personnel communications, thereby enhancing performance. Some observations from researchers on the subject and some new developments [Ref. 1] with respect to collective teams (i.e., teams having a common purpose accomplished through divergent skills and viewpoints) are described in this section.

<u>Establishing a Common Context.</u> People relate best to information relative to a common context. Part of this is because of the comfort of familiar background, but another important factor is that information is best derived as a relative change from an established baseline. In other words, people can more readily react to deviation from a reference rather than an absolute. As a result of this observation, optimum communication is enhanced by “getting to know” people. This requires investment of time to establish a relationship. It is obviously more difficult for transient or dynamic teams. However, when such a background can be established, communication of crucial information sent and received is more likely to be clear and open.

<u>Self-Centered Personal Motivation Channeled to a Common Benefit.</u> Changing basic individual selfishness to team selflessness requires specific leadership steps. One example starts from the basis of a “zero-sum” or “win-lose” situation (e.g., where individuals perceive that they benefit only at the expense of others). An effective leader can first identify demonstrations of “orthogonal” efforts that benefit one person without hurting others. In the team concept, a “Nash Equilibrium” [Ref. 2] is sought (e.g., where no person can benefit by individually changing strategy while the strategies of others remain unchanged). This step paves the way for a true selfless team strategy, known as a “Pareto-Optimal” outcome [Ref. 3] (e.g., where no joint deviation by a subset of team members can improve the performance of one of them without degrading another). Under this strategy, each team member is led to see the success of the entire team as being the most personally beneficial.

From "Fear" to "Passion." The best contributors to team effort operate on a basis of passion for the team mission, not fear of criticism or failure. The role of leadership is to discourage fear by encouraging team members to freely communicate with leadership, with team interfaces, and with each other, not being afraid to identify problems or raise concerns. Reducing fear generally enables passionate participation. Passion is not easily instilled where it is not natural, but can be encouraged by the example behavior by effective leaders and team members.

Self-Actualization. An acknowledged means of personal and team improvement is self-motivated learning of technical and interactive skills. This depends on a focused passion through self-enabled involvement [Ref. 4]. To accomplish this, team leaders should seek people whose passion fits with the team needs. Where this is not practical (e.g., lack of freedom in team selection), changed behavior toward self-actualization should be encouraged.

Interactive Feedback Facilitates Dynamic Strategies. Since humans respond to change, and since improvements require change, static situations (e.g., "status quo") are usually undesirable. One example of dynamic communication is for a team leader to continually assess team members (including self-assessment) in order to provide optimum guidance characterized by the dynamics of change. This means that team leaders continually look for new information that might influence the team strategy. One contribution is derived from asking questions and evaluating responses. Another is to observe situations and derive information from response to the situations. We term these information sources "Unique Signals" [Ref. 5] in that unambiguous patterns are sought through strategic modes of information-gathering.

Intuitive Response. Successful team members may appear to react intuitively to job-related challenges. Humans build up a reference catalog of patterns that guide such responses (intuition is influenced by pattern recognition). Establishing the optimum reference patterns in people's experience is essential in assuring desired unguided response. Team leadership depends on continually honing the desired passionate, selfless responses so that they become ingrained patterns, i.e., intuitive.

Conflict Resolution. In team situations, as well as in personnel-management interactions, conflict is inevitable. A successful team tends to self-police team members to be selfless contributors. There will be differences of opinion, and mistakes will be made. Successful conflict resolution is enhanced by surfacing conflicts so that they do not grow out of control. Discussion about how various sides see "the message" from the source of conflict is beneficial. The optimum response to a perceived "misbehavior" is generally what is called "tit-for-tat with forgiveness" [Ref. 6]. This means that the "offending" behavior is clearly identified and responded to in a non-deceitful, non-vindictive manner, and then the air is cleared with no hidden "grudges."

The results described in this section provide a foundation for effective team performance. We can build on this foundation by observing some real-world safety stresses that have resulted in important additional management lessons. This adds perspective on how many important considerations transcend team performance.

Overarching Root Cause Factors

Because of fairly recent high profile accidents [Refs. 7–15] (e.g., the tail separation on American Airlines flight 587 and the loss of the Columbia Space Shuttle), there is considerable interest in reactive root cause analysis and possible pre-emptive approaches. Of course, proactive measures are preferable, but since some foresight can be derived from historical lessons, this section addresses lessons first, before considering proactive safety analysis. Examination of documents such as the Columbia Accident Investigation Report [Ref. 9] helps demonstrate that physical analyses have not proven sufficient to give a prediction of reality. Realistically managing use of analysis results is essential. Organizational issues are equally important. In addition to keeping a technological edge, the *technology of management* is critical.

There are a number of factors that have been pointed out as a result of accident and incident investigations. Some of these are derived from material in the references; others have been deduced from the authors' experience in various organizations.

<u>Categorization of Factors.</u> It is helpful to partition factors in order to facilitate understanding and because addressing various factors takes advantage of a comprehensive suite of expertise. For these reasons, this section is organized by categories. As may be obvious from the discussion, there are two salient complicating effects. One is that the factors and their categories are interrelated, not independent. Second, some of the relations require a special kind of virtually "paranoid" thinking to determine the kind of unexpected effects that might occur (this is termed "red" thinking in Ref. 16).

<u>Formulating and Communicating a Strategic Mission Vision.</u> For the most effective performance, everyone in an organization needs to understand the mission of the organization, the strategies being pursued, the specific goals and objectives, the requirements, and the impacts of failures. These factors are best understood and supported if they are logical and consistent, with any necessary changes explained. The intent is to obtain and maintain "buy-in" by the involved personnel. For example, one organization we observed (responsible for energy and transportation critical infrastructures) has formulated a comprehensive strategy for the path from the present into a more sustainable future, encouraging ideas and contributions from all members of the organization. This has clearly built support for the organization and generally increased morale. In contrast, we found that another organization significantly changed its mode of operation over the past decade from vested responsibility of its personnel to management filtering of personnel recommendations. The personnel received no explanation of the reasons for the shift, and morale generally plummeted, as it was perceived that the filtering was not logical or consistent. The implications are that personal and team support for a mission can have significant effects on safety.

<u>Valuing Independent Assessment.</u> Independent assessment has minimal effectiveness if not valued. Our investigation found that strong independent assessment is one of the

most reliable predictors of safe operation. Organizations that treat safety assessment as a requirement, but do not give it weight reap little safety benefit. We observed some operations where dissent with majority views was encouraged, explored in detail, and recorded, even when the minority opinions were not enacted. One other organization tolerated ridiculing independent assessors with terms such as “safety zealots,” “ankle-biters,” “whiners,” and “leeches.” When dissent is discouraged and pride in findings is replaced by fear of findings, safety failures are almost certain to follow. One subjective metric in this regard is to determine whether the organizational philosophy is that systems must be “proved safe” (assumed unsafe if there is any doubt) or “proved unsafe” (assumed safe if there have been no failures). This is an important distinction. As an example, we found one organization that took the position that its designed systems were considered safe unless a formal, analysis-based, test-verified, formal-methods proof could be supplied showing that it was not safe. This clearly minimizes the effectiveness of independent assessment. Another indicator is management rewards for independent assessment performance.

<u>Fear of Problems.</u> Where management survival depends on not “making waves,” problems are eschewed throughout the organization. This means that management personnel view problems that surface as negative for their image, and this tends to make them reluctant to fight to resolve safety issues. In the Columbia Accident Investigation Board report, this problem was pointed out as a tendency of engineering personnel to be “overly polite” in surfacing potential safety problems, which consequently were not viewed as critical. A more productive environment is one in which problems are understood and resolved up front. This was put well by one company president, who said “We should respond to any problem reported to us with an honest statement of ‘How can I help?’ and then proceed to do so.” To establish a strong safety culture, it is even better for upper management to *seek out* potential problems.

<u>Judicious Risk-Taking.</u> Since much is learned through “failure,” failing is not always bad. Safety risks should be taken only with cognizance of the likelihood and consequences. One danger is that the most productive personnel are often those who exemplify a “can-do” attitude (difficult challenges are perceived as temporary barriers to be overcome). The Apollo program is a testimony to this type of spirit. This attitude is especially valuable for “blue-thinking” (function-oriented) people, but the risks must be carefully assessed by “red-thinking” (risk-sensitive) people. This balance is the “judicious” part of risk-taking.

Another aspect is offered by personnel who are willing to take on new educational or job challenges. Learning to use new technological tools is a similar consideration. Management decisions to take on projects others fear also fits this category.

<u>Willingness to Assume Responsibility and be Accountable for Decisions.</u> This means taking responsibility and personally accepting the risk inherent in dealing with risks. Many management decisions have consequences that can either be accepted in the spirit of accountability or “spin-minimized” in what amounts to cowardice. One approach we

have seen when requirements cannot be met with acceptable risk is to enunciate modified requirements that the accountable decision-maker is willing to accept.

Organizational Complexity and Bureaucracy. A significant number of organizations we observed tend to operate less safely as they "age," especially if they become more organizationally and technically complex. Increases in technological complexity tend to cause the supporting management bureaucracy to become more cumbersome and the decision-making process to become more obscure. Lines of communication can become more obstructed, communication of views from lower level personnel to upper level management can become more filtered, and the application of creativity can become stifled. As an example, the CAIB report cited the response to increasing technological complexity. We investigated another organization immersed in technological growth that set up artificial barriers to open communication and filtered personnel views before reporting to upper management. This tends to portray an unrealistically optimistic image and reduces motivation to correct problems. However, this is not necessarily predestined. One airline we observed has grown substantially and still maintained crisp lines of communication, along with corresponding operational safety.

Communication Venues. Some of the most successful organizations we have observed have open communication at all levels of management. In some organizations, high-level managers visit personnel, asking what concerns they have. Unfortunately, others insulate personnel from all management except immediate supervision. This encourages the previously mentioned "over-politeness" (important warnings to management couched in overly cautious terms can result in weaker meaning).

Resource and Schedule Pressures. "Faster, safer, cheaper" is unrealistic if carried very far. Although resource and schedule pressures are a necessary part of many business decisions, there are obvious implications. Many organizations have policies stating that safety has first priority among competing considerations, but treat the policy with lip service. Pragmatically, it is difficult to adhere to a "first priority" without some indication of the amount of favoritism amongst competing tradeoffs. Another consideration is that it is tempting, where a history of safety successes is building, to become overconfident. This can encourage safety compromises in response to schedule and monetary pressures.

Personnel Culture. There have been numerous studies [Refs. 7, 12, 13, 15] of the role of "culture" (attitude of employees and management toward safety, commitment to mission, passion for responsibility, persistence, ethical behavior, desire for communication, morale, selfless sharing in the interest of team performance) in operational safety. One important behavior characteristic corresponding to poor culture is the "check-the-box" approach, where requirements are met almost solely in order to avoid punitive response. In contrast, a desirable culture is to look behind the requirements to the intent and to be alert to problems that might not be addressed by requirements.

Management Culture. Although culture applies equally to personnel and management, our experience is that good personnel culture is difficult to maintain under bad management culture. One illustrative example came from an accident investigation we learned about. The accident resulted from failure of a particular part. The initial management response was to cite the cause of the accident as the faulty part, and the remedy was to not use the same part again. Eventually, outside pressure resulted in a more thorough and effective investigation. The circumstances leading to the use of the part were explored. A number of other system operation failures were identified that could easily have resulted in a more serious catastrophe. The difference between the easy path of blame on the most obvious final contributor and the more thorough identification of other problems that needed to be addressed demonstrates why management safety culture is so important.

The Inherent Environment. The operating environment (business competition, legal and regulatory constraints, financial limitations, labor union rules, weather effects, international agreements, etc.) is a strong influence on operation, but mostly hard to change. However, recognition of the effects has benefits, such as increasing awareness of the inherent problems. There is also the potential to seek long-term improvements. This effect has frequently been identified as a major contributor to decisions that degrade safety.

Analysis Capabilities. Analytical understanding can contribute to safety assessment, intelligent resource allocation, operational decisions, and robust design features. Impressive analysis advances have been made over recent years. A caution is that humans have a tendency to be overconfident in their understanding and “flawless foresight” [refs. 16, 17]. Historically, accidents happen at a much higher frequency than would be expected statistically based on prior analysis uncertainty [refs. 17, 18]. It is important to validate analytical approaches and results through testing, simulation, and comparisons with actual outcomes.

Interfaces and Interferences

All of the weaknesses described in the preceding section have been linked to safety failures of various types and magnitudes. Although it is helpful to address correction of each problem individually, it can potentially be more beneficial to address the overall situation as a “system,” leading to remedies that address each of the above problems, but provide a more coherent approach, considering interfaces and “interferences” [Ref. 19]. The categories discussed in the previous section are diagramed in Fig. 1. The categories are arranged such that items toward the lower and left part of the diagram generally influence items toward the upper and right part of the diagram. The arrows show the most significant influences. Most of the connections signify intended influences, but from a red-thinking viewpoint, there are potential interferences that are not indicated. For example, fear of problems can degrade culture. A structure such as that shown in Fig. 1 provides a guide for identifying problems, and also provides a model for analysis (demonstrated in the following development).

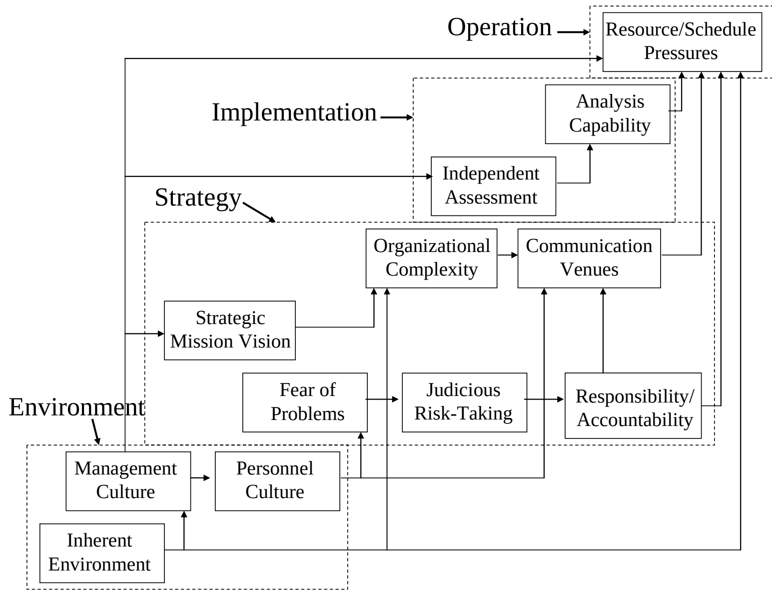

Figure 1. Interrelation of Categories

The dashed boxes in Fig. 1 group the categories into modules (Environment, Strategy, Implementation, and Operation). This grouping is partly arbitrary, and it is not necessary, but it is done here in order to simplify the demonstration following of how mathematical analysis of the overall structure can be formulated. There are various other ripple effects that are more complex than can be portrayed in such an illustration. For example, the independent assessment function, which appears under the Implementation module, has a path from management culture. This means that the seeds to the success of independent assessment are planted proactively early in the Environment category due to management approaches that value independent assessment, assuring that the function reports to high levels of management, and arranging as much independent funding support for the activity as possible.

Modeling the Overall Effects of the Identified Factors

This development addresses a frequently neglected aspect of analysis, modeling the previously mentioned strategic "technology of management.[10]" The problem involves bringing quantitative metrics and complex interrelations to bear on assessment of the operational aspects of the organization (management philosophy, communication venues, personnel commitment, selfless sharing, etc.). Although the inputs to these sorts of factors are subjective, constructive input guidance can be given that helps make the entries consistent and meaningful. The mathematical aggregation of the input entries is done with due consideration of the inter-module linkages, such as those illustrated in Fig. 1. This is done through a "latent effects model" (illustrated at a high level in Figure 2).

[10] "Technology of management" refers to a systemic model that both represents a strategic approach and provides a mathematically analytical representation of the overall "system" comprising individual functions.

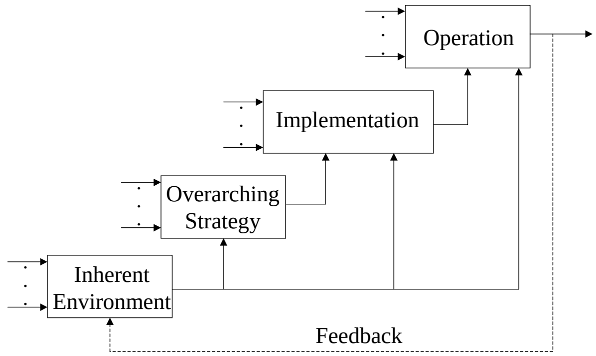

Figure 2. High Level Latent Effects Model

In this approach, any number of modules can be utilized, and each module can result from other latent effects structures. Here we show four modules for illustration. The process illustrated begins with the overall environment tailored to a particular organization, introduces an overall strategy for establishing a top-to-bottom safety culture, demonstrates specific implementations to support the strategy, and includes operational factors for monitoring organizational performance, encouraging personnel "self-actualization" and development, while providing for decision-support mechanisms that contribute to the overall approach.

This provides the framework for a comprehensive mathematical analysis [Refs. 20, 21]. Example inputs and input weights are specified in Fig. 3. In this example, only the most significant latent effect "feed-forward" paths are shown. The feedback path allows for changes that are made to improve the operation. The stability of this feedback structure depends on intelligent decision-making.

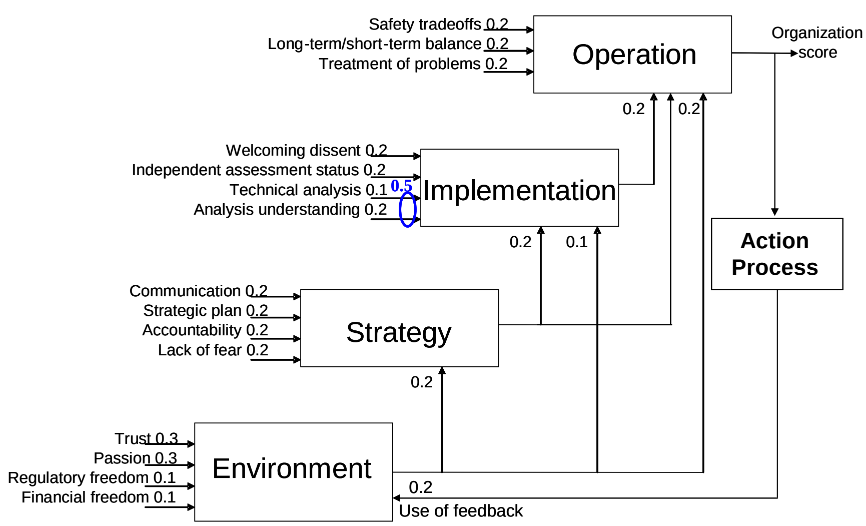

Figure 3. Inputs and Weights for an Organization Assessment

The ellipse denotes 0.5 dependence between two of the inputs. Dependence among inputs can vary from zero (independent) to one (completely dependent). The weights, which sum to one for each module, indicate the relative significance of the factors considered as inputs for a particular class of organizations used as an example. The weights and amount of dependence were determined through expert elicitation of a selection of people familiar with these types of organizations. Weights for inter-module connection indicate the relative significance of "secondary" inputs generated by a module. Each input value is specified subjectively in the range of zero to one, including uncertainty, in order to rate success[11]. The mathematical computation used is analogous to a weighted sum of inputs multiplied by the corresponding weights and added linearly (Eq. 1), although we actually use "soft aggregation" [Ref. 20].

$$m_j = \sum_{i=1}^{n} w_i x_i \qquad (1)$$

In Eq. 1, m_j is the result for module j, w_i is the weight for input i, x_i is the value for input i, and n is the number of inputs to module j. This approach has the desired mathematical properties, i.e., it assures that the module outputs are also in the range zero to one, the output cannot be larger than the largest input or smaller than the smallest input; and if all inputs are the same, the output will be the common value.

The relevance of the analysis approach is that safety-performance of an organization and/or sub-organizations can be measured (including portrayal of the inherent uncertainty), contributors to overall success can be identified through a ranked list, the most cost-effective or resource-effective areas for improvement can be similarly shown, the potential benefits of a variety of decisions can be measured, trends can be tracked, and early alerts can be constructed for proactive management action.

The derivation of mathematical metrics for subjective inputs follows an expert elicitation procedure. The input guidance is that numbers in the approximate range of 0.0 to 0.2 represent a situation that is "unacceptable," numbers in the approximate range of 0.2 to 0.4 represent "poor," numbers in the approximate range of 0.4 to 0.6 are "average," numbers in the approximate range of 0.6 to 0.8 are "good," and numbers in the approximate range of 0.8 to 1.0 are "excellent." Uncertainty (due to multiple expert opinions or due to unsure values) is represented by intervals (lower and upper bound). Eq. 1 (or its soft aggregation equivalent) can be used for deriving lower bounds of results from the lower bounds of the operands and upper bounds of results from the upper bounds of the operands.

A Brief Example

We prepared inputs to the organization model for one organization that we studied. These inputs are shown as intervals in Table 1.

Table 1. Organization Study Inputs

Inputs	Interval

[11] It is essential that this process involve a structured, guided, expert elicitation.

	value
Use of feedback	0.1, 0.2
Trust	0.2, 0.3
Passion	0.4, 0.6
Regulatory freedom	0.8, 0.9
Financial freedom	0.2, 0.3
Communication	0.1, 0.2
Strategic plan	0.2, 0.3
Accountability	0.2, 0.3
Lack of fear	0.1, 0.2
Welcoming dissent	0.1, 0.2
Independent assessment status	0.2, 0.3
Technical analysis	0.8, 0.9
Analysis understanding	0.6, 0.7
Safety tradeoffs	0.3, 0.4
Long-term/short-term balance	0.1, 0.3
Treatment of problems	0.1, 0.2

The results of the analysis for this organization are shown in Fig. 4.

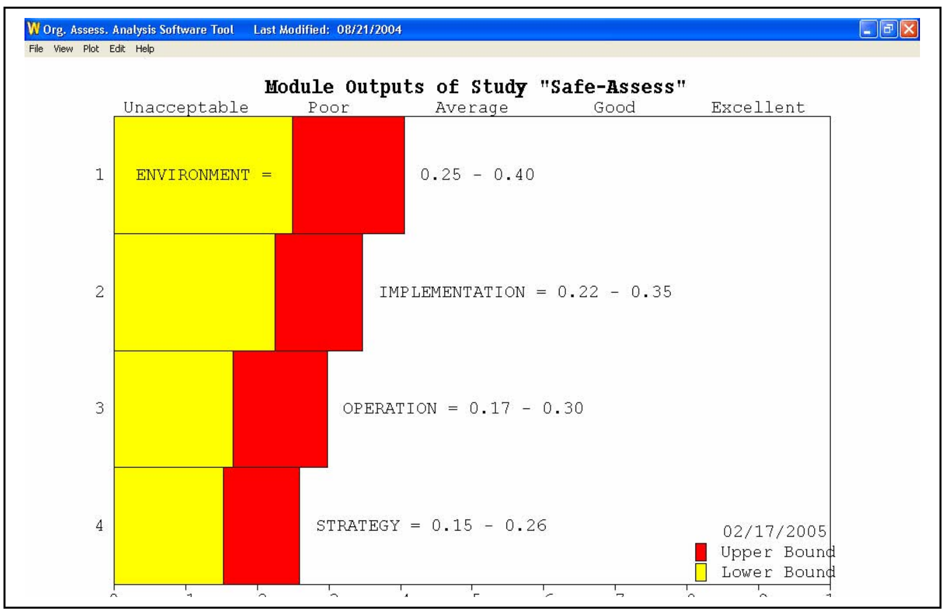

Figure 4. Analysis for an Example Organization

The dark bars depict the range of scores. The overall score computed for the operation of this organization from the weighted sum calculation corresponding to the latent effects model was 0.17, 0.30 (poor). The module scores were: 0.25, 0.40 for "Environment," 0.15, 0.26 for "Strategy," and 0.22, 0.35 for "Implementation." Our report for the organization was that their weakest areas were uncomfortably similar to those pointed out in the CAIB report.

A final (for this paper) consideration is important and will be addressed in the next section. This involves the manner in which personnel are rewarded for their contributions.

Demonstration of Personnel Attitudes in Response to Rewards

Management of personnel requires detailed knowledge of competitive and cooperative motivations. The modes used by management to reward personnel can have a significant effect on productivity and safety. We developed a game that illustrates the potential effects of rewards. The most common method of determining personnel rewards is to allocate available fixed salary funds in correspondence to the ranking of personnel. This establishes what is termed a "zero-sum" situation, where employees are in direct competition with each other (negative cooperation) for a fixed pot of available funds.

The "game" demonstration can be played with four players[12], or can be considered as a guide for a thought process. It generalizes to any number of participants and to other strategies not addressed in this paper. There are three modes of play. In all three modes, players are named 1, 2, 3, and 4. "Chit" allotments (c_i) are initially given as $c_1 = 4$, $c_2 = 6$, $c_3 = 8$, and $c_4 = 10$, respectively. These represent the general capabilities of the personnel that could potentially be applied to "production/safety" problems (which might be addressed over a period of one year, for example). A particular "production," p, will be represented in this game demonstration as:

$$p = \$1.85 c_1^{\,2} c_2^{\,3} c_3^{\,9} c_4^{\,10} \times 10^{-15} \tag{2}$$

where the c_i represent capabilities applied to the problem. This production model has the attribute of having an optimum solution [Ref. 22] that depends on how the chits are applied by the players (how capabilities are applied to the production problem).

Mode 1 illustrates direct competition among contributors, where this type of competition is encouraged by the rewards system. Here, payment for the job is $\$10^4 \times c_i$, without regard to production. There is a fixed salary allocation ($280,000). This will be distributed as "pay" by management, corresponding to their perception of the individual contributions to the problem. This is modeled in the game by a battle for perceived value through an initial "challenge" period. First, player 1 can challenge any other player by a coin flip. Then player 2 will be given a challenge opportunity, then 3, and finally 4. In each case, if the challenger loses, he/she will lose half (round down if non-integer) their chits to the challengee. If the challenger wins, the challengee has to give up half of his/her chits to the challenger. There is a statistical motivation (due to the rewards system) to challenge any player having more chits (to derive credits from more deserving players). This process models employees that might try to misappropriate credit/work from others in order to get increased rewards (at the others' expense) for job performance.

[12] More (or fewer) players can be accommodated by straightforward extensions to the basic strategy.

After the challenge round, the results can vary statistically from vanishingly small production (approximately 25 cents) to near-optimum production ($12.5 M). The total amount paid to the four players will be $280,000, regardless of production. For this reason, the players have no explicit motivation (under the Mode 1 management rules) to be concerned about production. They are being paid only on the basis of the chits they can obtain (their perceived value).

Mode 2 illustrates the effectiveness of working with others focusing on the team effort rather than individual effort. Here, payment to individuals is based only on team production. Each contributor receives payment of one percent of the production amount. The organization's motivation is that the team is encouraged to focus on the production results that are of direct value to the organization. The expectation is that any additional pay to employees will be justified by increased productivity.

The players, working together (or more likely individually), can determine an optimum distribution of chits. This has one feature of a "Nash Equilibrium" [Ref. 2] solution (no player is motivated to steal chits from any other player, i.e., change his/her strategy unilaterally from the optimum distribution). If they use their chits as allocated without an optimized strategy to improve productivity, the production will be $8.6 M, and the payout to the players will be $86,000 each. If they allocate $c_1 = 2$, $c_2 = 4$, $c_3 = 10$, and $c_4 = 12$, production will be $29.3 M, and the payout to the players will be $293,000 each. This provides direct motivation for the players to obtain an optimum solution. The optimum strategy can also benefit management through productivity increases.

Mode 3 illustrates the motivation of contributors to achieve team results along with the potential to increase rewards to top contributors, in the spirit of fair play [Ref. 23]. Here, payment to each player is tentatively set at one percent of the production amount. Then the players are allowed to collectively re-allocate the total amount (four percent of production) in order to reward individual value. In order to discourage an impasse, the players will all receive only 1/3 of the selfless sharing amount if they cannot agree unanimously on how to re-allocate the payout.

It is beneficial to provide analytical validation of the game results. In order to give an analytical indication, a latent effects model was constructed, representing personnel assessment under the conditions of Modes 1–3.

Determination of Latent Effects Inputs

Generation of quantitative values for uncertain subjective inputs is a matter of converting expert opinion into numbers. For our work, we used an "input guide" similar to that in Table 2 to help derive interval numbers for the 11 inputs needed.

The questions were to measure parameters about the organization as reflected in the game. The general guidance below refers to "personnel" in the context of the game's players. The guidance for all questions is:

Table 2. Input Derivation Guidance

- If there is no apparent recognition of the attribute, or if the personnel appear to attach no importance to it, an appropriate entry is in the range of 0 to 0.1.
- If there is minor recognition of the attribute, or if the personnel appear to attach minor importance to it, an appropriate entry is in the range of 0.1 to 0.3.
- If the recognition of the attribute is about average, and if the personnel appear to achieve the attribute with average success, an appropriate entry is in the range of 0.3 to 0.7.
- If the recognition of the attribute is somewhat above average, or if the personnel appear to achieve the attribute with somewhat above average success, an appropriate entry is in the range of 0.7 to 0.9.
- If the recognition of the attribute is outstanding, and if the personnel appear to achieve the attribute with outstanding success, an appropriate entry is in the range of 0.9 to 1.0.

The inputs we derived are shown in Table 3 for the three modes discussed in the previous section. Uncertainty is represented by intervals (lower bound, followed by upper bound).

Table 3. Latent Effects Model Inputs

Input	Mode 1	Mode 2	Mode 3
1. Recognizing capabilities	0.8, 0.9	0.8, 0.9	0.8, 0.9
2. Recognizing job skill needs	0.1, 0.2	0.8, 0.9	0.9, 1.0
3. Recognizing job needs	0.1, 0.2	0.8, 0.9	0.8, 0.9
4. Anticipatory effects	0.2, 0.3	0.4, 0.5	0.8, 0.9
5. Commitment to organization	0.1, 0.2	0.8, 0.9	0.7, 0.8
6. Selfless sharing	0.0, 0.1	0.9, 1.0	0.8, 0.9
7. Fair play	0.0, 0.1	0.4, 0.5	0.8, 0.9
8. Negotiation commitment/trust	0.0, 0.1	0.8, 0.9	0.9, 1.0
9. Personal accomplishments	0.0, 0.1	0.9, 1.0	0.8, 0.9
10. Innovation/creativity	0.4, 0.5	0.8, 0.9	0.9, 1.0
11. Long-term vs. short-term view	0.0, 0.1	0.7, 0.8	0.9, 1.0

The first input (recognizing capabilities) is to measure the personnel’s ability to recognize their own capabilities. This is relatively high, since players are issued chits. The second input (recognizing job skill needs) accounts for the difference between inherent skills and actual job skill needs for a particular problem. There is no motivation to recognize this in Mode 1, where effects on production output aren’t addressed. It is much higher in Mode 2, since there is a tie between skills applied and productivity. It is highest of all in Mode 3, where skills and productivity are both encouraged. The third input (recognizing job needs) is similar to the second, except that only effects on productivity are considered. The fourth input (anticipatory effects) measures the encouragement of the players to look ahead for implications of their actions. These become more important for the higher mode numbers. The fifth input (commitment to the organization) is not encouraged for Mode 1, is highly encouraged for Mode 2, and is reduced by personal considerations for

Mode 3. The sixth input (selfless sharing) follows the same trends as the fifth input, but the effects are more pronounced. The seventh input (fair play) is almost non-existent for Mode 1, then increases with higher mode values. The eighth input (negotiation commitment/trust) is minimal for Mode 1, high for Mode 2, and highest of all for Mode 3, which depends most on negotiation. The ninth input (personal accomplishments) is highest for Mode 2, and reduced slightly in Mode 3, where negotiations affect rewards. The tenth input (innovation/creativity) measures the amount of strategy that has to be planned for the job/game. It is significant for all three modes, but has higher requirements for higher mode numbers. The last input (long-term vs. short-term view) also increases with mode number (from essentially nothing to almost everything). Here, Mode 3 encourages both present rewards and long-term effects of the mode of reward.

These inputs were run in a latent effects computer model. Figure 5 shows the results for Mode 1.

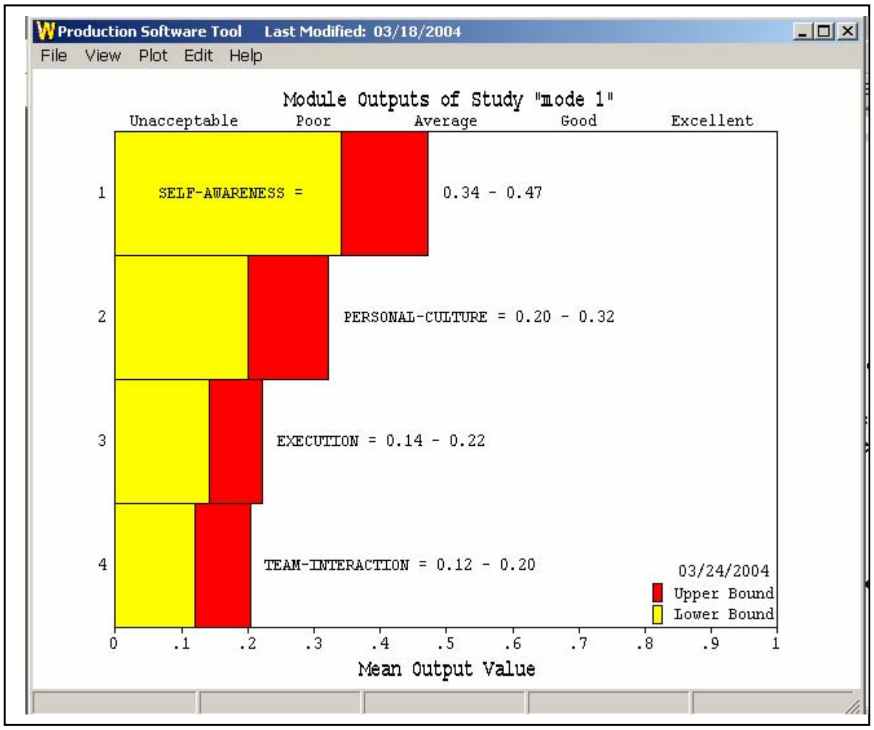

Figure 5. Mode 1 Results

The very poor score for "Execution" predicts low production. Team interaction is also very deficient. Note that these are the same effects achieved in playing the game demonstration.

The results for Mode 2 are shown in Fig. 6.

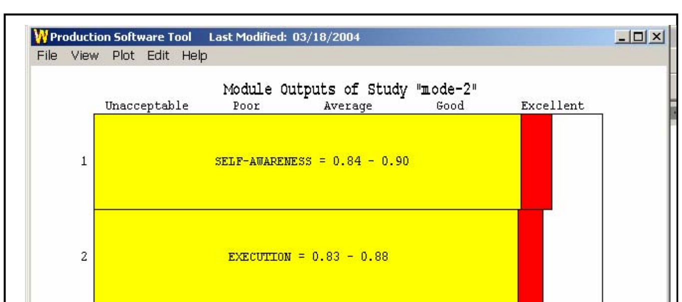

Figure 6. Mode 2 Results

These results show dramatic improvements in expectations for team interaction and correspondingly the game results show production enhancement.

The Mode 3 results are shown in Fig. 7.

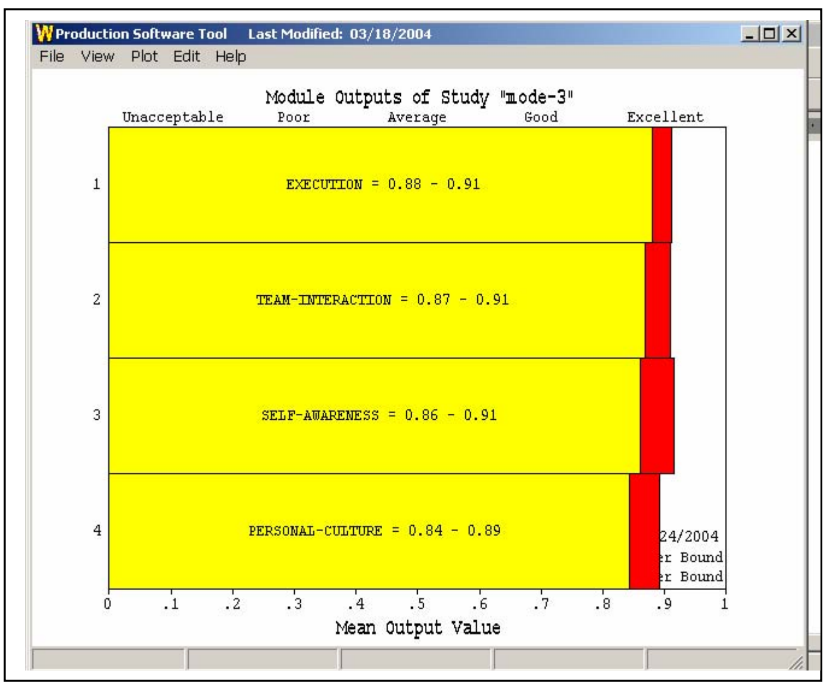

Figure 7. Mode 3 Results

These results improve on the Mode 2 results, presumably because there is an improved sense of fair play and because personnel are encouraged to look at the long-term view of their team interactions. The application to salary management is that zero-sum salary management can be counterproductive. As in many other aspects of safety management, there are no easy solutions, although peer ranking has apparent value. In any event, it is apparent that productivity and fair play are important components to salary management.

Conclusions

The work described in this paper demonstrates the importance of collective team considerations, the value of identifying productivity-related and safety-relevant weaknesses and successes (some potential) in the management of high consequence organizations, demonstrates an analysis approach that helps assess and guide improvement of organizational performance and management, and illuminates the value of salary management. Some of the important cultural safety factors identified are not ordinarily addressed quantitatively, and in fact are often overlooked in assessing safety posture. The results given in this paper both point out the effects and demonstrate a method for mathematical assessment. The analytical treatment is based on an organizational modeling tool. The analytical validation of the results lends credence to the results. A hybrid analysis combining the three aspects cited in this paper follows the same latent-effects structure demonstrated, but is beyond the scope of the paper. This will be a basis for future work.

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Appendix A.3

Analyzing and Overcoming Fear in Personnel Performance and Interpersonal Interactions

Key words: fear, game theory, latent effects, information processing

Arlin Cooper[13] and Rush Robinett III[14]

Abstract

Fear is examined because it can be a significant hindrance to personnel performance. The reasons for negative results of fear are shown, and means of identifying fear are described. A basis is established in how humans process information and why there is a human tendency toward counter-productive game-playing. Methods of reducing or eliminating the negative effects of fear and game-playing are described, and a quantitative analytical basis is demonstrated.

Introduction

Previous work [e.g., Refs. 1, 2, 3] has identified "fear" as an impediment to personnel performance and the interpersonal interactions that are essential to teams, organizations, and other collective efforts. This paper addresses methods for overcoming detrimental fear. For background on the concepts described here, consider a hunter lost in the woods with darkness approaching. This is a scenario that has clear fear-based threats, clear penalties for irrational behavior, and clear strategies for success. The applicability of the scenario to personnel performance in organizations will be developed in the following sections. For the hunter, fear may be introduced through lack of familiarity with the situation, increasing cold and darkness, the possible presence of animals, and emotional discomfort over the anxiety fellow hunters may experience when the hunter does not return to camp. If no or irrational action is taken, hypothermia could set in and the hunter could die. If the hunter tries to walk blindly, he could accelerate the onset of hypothermia, make it more difficult to find a way out, and it could become more difficult for others to find him. If he becomes angry over the situation, logical thinking will become more difficult. Pertinent background and lack of training can come into play. Negative effects could be childhood fear of darkness and animals. If there are companions with the hunter, negative effects could be a learned tendency to depend on others, to be embarrassed, or to blame others for the situation. Positive effects could be learned skills, such as fire and shelter building, direction identification, and strategies for finding familiar locations (e.g., wait for the next day and then move downhill, which is likely to lead to streams, which is likely to lead to people). The challenge for the hunter is to overcome the human tendencies toward "freeze, flight, or fight," as well as to defuse any such tendencies in companions. The hunter must instead rationally dismiss negative influences and must rationally respond as a result of positive training, which is a positive latent effect. These challenges (individual and collective) are addressed in this paper.

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For specific background on the proposed approach, the latent effects that can encourage counterproductive tendencies are first described. Then, some of the salient effects are noted, identification of fear is considered, and fear is established as a "root cause" of performance shortcomings. Corrective measures are addressed through identifying how humans process stored and real-time information and by applying "game theory" for helping to understand interactive effects. Additional understanding and validation of the subject is facilitated by description of a processing and an analysis structure.

Latent Effects

Latent effects (time-delayed contributions that can contribute to consideration of a real-time activity) have been studied for many years [e.g., Ref. 4]. The subject of this paper focuses on fear-related latent effects, which are an important basis.

<u>The Ultimate Goal</u>. The goal of an organization is to be successful (financially and by reputation), to maintain an ethical posture, to provide benefit for customers, to maintain safety for the organization personnel and for the public, and to reward employees as contributors. This requires a team effort, where synergism transcends individual actions. It requires attention to present conditions, providing bases for the future, and recognizing the effects in the past (latent effects).

<u>Contributions toward the Goal</u>. There are various approaches that can contribute toward organizational goals. One general approach is the technology of management [Ref. 1], where inter-related strategies of structure, communication, and rewards are implemented. A second important consideration is effective communication methods that build trust and reduce misunderstanding [Ref. 2]. A third key is encouraging order in activities and communication and suppressing disorder (implementing low entropy approaches) [Ref. 3]. A fourth key is reducing tendencies toward fear, and encouraging a "passionate" team-oriented self-actualization (learning how to achieve maximum individual and team performance). The latter factor is emphasized in this paper.

<u>Time Issues</u>. Since the groundwork for present and future performance is most effective if established early, time becomes an important consideration. Latent effects can be recognized analytically, and the consideration of such effects can assist in making decisions. An important example is recognizing the long-term effects of short-term and continuing investment (planting seeds to reap later benefits). Some efforts (e.g., continuous learning) can appear burdensome in the short term, but can pay significant dividends in the long term. For example, the hunter learns and continually practices the skills of fire and shelter building under controlled conditions (e.g., no fear) long before becoming lost and anxious. Latent effects are especially pertinent to psychoanalysis, where the key to therapy is to make individuals aware of factors (often unconscious) that may have developed over years, which determine current emotions and behavior. Psychoanalysis deals with elucidation; this paper will emphasize the development of systematically derived quantitative metrics.

Effects of Fear

The Emotions of Zero-Sum Relations. There is an unfortunate human tendency among many people to seek individual benefit guided by a belief that it can be achieved only at the expense of others. This, where it is practiced, can be at best a "zero-sum" relation. At worst, this type of behavior can introduce non-zero-sum negative effects. Negativity can occur where interactions begin to divert from the original goal, and migrate toward tit-for-tat retribution (aimed at preserving one's ego), which will be discussed in more detail in the game theory section. Fortunately, numerous examples show that these types of behavior can be overcome (e.g., team synergism, infrastructure development, and other civilization enterprises). Zero-sum thinking is frequently ingrained in students, who are motivated mainly by fear that one should look out for oneself or there will be others who will surpass them. In order to move beyond zero-sum thinking, there must be conscious effort to reduce the fear and replace it by a passion to contribute to a greater cause (e.g., this is emphasized in military units). Surprisingly to many, the elimination of fear can have the end result of simultaneously maximizing personal benefit, as well as contributing to team performance [Ref. 3]. These concepts provide a basis for game-theory analysis later in this paper.

Entropy Increases. Entropy is synonymous with disorder. For example, thermodynamic entropy can measure a dispersion of concentrations of energy states as a function of temperature. Communication entropy can measure a dispersion of concentrations of information. Fear tends to increase entropy, by trying to avoid the fear versus facing and dealing with it. This has latent effect costs and can be counterproductive to team efforts and effective communication [Ref. 2]. Learning how to suppress and replace fear (i.e., mental pain) helps to create order [Ref. 5] and an appropriate balance with passion [Ref. 3]. This demonstrates another reason for emphasizing the reduction of fear.

Interference with Passion. In order to be effective contributors to an organization, it is important for personnel to eliminate any tendency towards counterproductive fear and to replace it with an emphasis on passion (commitment to optimum individual and team mission effort) [Ref. 3]. Since fear potentially degrades passion, this is another reason for addressing and working to eliminate fear.

Interference with Self-Actualization. Self actualization [Ref. 6] was described by Abraham Maslow as an inherent human drive toward maximizing personal capabilities and therefore contributing to feelings of fulfillment. This is apparently the only guaranteed positive non-zero-sum game available to every individual. Furthermore, self actualization is best achieved through passionate effort. Self actualization is consistent with a person feeling unthreatened and unfrightened by the unknown. Since this, as well as team self-actualization, provides an important goal for an organization's personnel, it is another motivation for combating fear. Self actualization requires awareness of the overall goal, cognizance of potential detrimental effects, and identification of potential contributory actions.

Detecting Fear

The first step in addressing fear is to enhance the chances of detecting it, which can be done in a variety of ways. Some of the most important are discussed in the following paragraphs.

Importance of the Goal. One test that can be applied to individuals and to organizations is to determine whether the focus of an effort is on the overall goals of the organization(s). Fear tends to drive the focus to self-centered considerations, often away from the goal. The determination of this is not direct, but can be made through paying judicious attention to inter-personal communication and observation of behavioral clues.

Flight, Fight, Freeze. The traditional basic responses to stress are flight (e.g., avoiding the stress), fight (e.g., finding fault with the stressor), or freeze (e.g., avoid any action through "analysis paralysis"). These are all fear-based responses. A non-fearful response is also possible, based on "antithesis" (disarming) [Refs. 2, 7].

Unpredictability. People who can be depended on to do what they say they will do are *predictable* and trustworthy. People who are motivated by fear may be unpredictable and untrustworthy. This relates to orderliness in the former case and disorderliness (high entropy) in the latter case. Unpredictability and disorderliness can be an important indicator of fear. One manifestation of the characteristic is destructive "game-playing," to be discussed subsequently. The motivation of fear can not only drive people toward game-playing, but can also cause the games selected to vary unpredictably. The main issue is a tendency to avoid a fearful situation, e.g., by running away and/or win at a zero-sum game. The best way to maximize the minimum payoff in a zero-sum game (e.g., bluffing in poker) is to play an "unpredictable" strategy.

Unique Signals. In some cases, fear is camouflaged, but is still a contributor to behavior. There are strategic ways to get through the façade. Strategic forms of information-gathering [Refs. 2, 5] can provide clues to these tendencies. "Unique Signal" communication [Ref. 2] relies on randomization patterns of information-seeking, so that an unambiguous response is made more likely.

The Fear-Relevant Process. Considerable insight into the constraints that exist in information-gathering can be obtained by studying fear as part of a process. A framework for the generation of fear and the potential ways of dealing with it is given in Fig. 1. As illustrated in the figure, new physical activities can introduce physical pain, which is remembered as a painful experience. This memory becomes an emotional pain when it is recalled. A new social activity can also introduce emotional pain. These are both stored in the brain as painful memories, or fear [Ref. 5].

There is a human tendency to deal with fear by letting it become a phobia, and reacting to the phobia through one of the conventional alternatives, "freeze, flight, or fight." The freeze reaction precludes useful response. The analytical equivalent is sometimes called "analysis paralysis" (non-productive "wheel-spinning" analysis). The flight response is one of avoidance and/or procrastination. The fight response is to try to drive the source of the phobia away. None of these solve the problem. The productive path to dealing with fear is illustrated through the lower loops, but these are less "natural" and require an explicit choice to face the fear and deal with it in a logical, intuitive, and passionate manner. Many will recognize that this is the key to the reality TV series "Fear Factor."

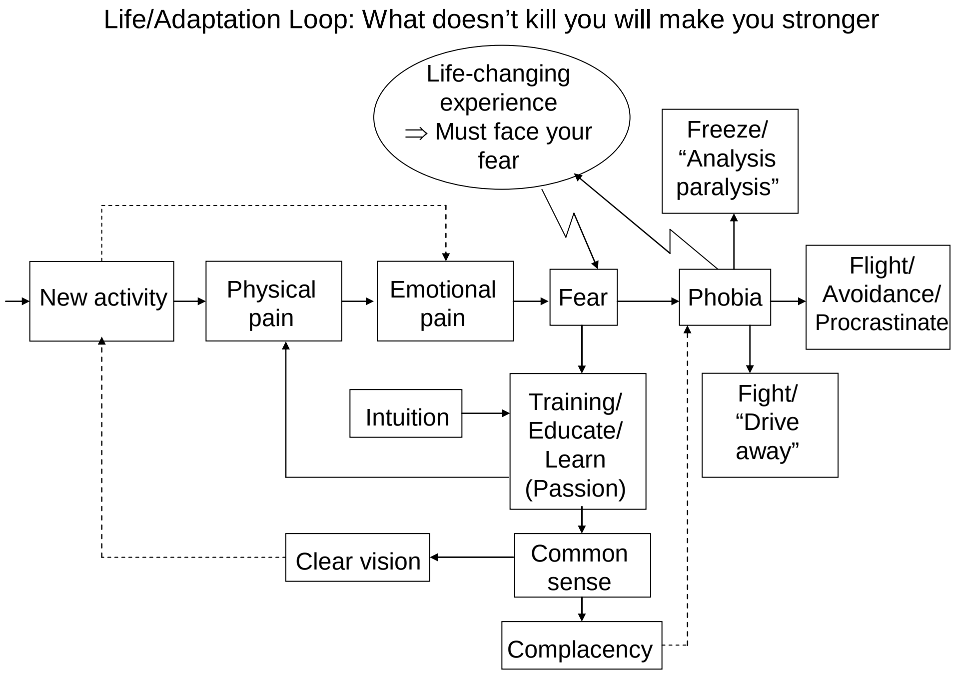

Figure 1. Structure for Introduction of Fear and Methods for Handling Fear

The choice to face fear can become a "life-changing experience" by enabling a productive response. Dealing with fear of physical pain can then be aided by a passion for training, education, and learning, assisted through a conscious choice to utilize intuition. The challenge of fear due to emotional pain requires these and common sense as well. This implies a clear vision of dealing with fear in a preventive mode, so that it does not become a phobia. Continuous effort to maintain this cyclic loop of "self-actualization" is required, because there is danger of complacency driving one back toward phobia-based responses.

With these constraints in mind, consider how one person can help another deal with fear. On the TV show "Fear Factor," the key is to directly face the fear. The first step by a "mentor" is to conduct a high level probe to determine the person's status in the structure represented by the self-actualization diagram. From a Unique Signal standpoint, reactions are observed in a variety of situations. As an example, people make decisions about how compatible they are with other people through observing responses to a variety of situations. These could include, for example, deciding whether or not to attempt to establish a marriage with a girlfriend (boyfriend) by introducing her (him) to social situations such as family gatherings, sports events, church activities, camping outings, concerts, etc. Potential facades can offer varying degrees of obfuscation, so the probe intensity and variety must adapt to the amount of "noise" found in the response. A communication within a common context contributes to understanding each other and tends to minimize the disorganization of information entropy. Finding a common context is through a family-like[15] environment and/or a common passion. The effect is analogous to synchronization or resonance, with the attendant noise-suppression. Alertness to potential changes in the receiver characteristics and consequent adaptation is required. Part of the information related to changes in the behavior of a communication partner is identifying the reasons for change.

Human Information Processing

The Human Computer. Human information processing can be modeled as a computer that processes stored and real-time data. A useful model that facilitates considerable insight is to assume a perfect computer that processes imperfect (human-interpreted) information derived from a perfect data memory [Ref. 5]. The inherent model is that the "perfect" data memory is filled with real (and therefore error-free) data along with self-generated (and therefore error-prone) data, with distinguishing tags to separate imagined data from real data. The working assumption that the processor is perfect is an artifact of the model, but is selected because the brain's immense capabilities have never been artificially duplicated. There can be errors made as data is retrieved from memory and processed, for example, if there are interferences or noise introduced.

Data for Processing. Data that are initially placed in human memory can come from experiences, postulates about potential future experiences, deductions about logical combinations of data, learned information, and various forms of imagination. The tags associated with the data are used to separate the real from the imaginary and to indicate priorities. The data can be corrupted by inadvertent modification or by mishandling of the tags, e.g., loss of separation of the real from the imagined. Hubbard [Ref. 5] cites the latter as a form of insanity. Pain contributes to corruption of the tags, and fear (mental pain) can create derogatory interference with how the tags are interpreted.

The Role of Reference Patterns. Human data processing relies on reference patterns, which enable detection of differences from a reference, similarities to a reference, and filtering with respect to reference patterns [Refs. 3, 5]. Reference patterns can be used by the human mind with the same considerations mentioned above for data. Because of temporal dynamics, time becomes an important dimension to patterns. Patterns include cyclic characteristics. Through cyclic references, expectations can become self-fulfilling prophecies. Human pattern recognition has many of the distributive characteristics of three-dimensional holographic storage and comparison [Ref. 8].

Transforms and Filtering. Information, including episodic information, is apparently transformed and replicated throughout large numbers of neurons. A possible model for time-related transformation is "wavelets" (a derivation of frequency constituents that

[15] The "family" reference denotes collective support of individual team members directed toward the overall optimization of the team performance.

avoids discontinuities). The end result is that reference patterns are processed by the brain with less importance placed on the absolute than the relative.

Visual, experience-based, and informational patterns are sensed and stored in brain memory during life experiences, hypothesized situations, imagination, and dreams. Experience-based intuition is also part of the memory. The flood of information to the brain requires "sensor fusion." Intuition is a synthesis process to create new patterns (i.e., a feel for patterns [Ref. 3]). When these varied sources are processed, the "healthy" brain can recognize the source, using its memory tags to distinguish, for example, imagination from reality. Because of the complexity of these aspects of brain memory and processing, no meaningful attempt can be made to simulate brain behavior. However, some simple illustrative concepts can give insight into a few important features.

It is useful to demonstrate how reference patterns, transformation, and filtering can apply to human derivation of information from data through a model. The example given here will be illustrative, and the model shown below is not intended to duplicate functionality of the human mind with any close similarity. However, the example has the potential to provide an illustrative and informative analogy. This will be done by using binary logic functions to represent inputs and reference patterns and by comparing inputs to reference patterns through transformations.

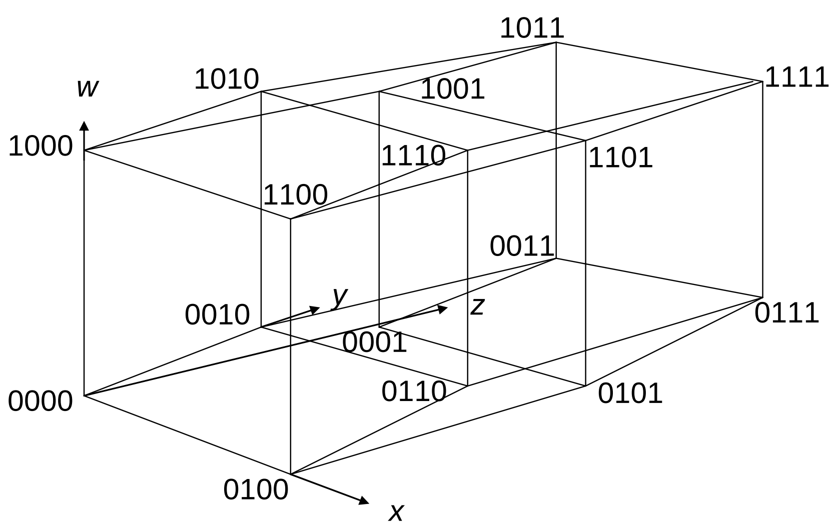

Figure 2. Four-Dimensional Hypercube Example

The example uses a digital transform called "Rademacher-Walsh (RW) expansion" [Refs. 9, 10], which provides a complete set of orthogonal mathematical functions for representing binary patterns and logic functions by their "modulo-two[16]" constituents [Ref. 4]. Consider a "hypercube" structure (2^4 interconnected vertices) that has four

[16] "Modulo-two" combination is equivalent to "exclusive-or," with a zero resulting from combination of an even number of ones and a one resulting from combination of an odd number of ones.

parameters, each of which can have value either "0" or "1." The 16 possible combinations lie on the vertices of the hypercube. An illustration of the example structure is shown in Fig. 2. The vertices are labeled with the appropriate binary combinations.

There are 16 RW expansion functions for four variables. These are shown in Table 1. The basic construction utilizes a constant (*c*), four independent variables (*w*, *x*, *y*, and *z*), and all combinations of modulo-two addition (exclusive-or) of the variables.

Table 1. RW Expansion Functions for Four Variables

c	***w***	***x***	***y***	***z***	***wx***	***wy***	***wz***	***xy***	***xz***	***yz***	***wxy***	***wxz***	***wyz***	***xyz***	***wxyz***
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	1	0	0	1	0	1	1	0	1	1	1	1
1	0	0	1	0	0	1	0	1	0	1	1	0	1	1	1
1	0	0	1	1	0	1	1	1	1	0	1	1	0	0	0
1	0	1	0	0	1	0	0	1	1	0	1	1	0	1	1
1	0	1	0	1	1	0	1	1	0	1	1	0	1	0	0
1	0	1	1	0	1	1	0	0	1	1	0	1	1	0	0
1	0	1	1	1	1	1	1	0	0	0	0	0	0	1	1
1	1	0	0	0	1	1	1	0	0	0	1	1	1	0	1
1	1	0	0	1	1	1	0	0	1	1	1	0	0	1	0
1	1	0	1	0	1	0	1	1	0	1	0	1	0	1	0
1	1	0	1	1	1	0	0	1	1	0	0	0	1	0	1
1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	0
1	1	1	0	1	0	1	0	1	0	1	0	1	0	0	1
1	1	1	1	0	0	0	1	0	1	1	1	0	0	0	1
1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	0

The analogy to brain processing suggested here is that the RW functions represent stored patterns that reference some experience or training. Experiences are transformed into sums of reference patterns. The example is modeled on storing 16 reference transformations to build any of 65,536 possible functions[17]. For example, assume that a logic function (shown in Fig. 3 with darkened nodes for function ones) is processed for comparison with the stored references:

$$f = wxy \cup wxz \cup xyz \cup wyz \cup \overline{w}\,\overline{x}\,y\,\overline{z} \cup \overline{w}\,\overline{x}\,\overline{y}\,z \qquad (1)$$

The symbol $\cup$ indicates logical "or," juxtaposition indicates logical "and," and the overstrike indicates logical negation.

[17] Since there are 2^4 possible function entries, there are 2^{16} possible functions.

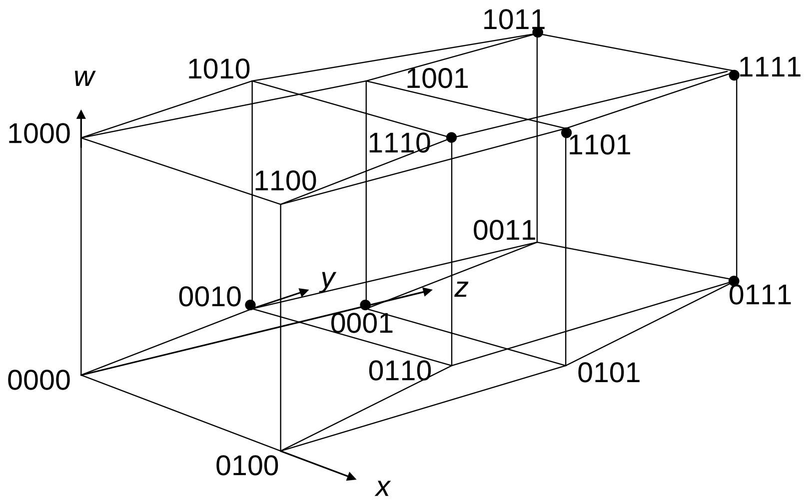

Figure 3. Depiction of Example Function

The expansion coefficients F_k, corresponding to each expansion function r_k (i.e., columns in Table 1), can be calculated by[18]:

$$F_k = \frac{1}{2^n} \sum_{i=0}^{2^n-1} [\, f(i) + \bar{r}_k(i) - f(i) + r_k(i)] \tag{2}$$

where i indicates each functional combination (i.e., rows in Table 1). The sum is by modulo-two addition. The resultant RW expansion is:

$$f = \frac{w}{8} + \frac{x}{8} + \frac{3}{8}y + \frac{3}{8}z - \frac{3}{8}wx - \frac{wy}{8} - \frac{wz}{8} - \frac{xy}{8} - \frac{xz}{8} + \frac{yz}{8} - \frac{wxy}{8} - \frac{wxz}{8} + \frac{wyz}{8} + \frac{xyz}{8} + \frac{5}{8}wxyz \tag{3}$$

The expansion gives "closeness of match" information for the function. The highest score for the reference pattern is in the last column, which represents $w + x + y + z$. In fact, the last column differs from f in only three bit positions. The deduction is that the input is very close to a known reference and differs only where w, x, y, and z are all one, where w is the only variable having value one, and where x is the only variable having value one. One form of filtering is to discriminate references patterns that have positive expansion coefficients from those that have negative coefficients. In the example, w, x, y, z, yz, wyz, xyz, and $wxyz$ have positive coefficients; wx, wy, wz, xy, xz, wxy, and wxz have negative coefficients. Positive coefficients demonstrate more similarity; negative coefficients demonstrate more contrast. Additional similarity/contrast filtering can be based on the absolute values of the coefficients. Although brain complexity transcends these illustrations, the example illustrates how transformations, reference patterns, and filtering can be used in brain-like processing.

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[18] This is for all non-constant expansion functions. The constant is used only for functions that have value one in the first (all-zero) combination.

The Application of Game Theory

There is a human need for interpersonal interaction. Since we respond to relative stimuli more than absolute, reference patterns are an important contributor to communication. As cited above, local lesions in the brain do not appear to affect brain processing, leading to the contention that holographic-like distribution of the reference information is probable. Since cortical cells respond to spatial frequencies of visual stimulus, one might expect that interpersonal communication could benefit from coherent resonance. A useful analogy is that each individual is a fragment of a collective hologram, which requires communication coherence and synchronization to construct and/or reconstruct the collective hologram [Ref. 3]. Perceptions can impede this coherence and synchronization. The basic C. G. Jung communication model [Ref. 3] accounts for the difference between actual communication and perceived communication (as influenced by personal relative perceptions) and is depicted in Fig. 4. When communication perception-related barriers are reduced or removed (e.g., by Unique Signal interchanges aimed at building a common context), actual communication and perceived communication can tend toward identity of actual and perceived communication. That goal can be approached or hindered by interpersonal interactions that can be described as "game theory" [Ref. 7].

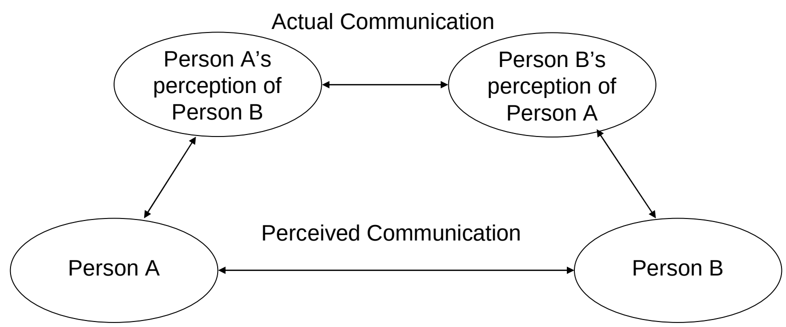

Figure 4. C. G. Jung Model for Communication

The basic three forms of interaction are material (information and data), social (targeted interpersonal communication), and individual (recognizing patterns that have been taught or experienced). The latter category helps establish a basis for latent effects and learning, and that combined mainly with the second and partially with the first leads to an interaction called "transactional games" (a series of interpersonal transactions directed toward a well defined predictable outcome) [Ref. 7]. The distinguishing feature that separates a transactional game from a "pastime" or ritual (e.g., "chit-chat") is ulterior or even dishonest behavior targeted toward the objective of the game. In ritual exchanges, people might exchange greetings, make jokes, or give personal updates. These are usually oriented toward open bonding and are rarely intended to achieve an advantage. Games of various forms are often taught to children by parents (intentionally or unintentionally), and many of these can contribute to successful participation in the real world. Some transactional games are learned in childhood development that are harmless or even beneficial. An example is "bargaining," for example for exchange of toys. "Good" games emphasize fun over domination. This is not true of most transactional games. It is possible for ulterior or dishonest behavior to have productive characteristics, but it is usually destructive. The root cause is a disordered understanding of means and ends. Fear frequently drives one toward participation in destructive games (usually because of selfish motives), and these do not contribute to organization, team, or individual success. The true goal of self-actualization depends on selflessness rather than selfishness. Collective participation can capitalize on diverse talents and approaches. The goal is to turn difficult situations into fun games, e.g., through humor, which can discourage destructive behavior and encourage productive results.

Interpersonal Perceptions. The avoidance of destructive games depends on identifying an attempt to initiate such a game, followed by a "defusing" action called "antithesis" [Ref. 7]. It is helpful to consider how games are initiated. Games can involve any number of participants. A general structure for a two-person game is shown in Fig. 5.

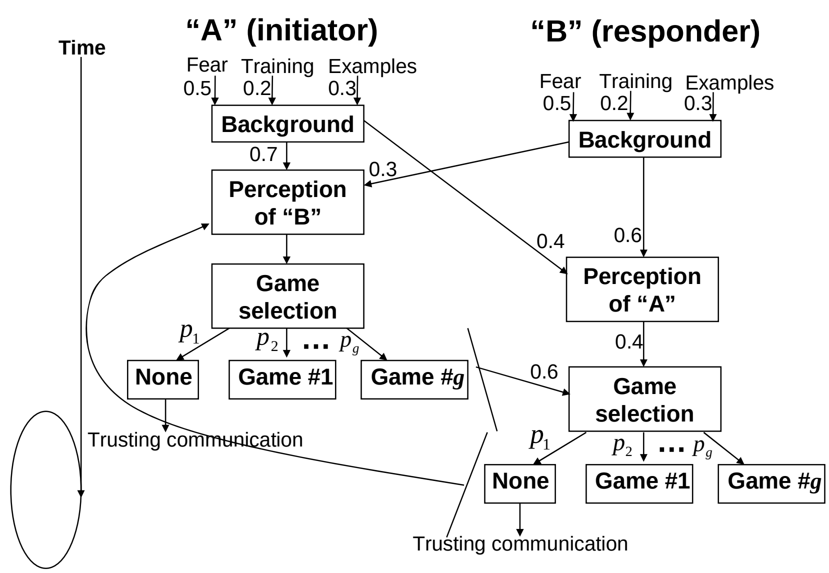

Figure 5. Transactional Game Model

In this model, Person A (termed "A") is influenced (i.e., through latent effects) to various degrees by training in game interaction, observed examples of interaction, and fear of the outcome of the interaction. An assignment of general importance of each of these appears in the diagram as an input "weight," where the sum of the weights to each box is one. This will be used subsequently for quantitative analysis. This background is blended with a perception of the other person ("B") in the potential interchange. "B" is also influenced by fear, training, and examples. Based on background and perception, "A" can select a game to initiate or elect to not enter into gamesmanship. "B" can respond to "A"'s game or no-game initiative, as influenced by a perception of "A". Then "B" can elect to participate in the same game or select a different one. As stated in the section on detecting fear, fear typically results in unpredictable game-playing (often confined to a single game). Once the gaming begins, there is a potential cycle, and when fear-based game-playing involves mixing games as a diversion, patterns can be detected through Unique Signal analysis. In the cycling, "A" can respond to the game selection by "B", as influenced by that selection in addition to background and perception, as well as by previous cycles. This model helps demonstrate that gaming can be defused by driving toward non-game responses. Examples will be offered. The model also provides an analytical basis.

Fair Play. Behavioral game theory [Ref. 12] can be used to illustrate some interesting communication-related messages. For example, a "Nash equilibrium" game is a situation in which a group of "players" have arrived at a "peak" where no player can benefit from initiating a change-related move or by changing strategy while the other players do not change. An appropriate starting place for this is "live and let live."

Synchronization, Phase-Coherence, Stability. Models such as the one shown in Fig. 5 can be used to study various situations that are analogous to transient analog systems. For example, consider the effects of synchronization (communication that is "in-sync") between two people or among those in a group. If the situation is dynamic, phasing is important. For example, a cyclic forcing function imposed on two people, one of whom responds quickly and the other of whom responds slowly can result in "out-of-phase" behavior. Cyclic responses can be stable, if there is moderate phase coherence and moderate response excursions. On the other hand, a dynamic forcing function can cause instability, which is detrimental to effective communication.

Examples of Destructive Games. Not all games are destructive, but the population of constructive games is relatively small. A short selection of transactional games will be described here to help illustrate the seductiveness of the stimuli and the deleterious effects that often result from destructive games. Detailed treatment of these types of games is available in Ref. 7.

1. "Laying Guilt": The initiator here tries to avoid responsibility for bad behavior or tries to enhance their image by blaming others. This can be used by staff against other staff and against their management or team leaders, blaming poor outcomes on higher-level decisions. It can also be used by management against their staff, blaming bad outcomes on staff performance. The tendency may be encouraged by example and training. However, the ultimate cause is often fear of being blamed for poor outcomes or simply of losing face.
2. "They're Against Us": An example is painting management as "out to get" staff. This is a common game played by staff that often begins as an attempt to build camaraderie, but transcends lateral cohesiveness with vertical divisiveness. It also has the appeal of enhancing self-image of the players. This is often exacerbated by a fear-of-management factor.
3. "You're bad; I'm good": This game can be structured around portrayal of another as "bad," or portrayal of one's self as "good," or both. The intent can be to glean better salary/promotion treatment or in general self-interest. This game is based

on "zero-sum" expectations (self-advancement depends on inhibiting others), and is usually based on fear of others.

Antitheses to Destructiveness. Fig. 5 shows the major contributors to game-playing (training, observation, and fear) as well as a motivation based on perception of another person or persons. These can offer pointers to the antithesis for destructive games. The best approach to resisting the initiation of games is to recognize the destructiveness and consequently to refuse to participate. This offers an immediate perceptive game-playing block to the other person(s). Refusal isn't an easy approach for most people. An effective antithesis is to correct any dishonest information provided in the stimulus. This is often a more engaging strategy.

As a more general technique, Berne (Ref. 7) suggests "correct" behavior as an antithesis. When a person is steadfastly honest, trustworthy, and ethical, this creates a perception that works against invitations to participate in games.

Another approach is based on observations about "dynamic programming." In dynamic programming, the focus is directed toward the goal, rather than how the goal is reached. Instead of considering all possible ways to reach the goal, recursive tests are made at each stage. These depend only on the path forward from a stage, not how the stage was reached. This form of re-direction of another person's plan often can be used to defuse game-based strategies.

An Analysis Structure

Analysis of outcome-focused games (game theory) [Ref. 12] helps guide decisions and strategies. Transactional games are less amenable to analysis, because the objective is relatively unquantifiable. However, there are various analytical techniques that are useful in measuring destructiveness as well as ranking defusing strategies. The basis for two of these techniques will be described below.

Latent Effects Analysis. Latent effects analysis [Ref. 13] offers a way to quantifiably account for sequences of influences that have immediate or later effects. An illustrative generic structure is shown in Fig. 6, where a basic selection of four "modules" (constituents to an operation) is shown.

The first module (lower left) is the "inherent environment" under which the operation is influenced. The second module addresses the management "overarching strategies" that are put in place as a structure for the operation. The third module is for the implementation of the activities, including analysis, business decisions, training, and mentoring. The fourth module applies to the actual operation, where skills, judgment, operational attitudes, and application of resources are considered. The feedback path is for lessons learned, root cause analysis, and evaluation of performance compared to projections.

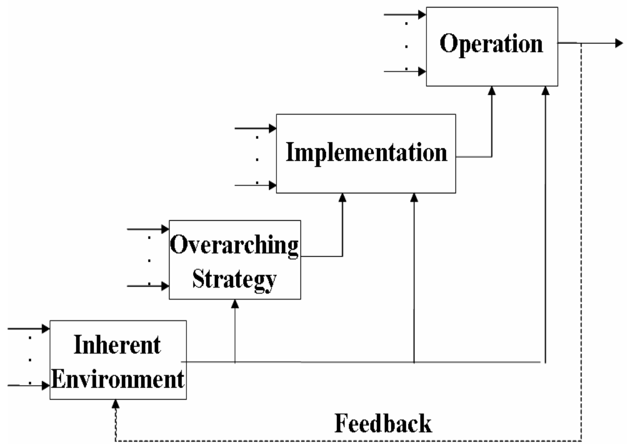

Figure 6. Basic Markov Latent Effects Structure

Each module has “primary” inputs (pertaining directly to that module), and most modules also have “secondary” inputs (coming from a previous module). Each input is “weighted,” just as a teacher might weight constituents to a grade (e.g., 40% for the final, 30% for the other tests, 30% for homework), so that the weights for the inputs to each module (primary and secondary) sum to one. The inputs are analogous to scores achieved by students on homework or tests, where the score on a scale of 0 to 1 indicates value contributing to the success of an operation (one being the highest possible value). The inputs to each module can be aggregated for that module by a weighted sum. The results for each module give a measure of “effectiveness,” with the overall effectiveness coming from the Operation module score.

Using this approach and the weights shown in Fig. 5, a basic structure for transactional games can be derived (Fig. 7).

The example indicates a possible game selection by “A,” followed by a response from “B.” Then “A” can act on “B”’s selection, etc. An example can clarify the steps. In the example, the entries in Table 2 will be used.

For the example scenario, the initial influences on “A” are the weighted sum of the first three inputs, which is 0.82. This means that “A” has substantial influences toward playing transactional games. The perception that “B” is a game player (0.8) adds to the pressures on game selection, a score of 0.81.

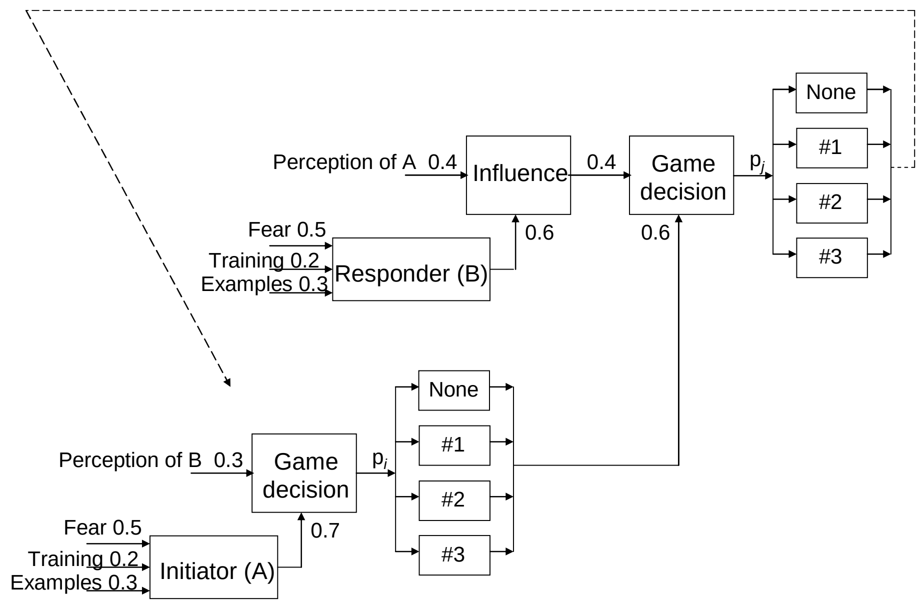

Figure 7. Transactional Game Analysis

Table 2. Inputs Chosen for the Example Analysis

"A"	**"B"**
Fear: 0.9	Fear: 0.3
Training: 0.8	Training: 0.3
Examples: 0.7	Examples: 0.5
Perception of "B": 0.8	Perception of "A": 0.9
Game Decision: 0.81	Influence: 0.58
Game Choice: #3	
Attraction: 0.2	
	Game Decision: 0.35
	Game Choice: #1
	Attraction: 0.5

The game selection can be probabilistic or possibilistic, but for the example, the selection will be based on the score, s: $0.0 \le s < 0.2$ results in a decision against game-playing, $0.2 \le s < 0.5$ results in a choice of game #1 (in the list given in the previous section), $0.5 \le s < 0.8$ results in a choice of game #2, and $0.8 \le s \le 1.0$ results in a choice of game #3. This is the (oversimplified) reason that the game decision score of 0.81 results in the choice of game #3 ("You're bad; I'm good"). Each game also has an inherent "attraction" score, indicating the amount of influence the game has toward continued game-playing. The example attraction scores are 0.5 for game #1, 0.8 for game #2, and 0.2 for game #3. At this point, "B" has a choice to make. The prior influence of "B" is 0.58. Including the influence of the game selection by "A," the game decision score for "B" is 0.35. In this example, this results in game choice #1 by "B." The attraction rating of this game is 0.5, which is incorporated in the subsequent choice by "A." In this manner, the cycle continues, with "A" making the next decision in the same manner as "B" made the last decision, etc.

Unique Signal Analysis. There are at least two basic functions of human communication that are performed simultaneously. One is to transmit information with no expectation of beginning an interchange. The other is to act as a "radar," either by sending out communications and processing the result (analogous to mono-static radar) or by observing response to a stimulus from another source (analogous to bi-static radar). In any case, the communication design needs to be carefully done to minimize miscommunication, to reduce the noise level, and to deduce an unambiguous response. In the latter case (bi-static), it is important to take a "dialectic synthesis" approach (assimilate a variety of types of information triggered in a variety of ways). An example is seeking how another person is feeling. One can simply ask, and if a trusting common context has been established, this may be sufficient. A more subtle approach is observation of the person's behavior and body language.

Insight into a systematic approach to communication analysis is afforded by "Unique Signals" [Ref. 14]. These are used in the U.S. weapons program for signifying an unambiguous intent to use a weapon. Unique Signals are carefully engineered to have high randomness for a large portion of subset bit lengths so that an unintended reception has minimal useful information. Conversely, transmission of intended Unique Signals conveys unambiguous information. This property provides insight into the analysis of game-related interchanges. If the initiator predictably encourages game-playing, the responder will find participation attractive and this can encourage destructive behavior. If the initiator uses a strategy analogous to the Unique Signal approach, the effect appears more random to the responder, and there are fewer inducements to fall into the cyclic game spiral. The main pertinent features of a Unique Signal strategy provide a useful basis for detecting and defusing games.

Unique Signals are sequenced patterns of "events," each event chosen to appear independent of every other event. Since the pattern is designed, it is not random. Since events are deliberately sequenced, they are not independent. However, the effect of a well chosen sequence with sequential delivery approximates the properties of random (independently chosen) events. Since Unique Signal patterns are for safety rather than security, there is no effort made to keep the patterns secret. The effectiveness is inherent in the robustness of the Unique Signal properties. Similarly, there need be no effort to keep communication strategies for defusing games secret. In fact, the trust-building inherent in rituals, pastimes, and open communication is an important contributor to discouraging game-playing.

From an analysis viewpoint, there are quantitative metrics that can be applied to Unique Signal patterns and transactional communication as well. Optimum Unique Signal patterns are restricted to two event types. Although transactional communication can be more diverse, the analysis basis can be demonstrated in more straightforward form by restricting the example to two types. Under this restriction, the first quantifiable metric is the number of events of each type. In order to combat inadvertent non-randomness, these should be as equal as possible. The next metric is that the transition pairs (with overlap) should be as equal as possible. This is to assure that once an event has been transmitted, the next event should be as likely to be the same as to be different. If the pattern is long enough, transition trios can be equalized, etc. Other metrics can reduce cycles (repeated patterns) so that these are minimal, including inversions (events replaced with their complements) and mirror images (forward-to-back replaced with back-to-forward). The space for potential metrics is extremely large, especially if more than two event types are utilized. The payoff has diminishing returns, but a reasonable amount of Unique Signal analysis is appropriate both for designing communication strategy and for analysis of emplaced strategies.

Conclusions

Fear-based responses are clearly detrimental to personal and team performance. These can result in immediate destructive reactions or in game-playing, which may have immediate or delayed deleterious effects. As a counter to fear and its effects, this work has demonstrated how fear can be detected, how it can be changed through training, through sensitization to human processing of patterns and intuition, through systematic recognition of effective strategies, and through instilling or developing a passion for collective results. The analysis strategies shown can contribute both to effective systemic approaches and to quantitative analysis used to measure degree of success.

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Appendix A.4

Engineering Optimal Individuals

Key words: passion, fear, interactive games, latent effects, exergy, sustainability, surety, systems, collectives

Arlin Cooper[19] and Rush Robinett III[20]

Abstract

This paper iterates between a top-down system approach and a bottom-up focus on individuals to develop methods for assessing and improving personnel productivity. Although skilled management, facilitated communication, and structured strategies are essential to productivity, the most important factor is shown in this paper to be individual behavior. Characteristics of optimum individuals are examined, the contribution of individuals to collectives is addressed, methods for enhancing the contribution of individual performance to collective goals are proposed, strategies for improving the utilization of sub-optimal individuals are developed, and a quantitative analytical structure is derived.

Introduction

This paper identifies a key contribution to improving the productivity and well-being of individuals, beginning with a top-down decomposition. Top-down *system*[21] views begin with an overall goal, where any subsystems are considered in the context of interactions and *interferences* between the subsystems. The initial top-down approach is generally effective in identifying some of the most subtle potential interferences and many of the most significant interactions. Following up a top-down examination with a bottom-up approach (and iterating) can have additional benefit. The system assessment and analysis necessarily include system environments that could be dynamic and unexpected. In order to support human productivity and well being, the appropriate overarching system framework is defined as collective *humanity*. An ideal top-down goal for humanity is *surety*, meaning perfect safety, security, and reliability, sustained into the foreseeable future (inherent *sustainability*). This would mean that a balance would have to be achieved among the development of infrastructures, population pressures, *exergy* sources, energy consumption; controls to assure personnel and infrastructure safety, security, and reliability; and strategies to not only put all this in place, but to respond effectively to dynamics of the earth's environment, unexpected natural occurrences, and the vagaries of human behavior. A secondary goal is productivity. Ideally, every participating person would have to possess perfect awareness and perceptive ability in order to achieve these goals.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

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[21] Italicized terms are defined in the glossary.

This overwhelming problem can be made more tractable by approaching the most important and highest priority key subsets of the inherent factors. For the purposes of this paper, the goal of perfection will be replaced temporarily with one of practicality, and the goal of "into the foreseeable future" will be replaced by a goal that can be achieved in the short term (as a step toward the long term). Even these goals, although generally easy to state, are much harder to achieve. Strategies, human behavior, and rewards must be *managed*, to make progress toward the goals. This requires management strategies, rewards, and metrics to judge success or failure. This need has been previously addressed [e.g., Ref. 1]. Management cannot function in isolation. Communication is an inherent necessity. An important requirement is that there be effective *interpersonal communication.* This was the reason that an *entropy*-related communication study was undertaken by the authors [Ref. 2]. Communication strategies and metrics are required. But management and communication strategies will not work in an atmosphere of *fear* and destructive *interactive games*. This problem has also been addressed by the authors [Ref. 3]. An important related consideration is the functionality of teams or *collectives* [Ref. 4]. Coordinating collective activities in a strategic manner can produce significant synergy. If implementations are to be successful, even a suite of management strategies, communication strategies, team strategies, and the elimination of fear may not be sufficient. All of the success or failure of these approaches depends on the *individuals* who participate. Strategies can look attractive on paper, but reasonable success requires substantial individual effort (and perfection would require incredible human effort). Following these considerations, a system-oriented chain of reasoning, illustrated in Fig. 1, frames the subject of this paper.

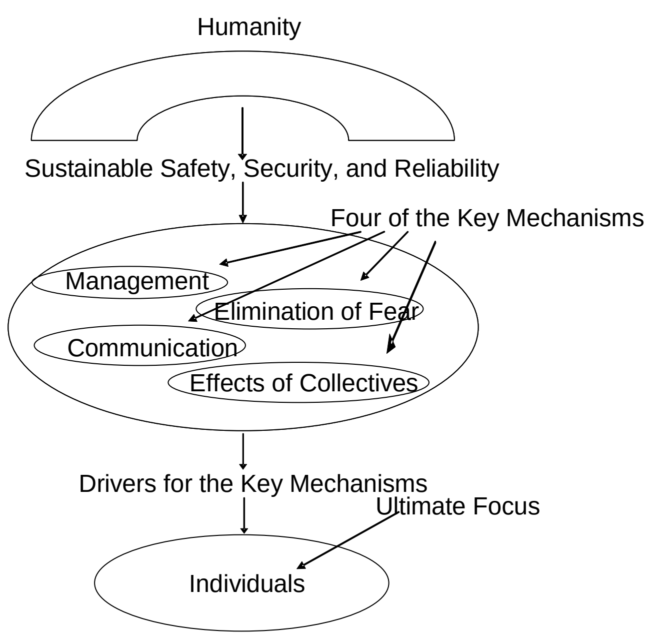

Figure 1. Top-Down Derivation Process

Various approaches to this subject have been previously attempted. A promising new approach was chosen for this paper. Following the top-down derivation pointing to individuals, the characteristics of an "optimum" individual will be deduced. Then, the contribution of individuals to collectives will be addressed. From this, the contribution of individuals to collective goals will be presented. Methods of utilizing non-optimal individuals to optimum advantage will be developed, and methods for encouraging non-optimal individuals to move toward the optimum ideal will be considered. A quantitative analytical structure that can be used to measure degree of success will be derived.

The emphasis on individuals does not mean that top down goals can only be achieved through bottom-up implementation. However, the strategies to meet such goals for humanity must be effective on an individual level. As an example, *democracy* is a management strategy that can be applied to arbitrarily large portions of humanity. In a democracy, individuals vote on representatives who implement policies, laws, judicial systems, enforcement details, and defense modes for individuals and the collective. The voters retain self-responsibility for the actions of their representatives. In this way, although individuals do not directly assure societal actions, they have an indirect voice. When elections take place, the focus is on the individual vote, which emphasizes individual responsibility. Another example is religion. Particular religions are practiced by large numbers of people who follow general doctrines. These are generally partitioned into congregations. However, the focus is on individuals and their participation in the religion. Other organizational examples are the military, economic systems, business organizations, and families. In these cases, group success depends on high level strategies that are mapped into intermediate strategies, with the ultimate aim of involving individuals and their core beliefs. So individuals are the ultimate key focus.

Derivation of Characteristics for an Optimum Individual

The starting point for (bottom-up) engineering design of an "optimum" individual is to consider the functional conversion of inputs to outputs within "constraints" (inherent restrictions that are invariant or relatively difficult to change without significant long-term effort). The inputs are the inherent environments that individuals can utilize. The outputs are the goals for the individual to achieve. Individual goals are reached or approached by choosing paths toward the goals, optimally if possible. One immediate complication is that inputs, output goals, paths toward the goals, constraints, and the degree of optimality are all relative, not absolute. In fact, all human perceptions are relative. This subject will be explored in more detail subsequently.

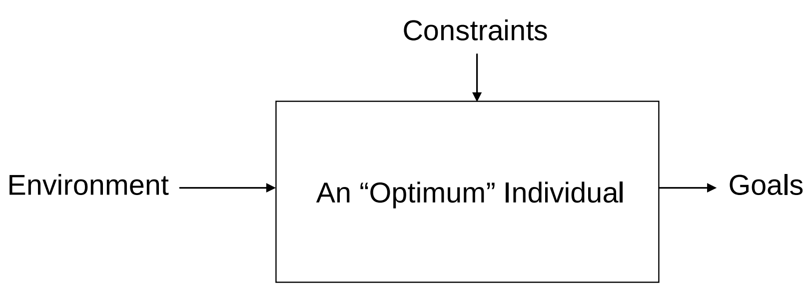

Figure 2. Starting Point for Engineering Design of an Optimum Individual

With reference to Figure 2, examples of the environment are energy sources to fuel the body, information sources to be processed by the brain, and “conventional” environments, such as light, heat, and air. Examples of constraints are societal laws that are intended to control or influence individual behavior and natural laws, such as the First and Second Laws of Thermodynamics (energy is conserved; thermodynamic entropy ultimately increases). Examples of goals are individual survival, surety, and productivity. In order to optimally achieve goals by processing inputs under constraints, some desirable individual characteristics can be strong contributors. For example, characteristics such as “fire in the belly,” passion in the heart, and extensive knowledge are desirable. These sorts of characteristics will be discussed subsequently.

Individuals within a Collective Structure

Before further developing the proposed engineering design of individuals, a top-down context can help determine a more informative framework. From a top-down view, numerous factors transcend the individual. One is that individuals almost always function as part of a collective. Collective teams have a clarity of purpose through a mutual context viewed from many different perspectives. These relative viewpoints from many members help improve the overall perspective, including relative views of team goals and paths toward those goals. Since humanity is a collective, interpersonal communication can be a strong contributor to humanity, team, and general collective performance. The benefits of collective participation [Ref. 4] are similar to the construction of a hologram from fragmented transforms: the whole entity benefits from multiple “views” and participatory contributions. It has recently been discovered [Ref. 4] that collectives comprising distributed minimally functional robots can outperform sophisticated centrally controlled systems. This is a dramatic demonstration of the synergistic power of cooperating team members.

A “management” overlay is also important. The management function can be accomplished in a variety of ways (individually, or in combination). Figure 3 depicts the context within which individuals perform.

Contribution of Individuals to Collective Goals

Individuals will now be examined again from a bottom-up view, but using the previous top-down context. The benefit of iterating between top-down and bottom-up structures is that the complementary views contribute to the identification of comprehensive considerations for individuals. Consideration of collectives demonstrates that individual input environments, output goals, and organizational constraints should be supplemented to achieve optimum individual design. And wherever there are interfaces and interactions (e.g., human-to-human or human-to-environment), there can be interferences (undesired ramifications, or “hazards”) [Refs. 5, 6].

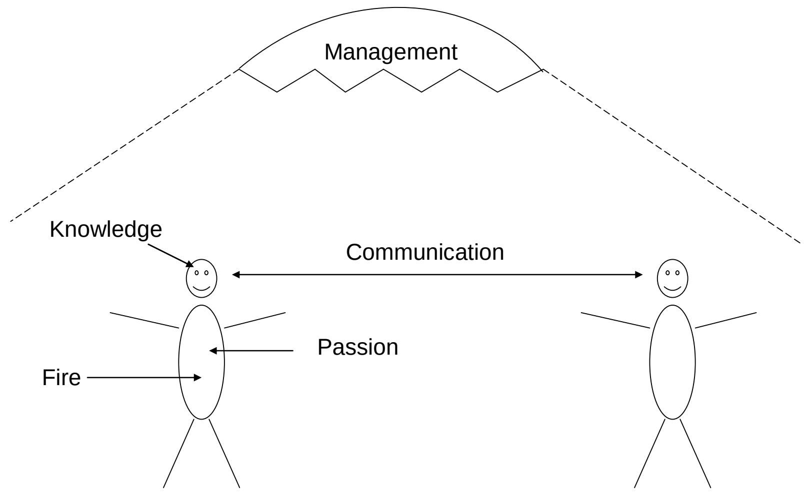

Figure 3. Indication of the Context within which Individuals Function

Communication from other individuals is another necessary input. External management must be added. Management examples are team leaders, organization management, local, regional, national, or international government. These are considered to be "constraints" (inherent influences) on individual performance. Outputs should include collective goals as well as individual goals. Individual goals should include self-improvement or *self-actualization*, which is also a collective goal. In cognitive science, self-actualization is used to mean perceived competence to satisfy basic needs in due time. Because the world is inherently non-ideal, there are hazards that can impede individual performance. Sources of these hazards include human limitations, human threats, and natural threats; and these are shown as influences at the bottom of the "individual" module. The individual traits desired include passion, skills, and judgment, so these must be added to the model. The development of such traits can be from several sources. Communication from other individuals and controls from management are potential contributors. Self-generated contributions are also important. The influences that are part of this sequence can be delayed in time. These are called *latent effects* (sources of influence that are not immediately influential, but can have later influence). The consideration of latent effects is similar to psychoanalysis, but from an engineering modeling viewpoint.

Part of self-actualization and collective contributions can be utilized through an action process as derived inputs to contribute to desirable traits. The action process involves self-testing in order to measure performance and decide on corrective steps when necessary. As a means of preventing the instability that can occur in feedback systems, the response time constant must be great enough that corrections will not cause uncontrolled responses. This means that the action process must be deliberate, judicious, and viewed over a long enough time to see latent effects. These considerations lead to an expanded bottom-up view of the engineered individual. The concepts are indicated in Fig. 4.

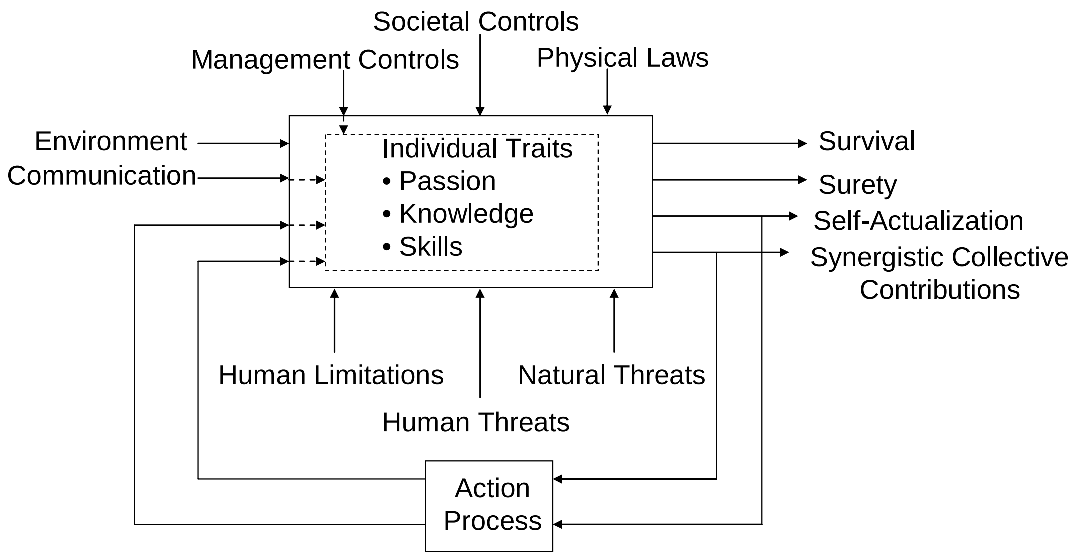

Figure 4. Expanded Engineered Design Model for an Optimal Individual

Some elaboration on the constituents in the structure diagramed in Fig. 4 further contributes to understanding the model's concepts.

Inputs

> Environment. The environment includes energy sources to fuel the body, since individuals are exergy parasites. The goal is to use exergy symbiotically, rather than destructively. Paradoxically, providing sources of exergy is an *order*-producing activity; consumption is an order-destroying activity. This will be discussed subsequently. There are also information sources to be sensed by seeing, hearing, touching, smelling, and tasting. These are processed by the brain. Humans are also exposed to light, heat, and air. An interesting observation is that all of these input sources are perceived relative to stored reference patterns, some of which may be highly dynamic. For example, exposure to a hot temperature feels hotter after exposure to cold temperature than it does following exposure to a warm temperature. After a period of exposure to a new temperature level, the reference changes. Our contention is that all human perception of inputs is relative to dynamic reference patterns. There do not appear to be any inarguable perception absolutes.

> Communication. Interpersonal communication has various purposes and various degrees of information. Issues include trust, honesty, semantics, and game-playing [Refs. 2, 3]. Unique-Signal communication approaches are a useful tool for enhancing communication effectiveness, and communication entropy is a useful tool for developing performance metrics [Ref. 2]. From an individual

viewpoint, information received can be utilized to improve individual functionality.

Self-Actualization. Self-actualization is an individual input, derived through a self-generated action process. The intent is to enable individuals to "test" their performance and to continuously improve. Self-actualization increases individual order, which increases the chances of individual and societal survival.

Synergistic Collective Contributions. This is another individually derived input, and is based on teaming skills, such as information sharing and mutual support. This input can also involve self-testing as part of the action process.

Constraints

Management Controls. Management controls are an organizational technique intended to encourage more ordered collectives. These can include rules, regulations, punishments, influences, and rewards. We will utilize the influential nature of management controls as a way to optimally utilize individuals for collective benefit in the following section.

Societal Controls. Societal controls are similar to management controls, but have some different motivations and effects. Examples are laws, infrastructures, and processes established by governments. Religions exert varying degrees of behavioral influence on individuals, especially regarding morality and ethics. There are also individual moral and ethical controls (e.g., conscience).

Physical Laws. Physical laws constrain the manner in which individuals survive and function. Two of the most principle-based laws are the First and Second Laws of Thermodynamics. The First Law of Thermodynamics basically asserts that energy is conserved; the Second Law of Thermodynamics states that ordered distributions of energy will ultimately disperse, measured by increasing thermodynamic entropy. A second law efficiency is the ratio of the minimum amount of available work required to do a particular job to the amount of available work used to do the job. This is in contrast to the first law efficiency, which is the ratio of energy out to energy in. These efficiency concepts can help us measure how optimal an individual is.

Goals

Survival. Individual functionality depends on survival. Since individuals consume exergy, they tend to increase entropy (decrease order). However, part of survival for humanity is to build ordered infrastructures, for example to enhance sustainability and increase information, thereby decreasing entropy. Fig. 5 indicates the quasi-equilibrium balance between order and dissipation that is inherent in human survival. The ordinate position as a function of the equilibrium point depends on the quality of life sought or derived. This obviously can be different for different individuals or societies, and can change with time. Since the equilibrium point on the transition slope is relatively adaptable and control over it is generally flexible, the balance is especially important for individuals and humanity. The process of dealing with competing contradictions such as balancing order and disorder is called *dialectic synthesis*.

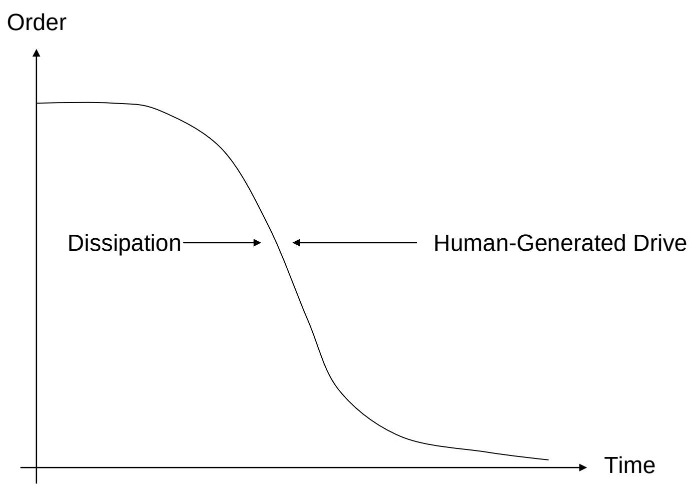

Figure 5. Quasi-Equilibrium Exergy/Entropy System

Surety. Functionality is enhanced through the surety conditions of sustained safety, security, and reliability, so this is a significant goal. Surety involves the production of order through a predictable path into the future, in the face of continuous change and uncertainty.

Self-Actualization. Traditional self-actualization [Ref. 7] builds on survival and surety to achieve perceived competence for material, cognitive, and subjective confidence. A necessary adjunct is self-exploration and action. This goal is met by the basic self-actualization output goal and by the feedback to enhance personal traits through an action process.

Synergistic Collective Contributions. The goal of contributing to team effectiveness is enhanced by open information sharing, trust in team members, and support of team objectives. Effective collectives usually have synergistic contributions by team members, enhanced by the variety of their relative views. This is an optimal means to deal with a fundamental individual constraint of being limited to a relative reference frame. Self-assessment is an important part of enhancing this output, as indicated by the feedback in Fig. 4. Societal quality of life depends on maximizing *exergy* over the long term, since humans are exergy parasites.

Hazards

Natural Threats. Since individual efforts cannot be assured to be carried out in pristine conditions, natural threats must be acknowledged. These can include earthquakes, fires, floods, and storms. In addition to the inherent hazards, the existence of such threats can distract from productive focus.

Human Threats. Human threats can include malicious attacks, mental or physical diversions, and game-playing [Ref. 3]. All of these can detract from desired individual functionality.

Human Limitations. Humans are not ideal, so they have inherent limiting emotional tendencies, such as fear, jealousy, and selfishness. In fact, humans are "hard-wired" to have fear. Fear is necessary for survival, but if not filtered and controlled into an optimal emotional state, it can become a destructive limitation. Humans are also limited by not being able to discern absolutes, but only relative relations to reference frames and to stored or deduced patterns. Also, humans must function through the exergy-entropy dichotomy illustrated in Fig. 5.

Individual Traits

Passion. Passion is an emotional commitment to individual functionality. It is required for individual excellence and for commitment to collective effort. Passion is the antithesis of fear and can overcome the destructive tendencies that fear instigates. A related trait is selflessness. Paradoxically, selflessness can be one of the most effective contributors to obtaining selfish goals, when applied to synergistic collectives. Another related trait is trustworthiness. People who can be depended on to predictably do what they say they will do without any deceit inspire trust in others. This is especially important, since building trust is relatively long term, but it can be quickly destroyed.

Knowledge. Continuous learning is essential for enhancing human functionality. This is especially evident in the scientific world because of rapid technological advances. It is also essential in the sociological world, where advances in individual and collective behavior strategies occur. Since knowledge is relative, human knowledge cannot be perfect. Decisions must therefore be made with incomplete information. However, knowledge and decision-making can be enhanced by utilizing relative views of collective members. Also, imperfect knowledge can be enhanced by heeding intuition (recognizing and responding to patterns stored in human memory). The optimum strategy appears to require both rational and intuitive thought processes, used in balance and iteratively.

Skills. Skills are generally distinguished from knowledge by requirements for actual performance and practice. For example, the theory of self-actualization skills is not sufficient for achieving effective self-actualization. Practice (continuing repetition) and learning from what doesn't work are required adjuncts.

Consideration of Non-Optimal Individuals

All individuals are non-optimal to varying degrees. It might appear to be obvious that an organization should seek the most nearly optimum individuals possible. However, any collective effort is more effective if the capabilities of the individuals available are used optimally. One ramification of this is that teams usually need "role players" in addition to "stars." For example, Michael Jordan was the main star of the Chicago Bulls basketball team and Scottie Pippen was a supporting star. Their teammates were role players. This argues that management can have two focuses: select the best fitting individuals for the particular functions required in the team effort, and influence the selected team members for maximum contribution to the collective.

Effective leaders of non-optimum individuals must be much more than managers. For example, these leaders should look for opportunities in the effects of non-optimal performance rather than enforce inflexible processes. These leaders should be persuasive, which helps re-direct any tendencies toward poor performance. They should take the risk of relaxing control, which usually contributes to enhanced personnel initiative. They should be patient, consistent, and persistent. In these ways, leaders can get improved results from non-optimal people (and then it is desirable to let them know they did it themselves). This is an illustration of building subjective competence in an analogous way to "raising children."

The feedback paths indicated in Fig. 4 provide avenues for improvements, using management influence, and personal self-assessment. Management initiatives [Ref. 1, 2, 3, and 4] include, for example, establishing a common context (i.e., a family-like environment) with individuals by getting to know them and their thinking processes; by demonstrating the potential of collectives for overall functionality and individual benefit; by encouraging them to follow paths that they are passionate about (rather than fearful of); by encouraging intuitive development through recognition of patterns; by building trust through honest, clear, and effective communication; and by assuring appropriate rewards systems. The inherent limitations of the human tendency (a phobia) to respond to stress by freezing, fighting, or fleeing can be guided toward a logical approach [Ref. 3] where fear is faced as an acknowledged hazard that can be overcome through passion and where destructive game-playing is defused. This is an example of the need for left-brain (objective, logical) balance with right-brain (intuitive, subjective) training.

Self-assessment is necessary to determine what personal initiatives might be appropriate. This evaluation depends on emphasizing awareness so that performance attributes can be sensed on a continuing basis, so that problems can be headed off before they become debilitating (an irreversible latent effect path) and so that successful traits can be reinforced. The benefits of self-assessment are often obvious to individuals, but can also be pointed out by management. Peer evaluations (continuous feedback from many sources, such as trusted people, hardware, animals, etc.) are another informative tool.

An important method of utilizing non-optimum individuals is to seek and take advantage of diversity of views. When differences arise, any potential for conflict can be re-directed by asking something like "What do you see that I don't?" This can open doors to learning opportunities. Also, "failure" due to non-optimal outcomes can be an important learning experience. Complete abhorrence of any failures can lead to fear of taking risks and failure. Judicious risk-taking is an important contributor to most significant achievements. We learn by emulation, experience, and synthesizing patterns from an intuitive reference. Risk-taking helps extrapolate our baseline to new levels.

Overall Summary Relationships Structure

The context for the work in this paper can be shown by a relational logic diagram, illustrated in Fig. 6.

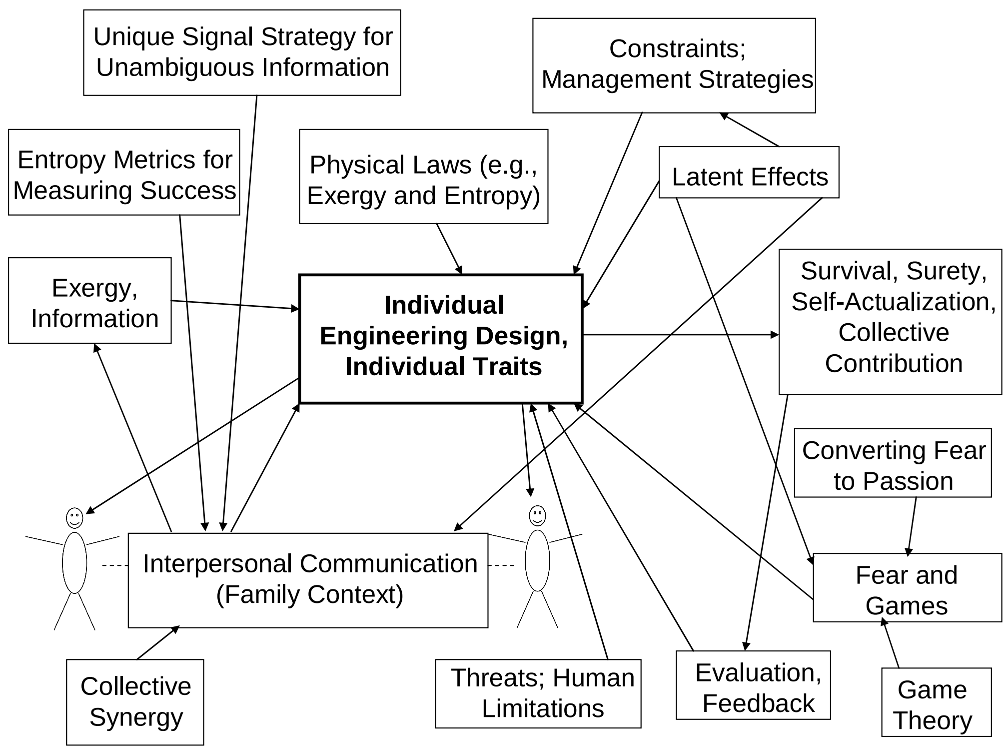

Figure 6. Overall View of Context for Individual Design Results

The focus of this paper on engineering design of optimum individuals is emphasized at the center of the diagram. The reference background mentioned in the Introduction on management strategies, interpersonal communication, converting fear to passion, and synergistic collectives are depicted as parts of the boxes at the upper right, just above lower left, just below middle right, and at the extreme lower left, respectively. Management strategies are part of the constraints that enter at the top of the design box. Other constraints are physical laws. The interpersonal communication is targeted toward enriched information and synergistic collective results, as well as state of health and connections to reality (seeking definitive markers in an attempt to identify "truth"). This is driven by the Collective Synergy box and the Unique Signal communication strategy box. The metric is furnished by communication entropy. The inputs to the individual engineering design box include exergy for consumption in addition to the information. The Interpersonal Communication box is also served by the output of the Individual Design box. Latent effects (effects that have been instigated earlier but contribute to later actions) contribute to several boxes. These are often limiting behaviors and biasing filters. The main individual outputs discussed earlier are shown at the middle right. Some of these are used in the Evaluation, Feedback box. The main threats shown are from the Human Limitations box and from the Fear and Games box, the latter of which has inputs from the box that depicts converting fear to passion and the Game Theory box. The Evaluation, Feedback box monitors the outputs and is used to contribute to the individual traits. All of this helps portray the overall context and helps illustrate why both top-down and bottom-up views contribute to overall understanding.

Mathematical Assessment of the Engineering Design of Individuals

All of the structure shown in Fig. 6 can be mathematically analyzed. Portions have been done previously [Refs. 1, 2, and 3]. While the overall analysis is beyond the scope of this paper, the analysis of the engineering design of individuals shown in Fig. 4 will be developed here. The progression that led to the model portrayed in Fig. 4 was logically derived. The actual success of applying the model can be enhanced by using mathematically based metrics. The aggregation of the factors in Fig. 4 is most effectively done through a strategy such as “Markov Latent Effects” aggregation [Ref. 8]. In Markov Latent Effects aggregation, early effects are derived and used to influence later effects in a structure that reflects the sequence of influences. An example latent effects structure is shown in Fig. 7.

Each module in Fig. 7 represents a weighted sum, so that the input values are each multiplied by an associated weight and added. Input values have positive response to value, so that, for example, a value of zero has minimum attribute, and a value of one has the maximum positive attribute. A value of 0.5 is considered “average.” The outputs represent a resultant value score. Example input weights are shown, where the sum of the weights into each module is one. The weights vary depending on the application. Those shown for the example are postulated for the “Self-Actualization” output.

As an illustration, a calculation for Self-Actualization was made using the following inputs, given as interval values in order to represent input uncertainty.

Environment: 0.6, 0.7
Interpersonal Communication, Information: 0.8, 0.9
Human Limitations: 0.3, 0.5
Human Threats: 0.7, 0.8
Natural Threats: 0.8, 0.9
Management Controls: 0.8, 0.9
Society Constraints: 0.4, 0.6
Physical Laws: 0.8, 0.9
Self-Actualization Feedback: 0.7, 0.9
Collectives Feedback: 0.3, 0.4

The resultant Self-Actualization score is 0.60, 0.74, which is a little above average.

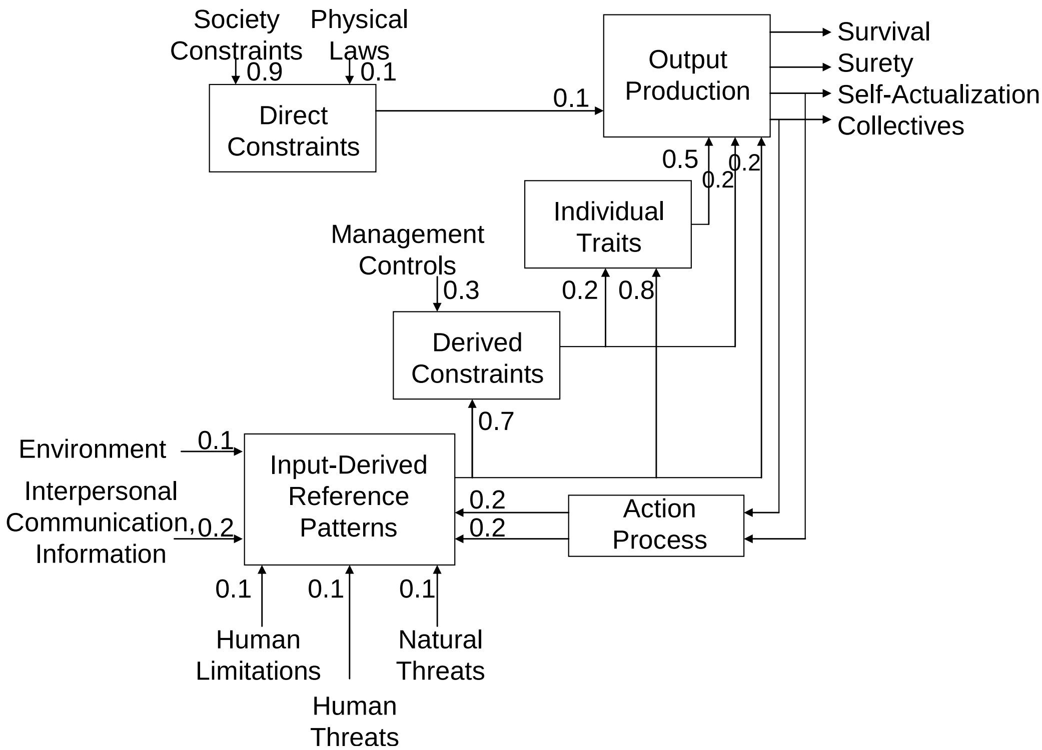

Figure 7. Markov Latent Effects Model for Individuals

Conclusions

The combination of a top-down and a bottom-up approach in this paper demonstrates the value of both an overarching strategy for success and a focus on the individuals who must carry out the strategy. Certainly nothing significant can be accomplished by a collective without contributions from the constituent individuals. While the focus is on individuals, it is important to maintain the overall top-down view with due consideration to the interactions among the constituent parts. As a result, individual attributes that can be synergistically combined were able to be derived in the paper. As an adjunct attribute, the approach provides an appropriate structure for quantitative analysis of the degree of success that individual and collective performance offers.

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Glossary

Collectives: A group of individuals that work together to produce a collective behavior that is greater than the sum of its parts. This synergism is achieved by using multiple perspectives.
Democracy: A strategy for combining humans into a voter-driven, participant-managed system that is intended to contribute to the overall benefit of the collective.
Dialectic Synthesis: Dialectic synthesis productively utilizes conflicting inputs. This form of synthesis is sometimes called “transcendence of dichotomies.”
Entropy: A metric that relates to dispersion or disorder in thermodynamics and information theory.
Exergy: That portion of energy available to do work.
Fear: Emotions to a perceived threat that produce mental or physical pain, and can prevent logical response.
Humanity: The collection of humans now living on earth and expected to live on earth in the future.
Individuals: Humans who are the most basic constituents of the humanity system.

Interactive Games: Initiation of a "contest" with a well-defined objective through interchanges with another person or persons.

Interferences: The unintended effects of system constituents on each other, usually detrimental.

Interpersonal Communication: Information (verbal and non-verbal) interchanges intended to contribute to an objective.

Latent Effects: Past occurrences that may not have immediate effect, but can influence outcomes at later times.

Managed: Guided through strategies, rewards, and resource management.

Order: The organization of entities such as information and energy, which can be measured by decreasing entropy.

Self-Actualization: Self-actualization is the achievement of perceived competence (material, cognitive, and subjective—"been there, done that"—abilities), and to satisfy basic needs (physiological, safety, love, and esteem needs) in due time.

System: A collection of constituents or subsystems combined to achieve an overall function or mission.

Surety: The state of optimal and sustainable safety, security, and reliability.

Sustainability: Continuous (foreseeable future, e.g., 200 years) availability of exergy and other consumptive resources, where the modes of use are matched to the developed sources.

Appendix A.5

Deriving Sustainable Ordered Surety by Overcoming Persistent Disorder Pressures

Key words: surety, fear, risk, latent effects, exergy, sustainability, terrorism, dichotomies

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Abstract

A large number of interrelated factors in our daily lives involve surety (safety, security, and functionality, all with sustainability). However, there are opposing (threat) factors. Strategies for dealing with the evolving and diverse factors that can contribute to surety and can detract from it are important in a variety of enterprises, such as national energy policy, national defense, homeland security, business operations, and personal collectives, such as families. This paper derives an innovative risk analysis structure for surety by considering technical and social factors that create diverse pressures and dichotomies. Based on the derived structure, a strategic surety approach involving a variety of effects is developed. An analytic treatment helps quantify the potential success of the approach.

Introduction

People's lives are affected by a variety of factors that have a common underlying theme: success is achieved only by overcoming inherent pressures that could potentially cause failure. These pressures are often dynamic and evolving. For example, the Energy Policy Act of 2005 was recently enacted in the U.S. The act seeks to encourage the development of new energy sources, reduce dependence on foreign oil, and reduce the rate of use of fossil fuels and water resources. The balance sought is to do all of this in a manner that affords environmental protection against pollution and greenhouse gases, while also protecting against resource depletion and minimizing financial burdens for the present and long-term future. Investments in new technologies have to be prudently distributed, for example because of the risk that these technologies will not prove to be cost-effective. In homeland security initiatives, greater access to information about those who might be terrorists, saboteurs, and malcontents is sought, but it is desired to constrain the amount of access to this information in order to protect personal freedom. When terrorist attacks occur, there is a need to balance natural tendencies toward paralyzing fear (which can cripple societal activities) by focusing on logical responses that can discourage terrorism, or at least damp its effects. In addition, terrorist tactics evolve in response to new defenses and because unpredictability is one of the terrorist goals, so dynamics are important. The NASA shuttle launches are carefully scrutinized for safety of the crew and the public, but there are pressures to take risk in order to contribute toward scientific advancement, and the goals evolve (e.g., for manned flights to Mars). There are also pressures for the Space Shuttle to deliver supplies and exchange crew members on the International Space Station. Managing business organizations requires a balance between micromanagement and delegation. Raising children, with the

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objectives of instilling intimacy, spontaneity, and freedom [Ref. 1], requires a balance between parental control and individual self-control in order to create an autonomous person with the desired characteristics.

In the next section of this paper, general surety goals are laid out. Safety, security, energy, functionality, and sustainability are addressed. In the section following that, pressures working against surety are considered. The objective of these sections is to create a framework for balancing the corresponding considerations. However, the balance is not amenable to conventional risk analysis for two major reasons. First, the factors involved are not directly comparable by any ordinary metric. Second, a large collection of interdependent effects and particular types of dichotomies are involved. This requires a new context for assessing the competing effects, which is a major result derived in this paper.

The developed context is applicable to many different situations, some of which are addressed in the paper. From this basis, an overarching strategy for dealing with collections of dichotomies in a variety of situations is proposed. Example applications will be indicated.

An illustrative visual construction that facilitates understanding of the multi-dichotomy situation will be derived, and this structure can be used as a basis for an analytical assessment of the achievement of the balance that is the ultimate goal.

Sustainable Ordered Surety Factors

For this paper, the definition of "surety" is maintaining required functionality in the face of constraints (e.g., limited resources) and doing so safely (e.g., avoiding significant accidental loss), securely (e.g., avoiding significant malicious events), and maintaining these conditions for a significant length of time (e.g., over the time frame of up to a few centuries). Safety implies relative freedom from loss of life, relative freedom from monetary loss, relative freedom from fear (due to uncertainty regarding safety), relative freedom from environmental damage, and relative freedom from loss of image or reputation. Security implies relative freedom from attacks by terrorists, vandals, and malcontents. Sustainable means relative lack of long-term degradation of required functionality, safety, and security, in spite of constraints (e.g., financial and legal).

The fact that there are multiple appearances of the adjectives "required," "significant," and "relative" in the definition is telling. The attributes of surety are rarely (or never) completely met. This makes quantitative assessments, such as those seen in conventional risk analysis, less meaningful than one would like. Also, there are multiple factors in surety, and they are not independent. And there is an indeterminate time factor. In addition to a weakly defined time goal, time allows for dynamic and evolving situations. For example, new surety and/or threat technologies can become available. In energy surety, new sources of renewable and non-renewable energy can be discovered. New "plug and play" combinations (flexible adaptive multi-source infrastructures) of energy and transportation can be developed. Improved treatment of water used in energy generation can enhance its recycle use. New forms of pollution control might be discovered. In social, government, and family structures, new agreements and alliances can be developed. For these complex reasons, a new innovative form of surety assessment is needed for this subject.

The desire to achieve surety goals and to do so in spite of pressures working against those goals can be treated more effectively through a meaningful metric. The metric we seek is related to "order." Order means a structured arrangement that has been optimized to achieve some goal or goals. In thermodynamics, thermodynamic entropy is a disordering effect [Ref. 2]. In information theory, communication entropy is also a randomizing (disordering) effect. There is also a relation between irrational fear and disorder [Ref. 3]. In fact, the basic structure of all entropy metrics has the same analytical basis [Ref. 4]. One of our objectives is to develop entropy as a measure of surety disorder.

Sources of Persistent Disorder

Surety goals (intended to create a form of order) are more familiar and direct than the threats to surety, which are essentially disordering effects. Threats are more unpredictable, more adaptable to human generation vagaries, and more psychologically based than surety goals. For these reasons, threats need special treatment and will be addressed in this section.

<u>Limited Sources of Energy and Exergy.</u> The initial example will be cast in terms of thermodynamics. The first law of thermodynamics asserts that overall energy is conserved. This means that the energy in the known universe cannot be lost, although it can be converted from one form into another, and order can be temporarily created. The second law of thermodynamics asserts that entropy increases (ordering will ultimately be lost). In using energy, it is not all available for desired applications. Exergy [Ref. 5] is that portion of energy available to do useful work. The portion that is unavailable is lost, e.g., in waste heat. All processes and activities using exergy result in waste, thereby increasing entropy. ("There is no free lunch.") Energy is not scarce, but exergy is a potentially scarce resource.

The energy context (e.g., first and second laws of thermodynamics) can be likened [Ref. 6] to a one-sided poker game with Mother Nature. You can't win (can't get out more than you put in). You can't break even (the "House" always takes a percentage of the stakes). You can't even get out of the game (existence involves consuming exergy). Humans are exergy parasites on host, earth, creating order to find and consume exergy (producing entropy and disorder) to survive. Humans are in a constant struggle with the second law of thermodynamics and entropy. Many people believe they are "fighting fire with fire" by fighting entropy with entropy over their lifetime. But actually, they are fighting entropy with exergy (order) through entropy, which means humans follow a pattern of ordering and disordering over time. Elaboration on this process is in the next section.

This perplexing situation can be dealt with strategically. For example, if there were unlimited cheap fossil fuel and unlimited amounts of clean air in the biosphere (i.e., the solution to pollution is dilution), humanity could be assured of an indefinite acceptable lifestyle. Since there is not, energy development and use strategies must be followed.

Resource Depletion. In addition to the depletion of fossil fuels, there are many other depletion threats involving energy use. One example is the use of water, which is an important cooling agent in many forms of energy generation. Water (especially fresh water) is becoming a world-wide scarcity, so preventing or restoring from water depletion, heating, and contamination is becoming more important. Many forms of energy generation produce pollution and greenhouse gases, which can affect human health, either directly or indirectly. Deforestation can threaten ecosystems and oxygen generation. Financial resources can also be seriously depleted. Something will almost certainly survive in the biosphere of the earth, but it may not be the human race if we are destructive versus symbiotic parasites.

Psychological Health, Terrorism, and Fear. Since humans are strongly affected by emotions, there are several threats to psychological health that must be considered. One example is terrorism. A minor goal of terrorism is to kill people who might oppose terrorists' goals. However, a much more important goal is to instill fear (by initiating what could be called "destructive games" [Ref. 1]), thereby crippling societal foundations such as economic systems, political systems, and personal enjoyment of life.

Some Pertinent Dichotomies

There are several dichotomies that can be considered in weighing competing effects in order to derive a desired strategic balance through dialectic synthesis (optimally dealing with dichotomies). Some of these will be outlined in this section. Note that they are not independent (many common relationships exist).

Entropy vs. Exergy. The availability of exergy (a desired commodity for consumption) requires creating order in the form of useful energy sources. Consumption and the ravages of time are a contrasting disorder effect. People are exergy parasites and are in a life-long struggle against entropy. However, people have choices in how they develop sources of energy and in how they consume exergy. One pertinent parameter is the "standard of living" for which people or societies strive. Another factor is development of new technologies and infrastructures. The challenge is to create order and disorder at the same time in an optimal way. One salient example is illustrated by the "Unique Signals" used to pre-arm nuclear weapons [Ref. 7]. The communication entropy of inadvertently transmitted signals that might be capable of pre-arming is as high as possible; the communication entropy of the reference pattern stored in the receiver is as low as possible to provide an unambiguous message to the weapon.

Fear vs. Passion. Fear is an inherent human tendency and necessary for survival. The classic responses to fear are flight (literally or figuratively "run away" from the source of the fear), fight (irrational strike-back in retribution at the source of the fear), or freeze (become physically or mentally immobile). However, fear can be handled differently [Ref. 3] by taking advantage of human intellect, learning, and intuition (specifically through a "feel" for recognizing reference patterns). The basic idea is that a passion to pursue logical responses that transcend fear can be instilled in advance (i.e., positive latent effects), so that when a new fear-based situation arises, a predetermined reference situation can be recognized and applied. In essence, a passion for a mission replaces fear. As a result, a confidence in being able to meet the situation is inherent. One example is training for the "two-minute drill" by a football team. As a result, when the team has the ball and needs to score with time running out, the team is more likely to confidently execute the trained response rather than giving in to flight, fight, or freeze tendencies.

An important observation is that the tendency for increasing entropy implies the possible availability of exergy (an initial order that can be disordered). The pressure toward entropy can be mitigated by the use of exergy. This balance of competing effects and use of a negative effect to produce a positive effect is fundamental to all of the dichotomies in this paper.

Response to potentially fearful situations provides one of the clearest examples of why conventional risk analysis is inappropriate for treating dichotomies in general. Most people clearly understand the statistical risk associated with driving automobiles, but do so without significant fear for a variety of reasons, such as convenience and personal control. People also understand the low risk (including terrorist risk) associated with flying, but flight miles have not yet returned to pre-9/11 levels. In fact, there are extremely interesting and diverse responses to terrorist attacks. For example, some people do not change their transportation patterns at all following transportation attacks, possibly out of necessity. Some people return repeatedly to previous attack locations because their enjoyment of the social atmosphere, e.g., in coffee shops and market places, outweighs the perceived threat. Some people refuse to "give in" to intimidating threats as a matter of principle. Some others are frozen by irrational fear. The issues of enjoyment of life, irritation at sources of threats, personal value judgments, and decisions about risk are extremely complex. These are dependent upon how a person weighs the multiplicity of life values.

It is helpful to decompose such uncertainty-driven complex decision processes under incomplete information as an aid to understanding how people generally react. One common categorization is "aleatory" (objective variability) and "epistemic" (subjective judgment). A more comprehensive partitioning is "normative" (e.g., aleatory), "availability" (e.g., surrogate-information-based or pattern-recognition-based), and "individual" (e.g., influenced by biases, emotion, values, risk-aversion, loss-aversion, experiences, and personality) [Ref. 8].

<u>Selfishness vs. Selflessness.</u> Humans also have selfish tendencies that are inherent, but often are exacerbated by fear. The apparently contrasting selflessness may appear personally counterproductive. However, there can be selfish benefits to selflessness [Ref. 9]. Examples are plentiful, most based on achieving synergistic production for a "collective" (collection of individuals that works together to produce a collective

behavior that is greater than the sum of its parts). For example, sports teams can derive greater benefit for all of the individual team members by having “role players.” Business organizations and teams can similarly derive improvements for all members of the collective. Families can also achieve synergistic benefits by judiciously establishing contributing roles for family members. Even collectives of extremely simple individual robots can achieve collective functionality that is extremely difficult for centrally controlled systems [Ref. 9]. Recently, the U.S. and Germany embarked on an energy-efficiency assistance program for developing nations, such as China and India, that is intended to help not only those countries, but more importantly the world community, reduce pollution and greenhouse gases [Ref. 10]. The pertinent paraphrase is “The more you help others get what they want, the more you will get what you want.”

<u>Analytic vs. Holistic Brain Processing.</u> The brain functions in two different ways [Ref. 11]. The left brain processes information in a structured analytical manner. Some of the descriptors associated with this forma of processing are “logical,” “objective,” “bottom-up,” “sequential,” and “detail-oriented.” In contrast, the right brain processes information in a more holistic manner. Some of the corresponding descriptors are “global,” “intuitive,” “overarching,” “spontaneous,” and “top-down.” Human deductions and decisions depend on how these competing modes are balanced and assimilated.

<u>Control vs. Freedom.</u> Various situations are affected by the tradeoff between freedom and control. For example, resistance to terrorism activities can be enhanced by giving law enforcement agencies the ability to wiretap, relax the criteria for use of deadly force, seek financial records, and detain suspected individuals without the usual protections afforded citizens. However, the result of such measures is that individual freedoms are impacted for the entire community, including law-abiding citizens. A somewhat analogous consideration is faced by parents in raising children. Giving children complete freedom while growing up does not teach responsibility, morals, and work ethics. Completely controlling children does not allow them the freedom to learn through failure, develop initiative and fully explore their individual talents and ambitions. There is an initial need for control, through which freedom can be introduced and control reduced. A judiciously balanced parental strategy is necessary.

The Role of Dialectic Synthesis of Dichotomies in Self-Organizing Systems

It is important at this point to put the types of dichotomies discussed in the preceding material into the context necessary for considering strategic resolution. This discussion utilizes the concept of “self-organizing systems.” Self-organizing systems are nonlinear feedback-based systems comprising entities that can spontaneously create globally coherent patterns out of local interactions between system components, with the properties that the system is in a stable state in response to small perturbations, but can move to a different stable state in response to more pronounced perturbations. Such systems are robust to minor faults or loss of element functionality, because the system functionality is distributed rather than centrally controlled. Some examples are: magnetic materials, Bénard rolls [Ref. 12], crystal structures, the human brain (comprising its neurons), collections of associated animals (e.g., flocks of birds in flight, shoals of fish, swarms of bees, herds of sheep), ecosystems, economic market systems, and human societies. An additional distinguishing property of such systems is that they are “emergent” rather than “Newtonian” because the most significant effects are top-down on the entire system, rather than bottom-up on its constituents. The nonlinear property assures that input perturbations can cause multiple possible outcomes (and model solutions), rather than a single outcome. The multiplicity of stable states for which choice depends on the input perturbation creates the property of “adaptability” (the system can improve its performance in response to changes that might otherwise degrade performance [Ref. 12]). Since the potential state changes can be chaotic and temporarily unstable if input perturbations are sufficiently large, self-organizing systems are said to be “on the edge of chaos.”

Self-organizing systems are highly ordered. Ordering is inversely related to entropy [Ref. 7], so appropriate metrics for the success of self-organizing systems would correspond to low entropy. Perturbations can enhance or degrade ordering. For all self-organizing systems, both ordering and disordering pressures exist. This was the case for all of the dichotomies discussed in the preceding section. Self-organizing systems are fragile because if the exergy input (i.e., ordering pressure) is turned off, the system will disintegrate.

One way to illustrate the stable balance in a family of potential balances that competing pressures can create is to portray the multiplicity of possible states as a function of time under various ordering/disordering pressures. An example is shown in Fig. 1 [Ref. 13], where a particular stable balance state (ordinate position) has been achieved. The system will remain in this state unless order or disorder pressures change. The relative abruptness of the transition between high order and low order represents the sensitivity that self-organizing systems have for adaptation on the edge of chaos. In this transition region, changes in balance have significant effect. Two other important points about the relationship are: 1) in the absence of other changes to the system, the second law of thermodynamics assures that the disorder pressure will with time lower the ordinate value, and 2) humans have the capability to temporarily increase the order.

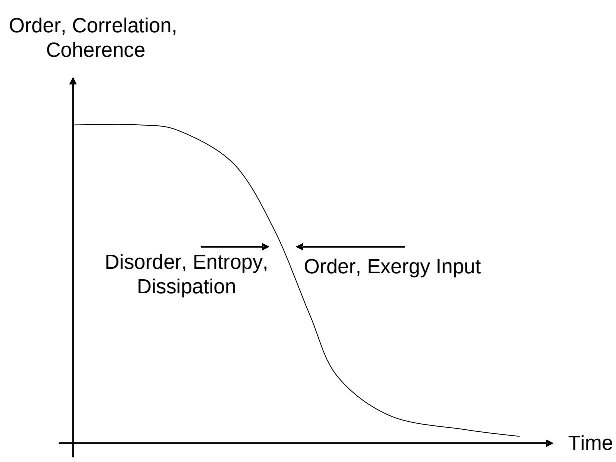

Figure 1. Quasi-Equilibrium Self-Organizing System

The entire time-dependent system stable state and the rate of transition from order to disorder can be re-set by changes in sources of order and/or disorder. The goals are to create enough order pressures to increase the ordinate position (e.g., representing standard of living), while also providing a long-term control over the transition rate. Balancing these two goals is the classic tradeoff between short-term and long-term effects.

A Strategy for Balancing Goals and Opposing Pressures

The goals and threats discussed in the preceding sections are not directly amenable to conventional risk analysis treatment. Risk analysis [Ref. 14] is best applied where threats can be treated probabilistically; and where benefits, costs, and consequences can be measured in common terms, such as dollars. Measurement of entities such as standard of living, fear, and values requires a quite different approach. Trading off long-term effects against short-term decisions is difficult; performing such tradeoffs under dynamic and evolving conditions affected by technologies that are both developing and subject to depletion is even more difficult. The overall problem is a mix of technical, social, and emotional effects, all governed by a human capability to create order that can at least temporarily counteract the disordering pressures, as governed by the second law of thermodynamics. The required strategy is to optimally balance a series of counter-effects. These counter-effects are exemplified by the dichotomies we have discussed. Overcoming the problems inherent in such counter-effects is called transcendence of dichotomies. The necessary strategy is a dialectic synthesis of the surety-pertinent dichotomies, where the short-term and long-term effects are both weighed. "Rules-of-thumb" strategies for investing in the stock market are good examples.

An Illustrative Three-Dimensional Representation

The dichotomies considered so far provide multiple dimensions that can be part of a multi-criteria multi-objective decision process (multi-criteria optimization). However, the basic considerations we have outlined and the basic effects involved can be illustrated by a three-dimensional effects structure, such as that shown in Fig. 2. Almost the entire context of the previous discussion can be couched in terms of order and disorder. The three axes illustrated are basic to most considerations of order and disorder. The time axis is illustrative of the expected eventual increase in entropy, which is a disordering effect. The resources axis represents effects such as sources of energy, technology, inherent constraints, management and parenting functions, selflessness, and passion, all of which are ordering effects. The consumption axis represents disordering effects, such as exergy consumption, privacy provisions, controlling behavior, selfishness, threats, and irrational fear.

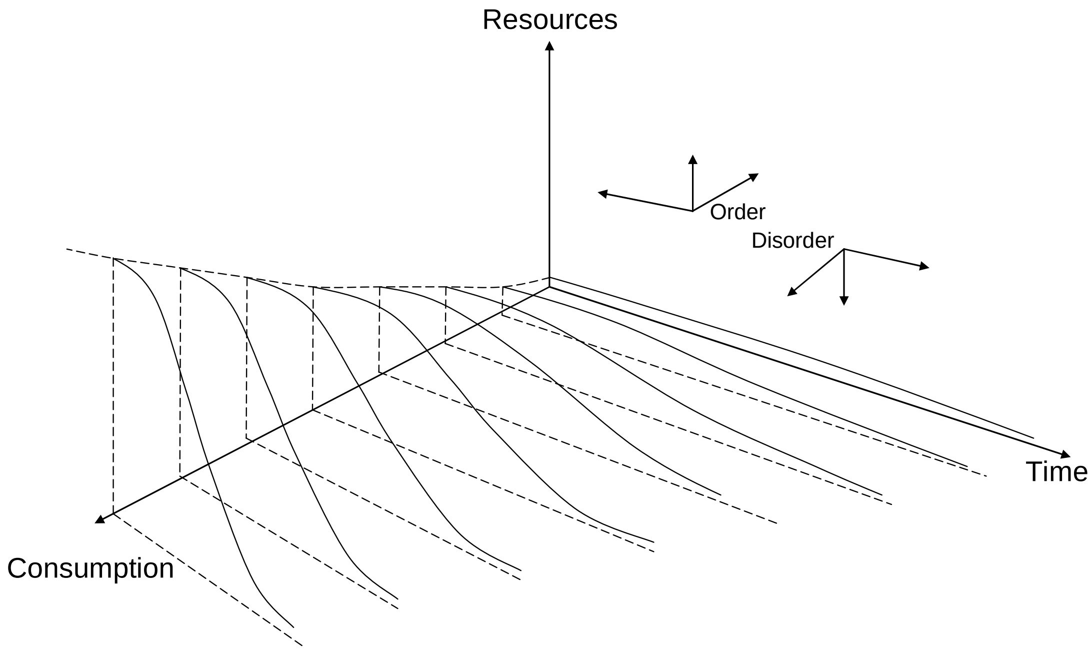

Figure 2. Conceptual Three-Dimensional Structure for Balancing Dichotomies

The family of curves shown illustrates the interaction of effects. Conceptually, the family of curves is continuous, although a discrete representation of the continuity is used in Fig. 2 for illustration. In order to explore the concept, assume a particular level of resources (resources that are inherently available or the controlled amount that are made available). This resource position at the origin of the time axis identifies a particular member of the continuous family of curves. The resources made available can be a percentage of the total resources. This allows control at a particular level of consumption. The curve depicts the disordering effects of the consumption with time, assuming that there are no changes introduced in resources or consumption. Any such changes can cause movement to a different point in the three-dimensional structure. There are several important points related to the structure of Fig. 2. One is that higher resource allocation generally enables higher consumption. The higher the consumption, the more rapidly the transition as entropy increases (order decreases). But this need not be insurmountable. Resource allocation can be controlled and consumption can be controlled. This is a major part of the strategic balance sought. Another point is that short-term benefits come at the expense of long-term effects. This is clearly illustrated by the balance between short-term order and long-term disorder. It is also straightforward to recognize from the three-dimensional structure that resources (order) come in a variety of forms, and consumption (disorder) sources are also varied.

Analytic Treatment of Illustrative Structure

The relationships in Fig. 2 can be treated quantitatively by generating a three-dimensional mathematical model. An example is given in Eq. 1.

$$z = z_i \frac{e^{-\frac{e^{4x}}{35}(y-100e^{-4x})}}{1+e^{-\frac{e^{4x}}{35}(y-100e^{-4x})}} \tag{1}$$

Here, the *x* axis represents consumption order, the *y* axis represents time, and the *z* axis represents resource order. z_i is the resource utilization input. Eq. 1 was chosen to approximately normalize the *x* and *z* axes between zero and one, and to allow the range of values on the *y* axis to vary out to approximately 200 years. The parameters were also chosen to follow the general curve shapes shown in Figs. 1 and 2.

This relationship can be applied directly to individual dichotomies. For example, consider an exergy-entropy relationship based on fossil fuel resources, and consumption based on a fossil-fuel-based infrastructure. Assume that the fossil fuel resource base has a value of 0.5 on a scale between zero and one, and the consumption rate is fully utilizing the resource base (meaning that it fully uses the resource value of 0.5). Putting $x = 0.5$ in Eq. 1, the result is:

$$z = 0.5 \frac{e^{-0.211y+2.86}}{1+e^{-0.211y+2.86}} \tag{2}$$

Initially, the value for z (its order) is about 0.5. After 13.5 years, the order has reduced to approximately 0.25. After 27 years, the order is about 0.03. This corresponds to a warning that present fossil fuel reserves and present consumption are not compatible with sustainability, assuming no changes in the present conditions.

In a multi-parameter problem, *x* and *z* are aggregates of the appropriate constituents. For this, we propose a weighted sum aggregation, where the weights correspond to the general importance of the various parameters and the corresponding values are determined by relative contribution for a particular case (Eqs. 3, 4). This expression allows *n* weights and parameters for *z* and *m* weights and parameters for *x*. The sum of the weights for *z* is one, as is the sum of the weights for *x*. The parameter values are bounded between zero and one (inclusive).

$$z = \sum_{i=1}^{n} w_{zi}\, p_{zi} \tag{3}$$

$$x = \sum_{i=1}^{m} w_{xi}\, p_{xi} \tag{4}$$

Uncertainty can be included in the analysis, for example by treating the parameter values as intervals. These concepts can be clarified through another example, which is intended to model design of a conceptual system for energy infrastructure.

For this example, the resource inputs are “energy availability,” “technology status,” “constraining controls,” “management guidance,” “personnel selflessness,” and “public passion,” weighted in importance to the project as $w_{z1} = 0.3$, $w_{z2} = 0.2$, $w_{z3} = 0.1$, $w_{z4} = 0.1$, $w_{z5} = 0.2$, and $w_{z6} = 0.1$, (necessarily summing to one). The resource parameter values entered are interval values, $p_{z1} = [0.6, 0.8]$, $p_{z2} = [0.3, 0.4]$, $p_{z3} = [0.2, 0.3]$, $p_{z4} = [0.8, 0.9]$, $p_{z5} = [0.8, 0.9]$, and $p_{z6} = [0.6, 0.8]$, respectively, where the first entry in each pair represents the lower bound on the order metric for the input, and the second member of the pair represents the upper bound. The consumption inputs are “exergy consumption,” “consumer selfishness,” “threats,” and “irrational fear.” The weights for these are $w_{x1} = 0.3$, $w_{x2} = 0.2$, $w_{x3} = 0.2$, and $w_{x4} = 0.3$. The input values for the disordering pressure parameters can only be entered initially as goals. Then the goals will have to be compared with the available resources. The goal inputs for the example are $p_{x1} = [0.7, 0.9]$, $p_{x2} = [0.7, 0.9]$, $p_{x3} = [0.5, 0.6]$, and $p_{x4} = [0.3, 0.4]$, respectively.

The next step is to calculate the resource order, z, from Eq. 3, which for the example is [0.56, 0.7]. The consumption goal solution, x, from Eq. 4, is [0.54, 0.69]. Because of the uncertainty, and because consumption cannot exceed resources, the lower bound of the resource order must not be less than the upper bound of the consumption order. This means that no more than about 80% of the potential resource order (0.56/0.69) can be consumed. As a result, z_i (to be used in Eq. 1) is [0.45, 0.56]. The resulting equation is:

$$z = [0.45, 0.56]\frac{e^{-[0.173,0.268]y+2.86}}{1+e^{-[0.173,0.268]y+2.86}} \tag{5}$$

In this interval equation, the lower bound of z_i, the upper bound of x in the numerator, and the upper bound of x in the denominator are required to give the lower bound for z (conventional interval analysis). The upper bound of z_i, the lower bound of x in the numerator, and the lower bound of x in the denominator are required to give the upper bound of z. The result for $y = 20$ years is [0.076, 0.23]. The meaning of this result is that entropy might be expected to degrade the order of the infrastructure system being designed in a relatively short time. Because of the short time frame for loss of order, this is an argument for resetting the goals for the infrastructure design. For example, exergy consumption goal might be reduced, or technology improvements might be sought.

A metric that converts order/disorder to amount of entropy completes the analysis. The basic equations used to relate order to entropy are:

$$H_z = 1 - z \tag{6}$$

$$H_x = 1 - x \tag{7}$$

where the additive inverse of the parameters for either x or z represent entropy. Because of the restriction to an additive inverse, and because x and z are restricted to [0, 1], this result is a normalized entropy bounded by zero and one. Returning to the last example, the entropy for the infrastructure design after 20 years of operation is expected to be a relatively high [0.77, 0.92] if no changes or improvements are made.

Conclusions

The results derived in this paper demonstrate how a structured strategy can be formulated to deal with a variety of dichotomies, where a balance must be chosen among multiple trade-off factors. Also, the importance of time effects and short-term vs. long-term considerations is clearly indicated by the three-dimensional model that was developed.

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ENTROPY Analysis Tool User's Manual

Version 1.00

Robert J. Roginski March 15, 2005

General Information

This document describes the operation of a software tool specifically designed for the analysis of latent effects entropy relationships of interpersonal communications. This MS Windows application utilizes the entropy methodology defined in Reference 1. However, the entropy analysis tool acknowledges only a very specific combination of entropy modules and inputs.

The entropy executable program (entropy.exe) will allow the User to create a new entropy study using a set of default input values, modify these input values, and save the modified study under the same or a different name. It also has numerous plotting options that display the various entropy results using an easy to understand bar-graph format. Plotting options include but are not limited to: (1) primary and secondary importance and sensitivity, and (2) entropy module outputs.

<u>To execute the Entropy Analysis Tool</u>

1. Copy the executable file entropy.exe to the desired folder (directory).

2. Simply type "entropy" and press the "Enter" Key. First-time Users should now click File > New. This will load a dialog that will allow the User to create an entropy study in an .ENT text file. This dialog will prompt the User for a study name that will be used in the actual name of the entropy text file.

3. The new study can now be edited, saved, plotted or viewed using the various menu options that are now available to the User. These options are subsequently described in this document.

Contents

Table of Figures

Program Menus

The current version of the Entropy Analysis Tool utilizes displays five MS Windows menus for User selection. However, three of these menus (View, Plot and Edit) that require data are disabled (grayed-out) until an entropy file has been loaded using either of the File > New or File > Open selections. A brief description and graphical image of each menu will follow. In certain cases, the results of the menu selection will also be shown. Some of the menus contain submenus that will also be explained and/or shown as required.

File Menu

The File Menu shown below will be familiar to users of other MS Windows applications. When the program is first entered, the Save and Save As selections are unavailable. These will be enabled for the User after a successful File > New or File > Open has been executed.

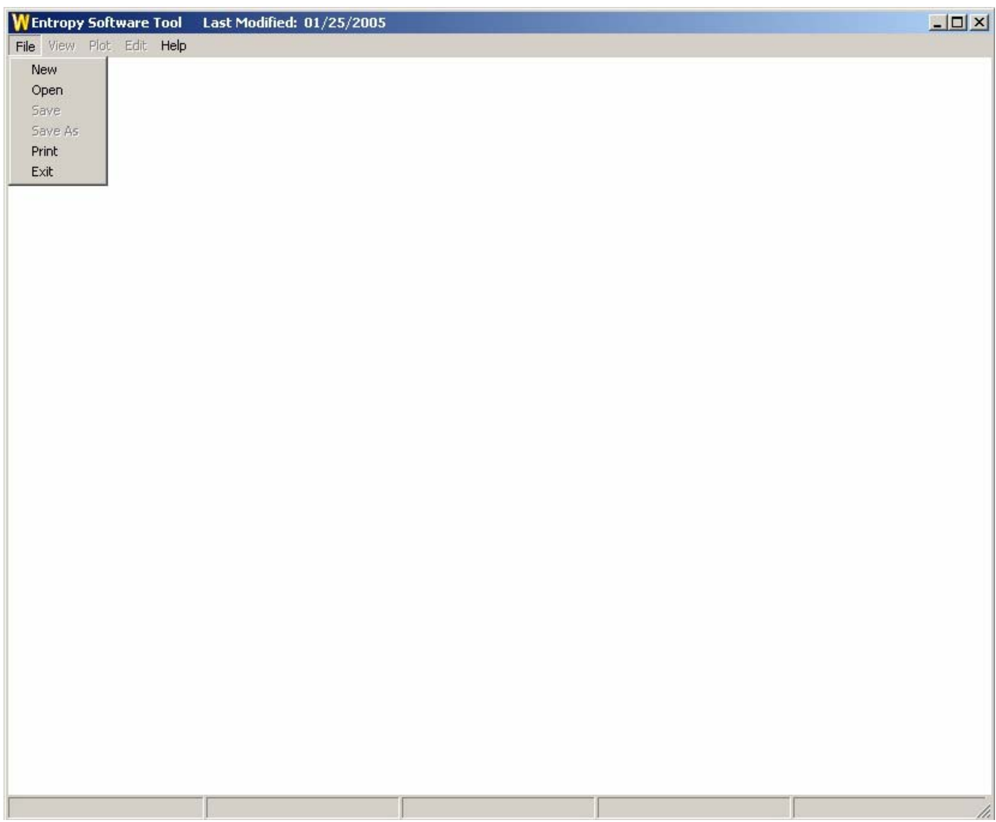


Figure 1: File Menu

File > New

The File > New option will create a new entropy study file that can be subsequently viewed, plotted, edited, saved or opened using the appropriate menu selection. A 1-12 character study name will be requested from the User. This name will be embedded in the actual MS Windows filename – a feature that allows for multiple studies in the same folder (directory) of the User's hard drive. The dialog used to request the name of the study is shown below.

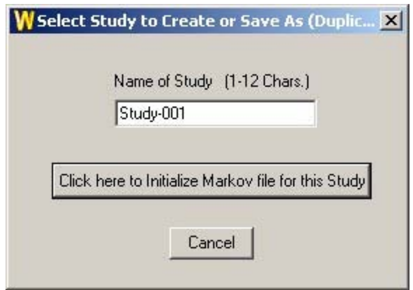


Figure 2: Select Study Dialog

The name of the study entered by the User must be different from the study name used in any existing entropy file. This will eliminate the accidental loss of effort by disallowing any overwrite of a study file bearing the same name.

It is important to understand that the entropy file created is specific to the Entropy Analysis Tool, which is designed to manipulate a fixed entropy data structure[24]. For this reason, the User is strongly advised to avoid revising the entropy (.ENT) file using any method other than the Edit Menu options provided in the Entropy Analysis Tool. To do so may result in unpredictable and/or undesirable results.

When the entropy study file is created, all primary inputs are assigned the default values defined by J. Arlin Cooper. However, these input values could be revised using the Edit > Module Input Values selection, and the file can be saved once again using the same or a different study name.

File > Open

The File > Open option will allow the User to load a previously saved entropy study file into working memory. A common MS Windows file dialog appears and displays all entropy study files in the current folder. The names of these files will use the convention *studyname*-D62.ENT, where *studyname* is the 1-12 character name of the study specified when the file was initialized using the File > New option.

The User can single-click the desired file and click the Open button, or simply double-click the desired file. Either method will load the file into working memory.

[24] An entropy data structure consists of one or more modules, inputs and early alert equations defined in accordance with the documents referenced near the end of this User's Guide. With the exception of the first defined module that can have only primary inputs, each module can have a combination of primary and secondary inputs. The secondary inputs are in fact outputs of previously defined modules, and are analogous to branches connecting the modules in tree-like fashion.

Any error(s) encountered in the entropy study file will be described in the QA Output File. This file will have the same base name but its extension will be .QAF. One or more errors will cause the program to immediately display the QA Output File in read-only mode using an internal text editor. The error diagnostic is typically found following the offending line in the listing found in Part 1 of the file. Errors reported in this fashion are most likely caused by manually editing the entropy study file outside of program control. As previously stated, this practice is strongly discouraged.

File > Save

The File > Save option will allow the User to update the current entropy study. All changes made to primary input values will be written to file *studyname*-D62.ENT, which is the name of the most-recently opened file.

Because the original remains unchanged until a File > Save is executed, the User is able to make temporary modifications and view/plot the results without affecting the "Opened" file in any manner. Use of temporary files makes this possible. It also makes it possible to discard all changes made (since the last File > Open or File > Save) by simply not executing File > Save.

File > Save As

The File > Save As option performs the same function as File > Save except that the User is given the opportunity to specify a different 1-12 character study name. This is accomplished by once again displaying the Select Study Dialog shown on Page 124. This option makes it convenient to initialize a family of similar or related study files based on a single previously defined study.

File > Print

The File > Print option will copy the plot that is currently displayed on the CRT to the default (User-defined) Windows printer. Additional print options may be implemented in a future version of the Entropy Analysis Tool.

File > Exit

The File > Exit option terminates execution of the Entropy Analysis Tool. If the current study has been revised since it was loaded into working memory using either of the File > New or File > Open options, the User will be given a final opportunity to save these changes before the program terminates.

View Menu

The View Menu allows the User to examine the contents of the various files read and written by the Entropy Analysis Tool. A text editor (internal to the entropy program) is used to display the selected file type in read-only mode.

In both View Menu options, the User will be able to select, copy (to the Windows Clipboard) or search for a specific text string. However, revising the text in any manner is not permitted. The two grayed-out options are not currently available but may be implemented in a future version of the program. The View Menu is shown as follows.

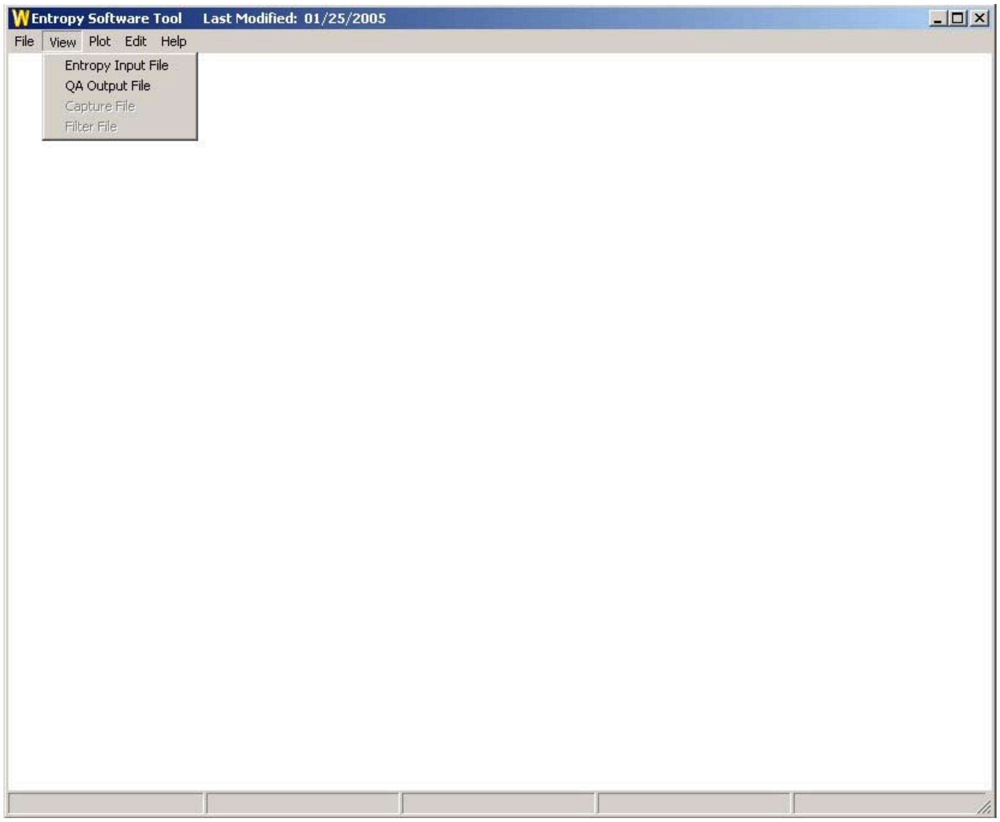
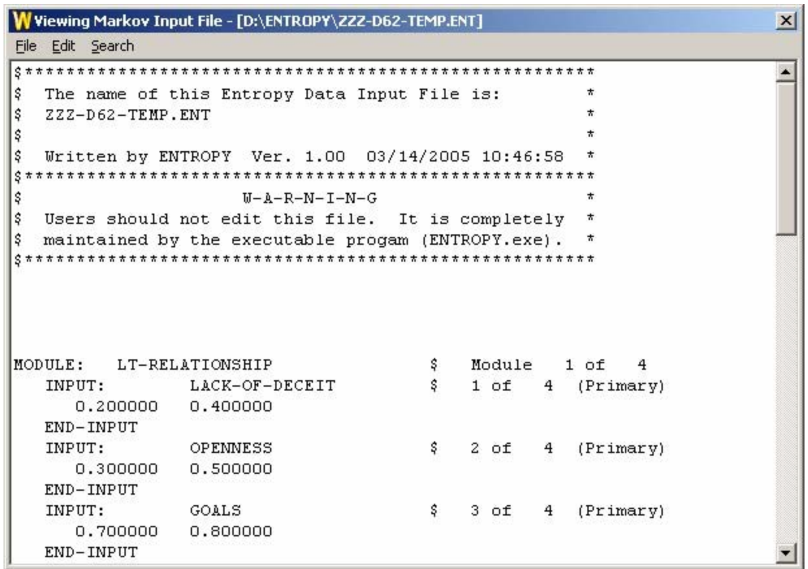


Figure 3: View Menu

View > Entropy Input File

This option will display a working copy of the current entropy study file in read-only mode. An example of this option is shown below.



Viewing Markov Input File - [D:\ENTROPY\ZZZ-D62-TEMP.ENT]

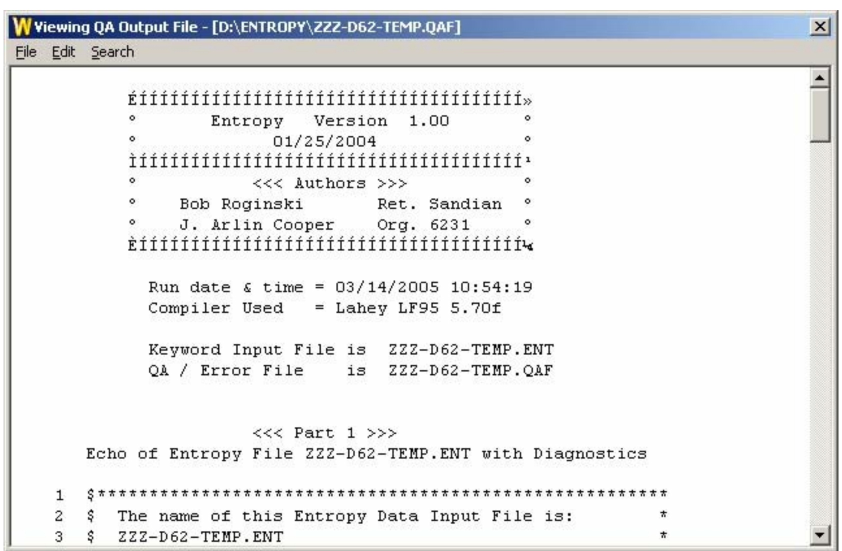
File Edit Search

```
$**********************************************************
$  The name of this Entropy Data Input File is:          *
$  ZZZ-D62-TEMP.ENT                                      *
$                                                        *
$  Written by ENTROPY  Ver. 1.00  03/14/2005 10:46:58    *
$**********************************************************
$                      W-A-R-N-I-N-G                     *
$  Users should not edit this file.  It is completely    *
$  maintained by the executable progam (ENTROPY.exe).    *
$**********************************************************



MODULE:    LT-RELATIONSHIP                $    Module   1 of    4
   INPUT:         LACK-OF-DECEIT          $    1 of    4  (Primary)
      0.200000    0.400000
   END-INPUT
   INPUT:         OPENNESS                $    2 of    4  (Primary)
      0.300000    0.500000
   END-INPUT
   INPUT:         GOALS                   $    3 of    4  (Primary)
      0.700000    0.800000
   END-INPUT
```

Figure 4: View > Entropy Input File

View > QA Output File

This option will display the QA Output File generated from the working copy of the current entropy study file in read-only mode. All entropy results calculated by the program can be found in Part II of this file. Result values are shown using more significant digits than indicated on the corresponding plot. An example of this option is shown below.



Viewing QA Output File - [D:\ENTROPY\ZZZ-D62-TEMP.QAF]

File Edit Search

```
           ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»
           º       Entropy   Version  1.00       º
           º             01/25/2004              º
           ÌÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¹
           º          <<< Authors >>>            º
           º    Bob Roginski       Ret. Sandian  º
           º    J. Arlin Cooper    Org. 6231     º
           ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼

             Run date & time = 03/14/2005 10:54:19
             Compiler Used   = Lahey LF95 5.70f

             Keyword Input File is  ZZZ-D62-TEMP.ENT
             QA / Error File    is  ZZZ-D62-TEMP.QAF


                        <<< Part 1 >>>
       Echo of Entropy File ZZZ-D62-TEMP.ENT with Diagnostics

    1  $**********************************************************
    2  $  The name of this Entropy Data Input File is:          *
    3  $  ZZZ-D62-TEMP.ENT                                      *
```

Figure 5: View > QA Output File

Plot Menu

Once the User has loaded an entropy study file (using either the File > New or the File > Open option) the Plot Menu will be enabled. This menu option will allow the User to plot (in bar graph format) any of the five categories of entropy results.

As indicated in the figure that follows, two of the five categories have sub categories that allow the User to select a specific module, input or early alert as a plot object. The number of different plots is too large to provide an example of each one in this document. However, examples of the Plot > Primary Importance and the Plot > Module Outputs options are respectively shown in Figures 7 and 8.

The User should be aware that no plot is initially displayed when an entropy study file is loaded. But once a plot type has been selected via the Plot Menu, it will continue to be displayed until such time as a different plot type is chosen.

If the User elects to modify any of the primary input values (using the Edit > Primary Inputs menu option), the entropy results are immediately recalculated, and the most recently selected plot type is redisplayed using the new values. This feature gives the User a nearly instantaneous update of the graphical results without destroying any of the original input values; these remain unchanged (in the entropy study file) until the File > Save option or the File > Save As option is executed.

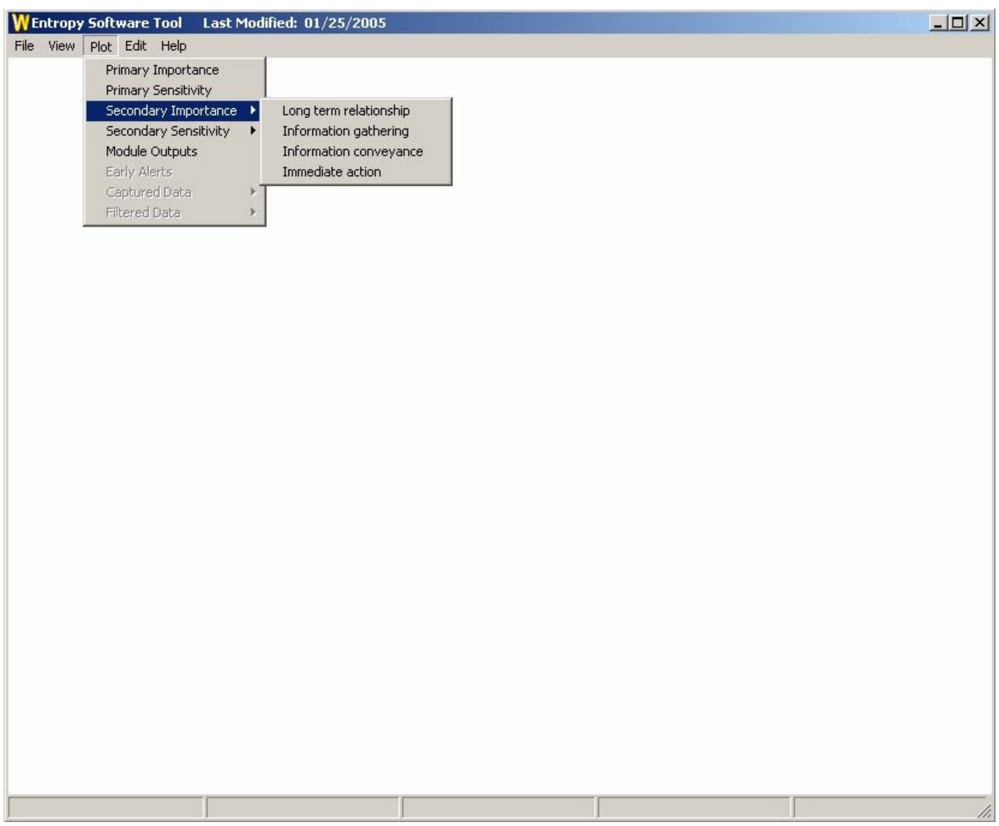


Figure 6: Plot Menu

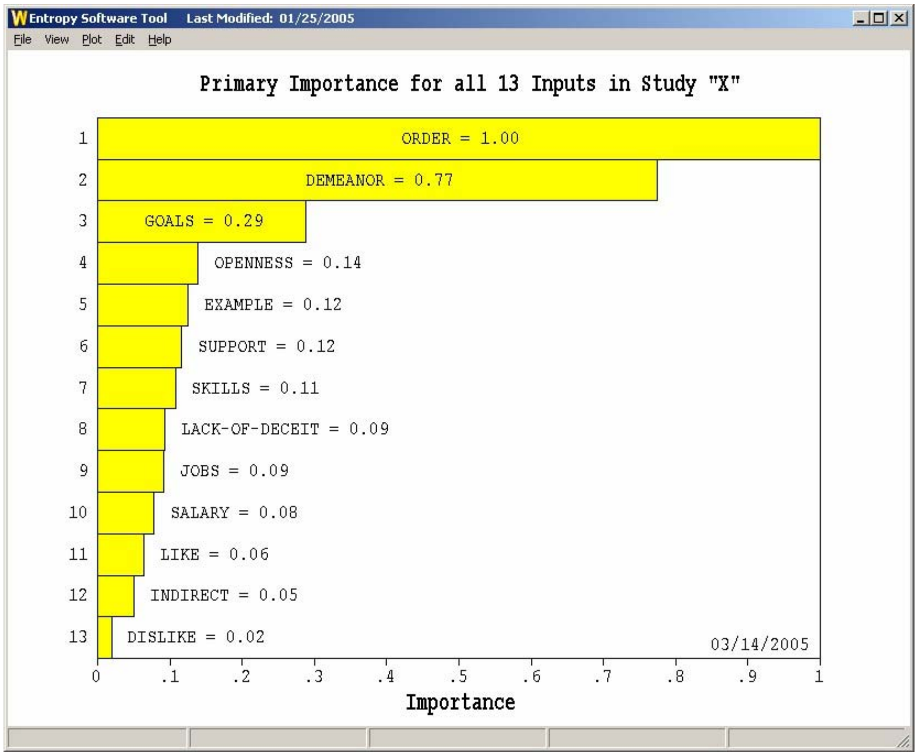


Figure 7: Plot > Primary Importance

Plot > Primary Importance

This option will plot a bar graph displaying the importance relative to the final output, of each defined primary input. The most important input or inputs will have a relative importance value of 1.0. As shown in the example in Figure 7 on Page 114, the bars representing these values are displayed in descending order of relative importance.

Plot > Primary Sensitivity

This option will plot a bar graph displaying the sensitivity relative to the final output, of each defined primary input. The most sensitive input or inputs will have a relative sensitivity value of 1.0. An example of this plot type is not shown. However, the display format is identical to that of the Plot > Primary Importance option. The bars representing the sensitivity values are displayed in descending order of relative sensitivity.

Plot > Secondary Importance

This option will plot a bar graph displaying the importance relative to the output of the User selected module, for each primary and secondary input defined for that module. The most important input or inputs will have a relative importance value of 1.0. An example of this plot type is not shown. However, the display format is identical to that of the Plot > Primary Importance option. The bars representing these values are displayed in descending order of relative importance.

Plot > Secondary Sensitivity

This option will plot a bar graph displaying the sensitivity relative to the output of the User selected module, for each primary and secondary input defined for that module. The most sensitive input or inputs will have a relative sensitivity value of 1.0. An example of this plot type is not shown. However, the display format is identical to that of the Plot > Primary Importance option. The bars representing these values are displayed in descending order of relative sensitivity.

Plot > Module Outputs

This option will plot a bar graph displaying the possibilistic number calculated for all modules. The range of this number is represented by the red portion of the bar representing a given module. The values of this range are also shown but are rounded to two decimal places.

The bars in this plot are also displayed in descending order, but in this case, it is the average of the range calculated by the program that is used for the sort. In other words, the sort key value is the center of the red portion of the bar along the abscissa.

An example plot is shown in Figure 8 on Page 115.

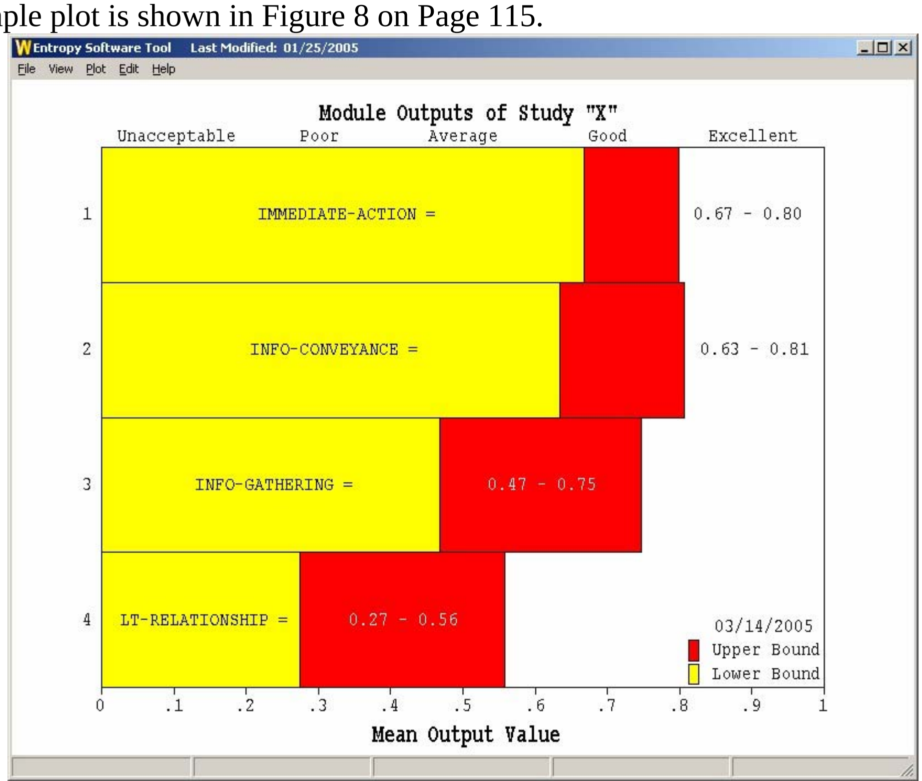


Figure 8: Plot > Module Outputs

Plot > Early Alerts

This future option will plot a bar graph displaying values calculated for all predefined early alert equations[25].

Plot > Captured Data

This future option will give the User the opportunity to view data output trends graphically. There are three categories of data that can be plotted: Module Inputs, Module Outputs and Early Alerts.

Plot > Filtered Data

This future option will give the User the opportunity to view the average of corresponding result values over the range of unique dates found in the date/time headers in the Capture File. If two or more dates are identical, then results for that date are averaged. Interim days in the chronological sequence are interpolated.

As in the Plot > Captured Data option, the three categories of data that can be plotted are Module Inputs, Module Outputs and Early Alerts.

Edit Menu

The Edit Menu provides a means to revise the primary input values of any module. A future version will allow the User to enable or disable entropy data capturing by revising the name of the User's Capture File. The Edit Menu is shown in Figure 9 on Page 117.

Edit > Module Input Values

This option allows the User to modify the input values of any primary input in any of the defined modules. When the User clicks this selection, the Edit Inputs Dialog appears on the CRT. The primary inputs of the first module (Long Term Relationship) are initially displayed, but the inputs of any module can be displayed by selecting its corresponding radio button.

Once the desired module is selected, its input values (shown in the grid control) can be revised. The dialog will perform error checking to ensure the validity of all modified values. The User can continue editing the input values of some other module (by selecting its radio button) or terminate the editing session by clicking the button labeled "Exit (End Revisions)". The Edit > Module Input Values dialog is shown in Figure 10 on Page 117.

[25] An early alert equation is combination of minimums and maximums of two or more module inputs or outputs. Its purpose is to determine a logical range of concern.

The User should be aware that any changes made are not saved in the .ENT file until the File > Save or the File > Save As option is executed. This allows the User to view the results of a revision with the option to discard that revision. This is useful in the case where the results of the recent modification(s) are undesirable.

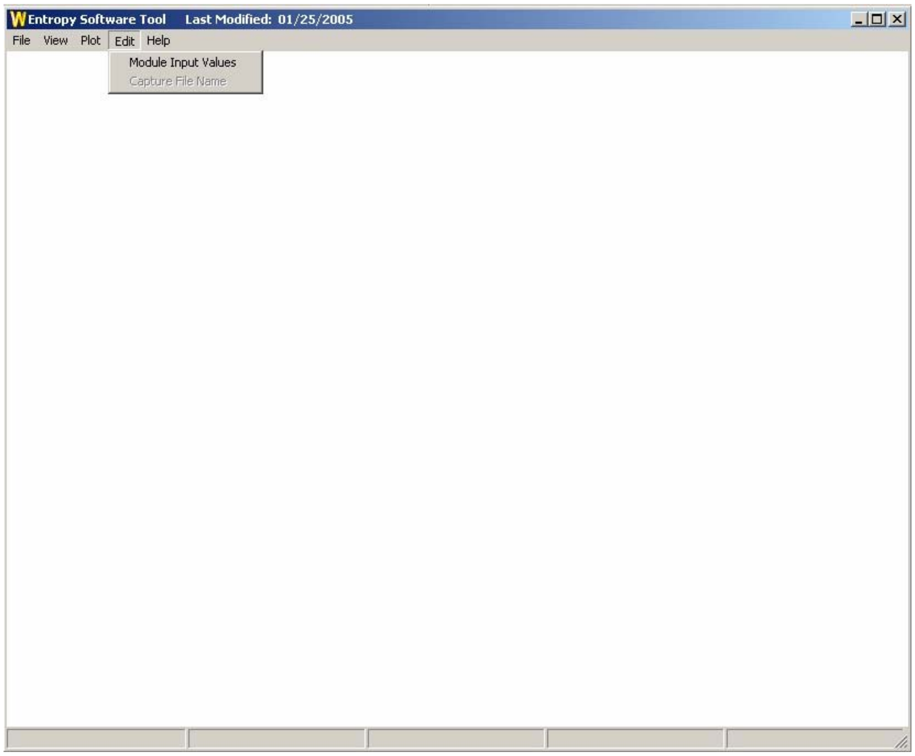


Figure 9: Edit Menu

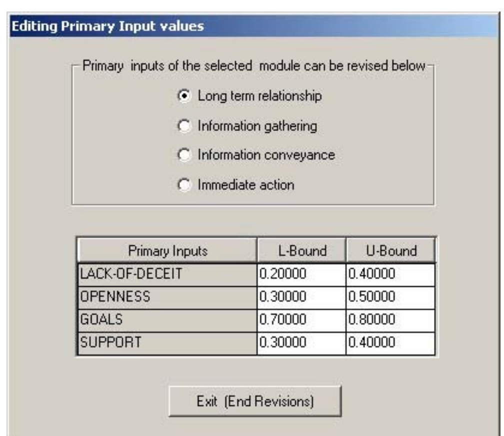


Figure 10: Edit > Module Input Values

Help Menu

The Help Menu contains the single option Help > About. Additional help options may be added in future versions of the program.

Help > About

This option displays information regarding the program. An example is shown below.

Figure 11: Help > About

References

1. Cooper, J. A., “The Markov Latent Effects Approach for Safety Assessment and Decision-Making,” Sandia National Laboratories Report SAND2001-2229, September 2001.

2. Cooper, J. A., and Roginski, R. J., “Hybrid Processing of Measurable and Subjective Data.” Sandia National Laboratories Report SAND2001-3317, October 2001.

Management Collective Teams

Markov Analysis User's Manual
Version 1.00

Robert J. Roginski March 7, 2005

General Information

This document describes the operation of a suite of software tools specifically designed for analyzing management details. These MS Windows applications utilize the Markov methodology defined in Reference 1. However, each program acknowledges only a very specific combination of Markov modules and inputs. For those interested, the generic format of all Markov files is described in Appendix B of Reference 2.

Each program in the suite will allow the User to create a new study using a set of default input values, modify these input values, and save the modified study under the same or a different name. They also have numerous plotting options that display the various Markov results using an easy to understand bar-graph format. Plotting options include but are not limited to: (1) primary and secondary importance and sensitivity, and (2) Markov module outputs. The User will notice that the "Early Alert" feature is currently unavailable, but may be implemented in a future version of each program.

Specific Program Information

The following table defines the programs that comprise this code suite. The last entry (Overall Assessment) will create and manipulate a study that includes all components.

Component Name	**Executable File Name**	**Input File Naming Convention**	**No. of Modules**	**No. of Inputs**
Management Assessment	MGM.exe	*Study-name*-MGM.MKV	4	16
Organization Assessment	ORG.exe	*Study-name*-ORG.MKV	4	16
Team Performance	TPF.exe	*Study-name*-TPF.MKV	4	12
Environment, Safety and Health	ESH.exe	*Study-name*-ESH.MKV	4	17
Personnel	6200.exe	*Study-name*-D62.MKV	5	24
Overall Assessment	overall.exe	*Study-name*-OVR.MKV	21	85

The input file naming convention was designed to allow the User to create multiple Markov studies or a single study that uses more than one program in the suite – all in the same folder. This is possible because each program will acknowledge files that adhere to its convention and ignore all others. It is also necessary because each program uses a different Markov structure.

General Program Execution

The remainder of this document uses the Management Assessment component as an example for describing operations, inputs, outputs and plots. However, the process is also valid for the other components in the suite. The User should simply bear in mind that all example screens and figures have been generated using the executable program MGM.exe. For components other than Management Assessment, the table on Page 120 indicates the three letters that should be substituted wherever "MGM" is subsequently referenced.

<u>To execute the Management Assessment Markov Analysis Tool</u>

1. Copy the executable file (MGM.exe) to the desired folder (directory).

2. If using a MS-DOS window, simply type "MGM" and press the "Enter" Key. Alternatively, the program can also be launched from MS Explorer by double-clicking on file MGM.exe.

3. First-time Users should now click File > New. This will load a dialog that will allow the User to create a Markov study in an .MKV text file. This dialog will prompt the User for a study name that will be used in the actual name of the Markov text file.

4. The new study can now be edited, saved, plotted or viewed using the various menu options that are now available to the User. These options are subsequently described in this document.

Contents

Table of Figures

Program Menus

The current version of the Mgmt. Analysis Tool utilizes displays five MS Windows menus for User selection. However, three of these menus (View, Plot and Edit) that require data are disabled (grayed-out) until a Mgmt. Markov file has been loaded using either of the File > New or File > Open selections. A brief description and graphical image of each menu will follow. In certain cases, the results of the menu selection will also be shown. Some of the menus contain submenus that will also be explained and/or shown as required.

File Menu

The File Menu shown below will be familiar to users of other MS Windows applications. When the program is first entered, the Save and Save As selections are unavailable. These will be enabled for the User after a successful File > New or File > Open has been executed.

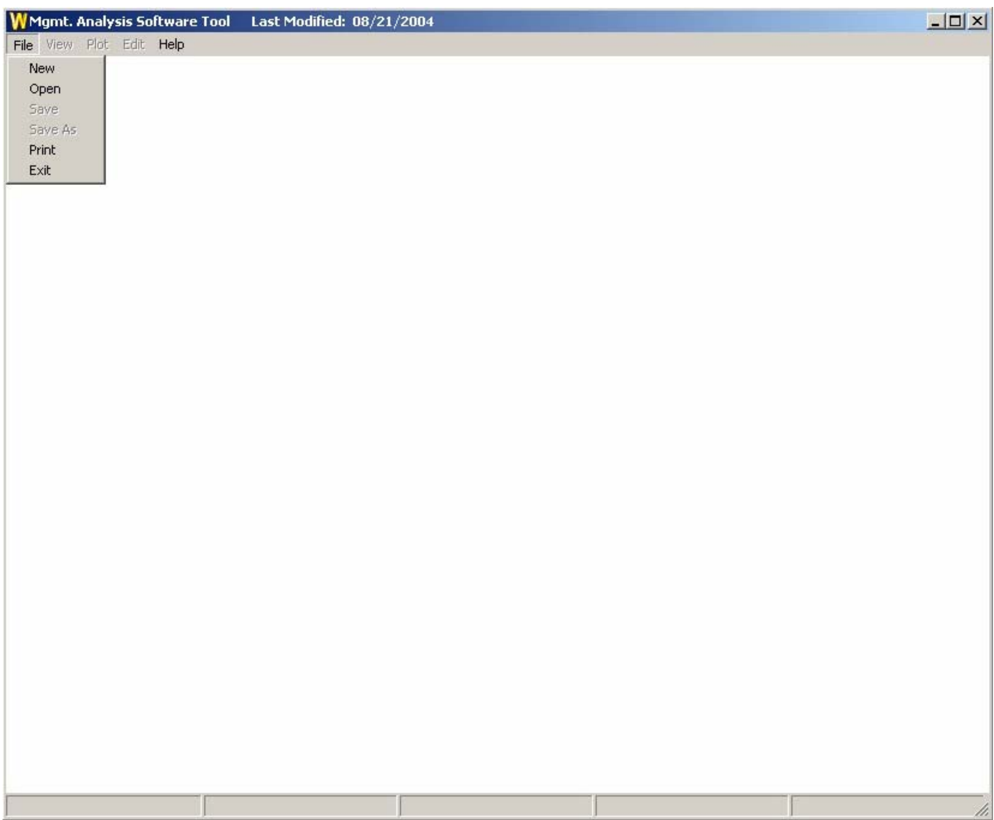


Figure 1: File Menu

File > New

The File > New option will create a new Mgmt. Markov study file that can be subsequently viewed, plotted, edited, saved or opened using the appropriate menu selection. A 1-12 character study name will be requested from the User. This name will be embedded in the actual MS Windows filename – a feature that allows for multiple studies in the same folder (directory) of the User's hard drive. The dialog used to request the name of the study is shown below.

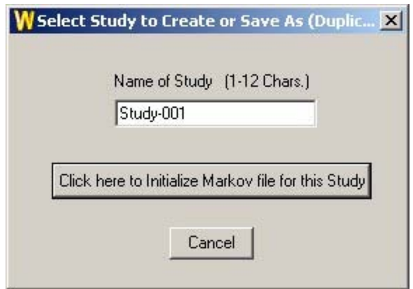


Figure 2: Select Study Dialog

The name of the study entered by the User must be different from the study name used in any existing Mgmt. Markov file. This will eliminate the accidental loss of effort by disallowing any overwrite of a study file bearing the same name.

It is important to understand that the Markov file created is specific to the Mgmt. Analysis Tool, which is designed to manipulate a fixed Markov data structure[26]. For this reason, the User is strongly advised to avoid revising the Markov (.MKV) file using any method other than the Edit Menu options provided in the Mgmt. Analysis Tool. To do so may result in unpredictable and/or undesirable results.

When the Markov study file is created, all primary inputs are assigned the default values defined by J. Arlin Cooper. However, these input values could be revised using the Edit > Module Input Values selection, and the file can be saved once again using the same or a different study name.

File > Open

The File > Open option will allow the User to load a previously saved Mgmt. Markov study file into working memory. A common MS Windows file dialog appears and displays all Mgmt. Markov study files in the current folder. The names of these files will use the convention *studyname*-MGM.MKV, where *studyname* is the 1-12 character name of the study specified when the file was initialized using the File > New option.

The User can single-click the desired file and click the Open button, or simply double-click the desired file. Either method will load the file into working memory.

[26] A Markov data structure consists of one or more modules, inputs and early alert equations defined in accordance with the documents referenced near the end of this User's Guide. With the exception of the first defined module that can have only primary inputs, each module can have a combination of primary and secondary inputs. The secondary inputs are in fact outputs of previously defined modules, and are analogous to branches connecting the modules in tree-like fashion.

Any error(s) encountered in the Mgmt. Markov study file will be described in the QA Output File. This file will have the same base name but its extension will be .QAF. One or more errors will cause the program to immediately display the QA Output File in read-only mode using an internal text editor. The error diagnostic is typically found following the offending line in the listing found in Part 1 of the file. Errors reported in this fashion are most likely caused by manually editing the Mgmt. Markov study file outside of program control. As previously stated, this practice is strongly discouraged.

File > Save

The File > Save option will allow the User to update the current Mgmt. Markov study. All changes made to primary input values will be written to file *studyname*-MGM.MKV, which is the name of the most-recently opened file.

Because the original remains unchanged until a File > Save is executed, the User is able to make temporary modifications and view/plot the results without affecting the "Opened" file in any manner. Use of temporary files makes this possible. It also makes it possible to discard all changes made (since the last File > Open or File > Save) by simply not executing File > Save.

File > Save As

The File > Save As option performs the same function as File > Save except that the User is given the opportunity to specify a different 1-12 character study name. This is accomplished by once again displaying the Select Study Dialog shown on Page 124. This option makes it convenient to initialize a family of similar or related study files based on a single previously defined study.

File > Print

The File > Print option will copy the plot that is currently displayed on the CRT to the default (User-defined) Windows printer. Additional print options may be implemented in a future version of the Mgmt. Analysis Tool.

File > Exit

The File > Exit option terminates execution of the Mgmt. Markov Analysis Tool. If the current study has been revised since it was loaded into working memory using either of the File > New or File > Open options, the User will be given a final opportunity to save these changes before the program terminates.

View Menu

The View Menu allows the User to examine the contents of the various files read and written by the Mgmt. Markov Analysis Tool. A text editor (internal to the Mgmt. program) is used to display the selected file type in read-only mode.

In all four View Menu options, the User will be able to select, copy (to the Windows Clipboard) or search for a specific text string. However, revising the text in any manner is not permitted. The View Menu is shown as follows.

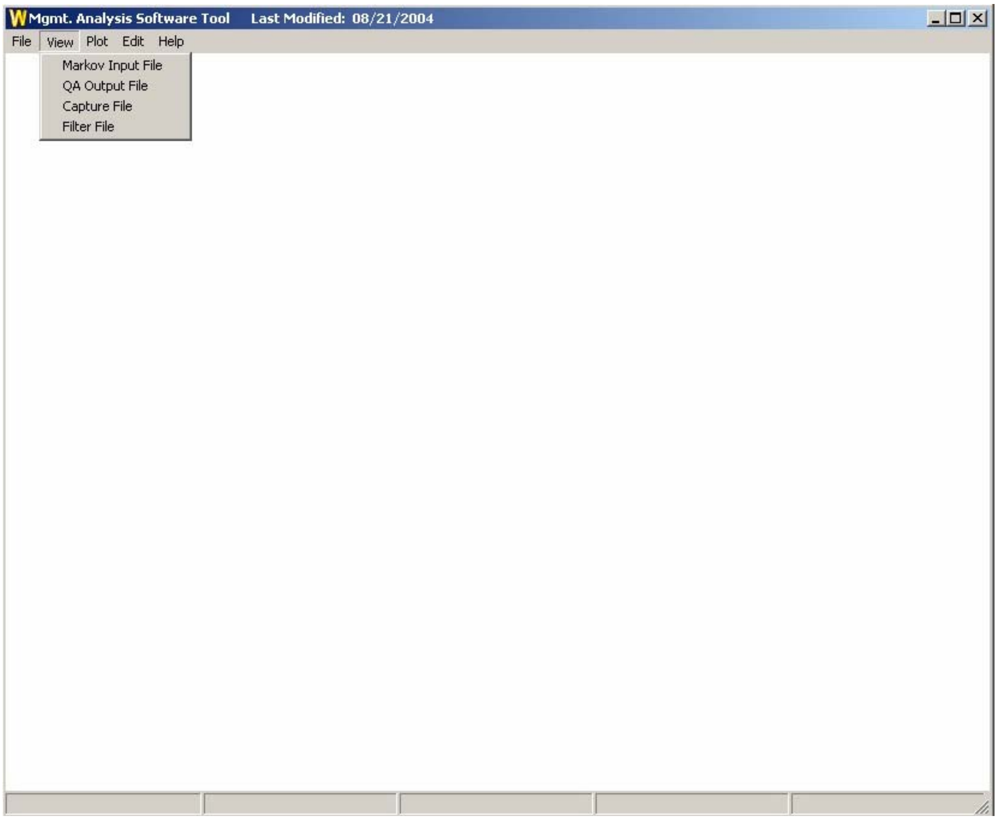
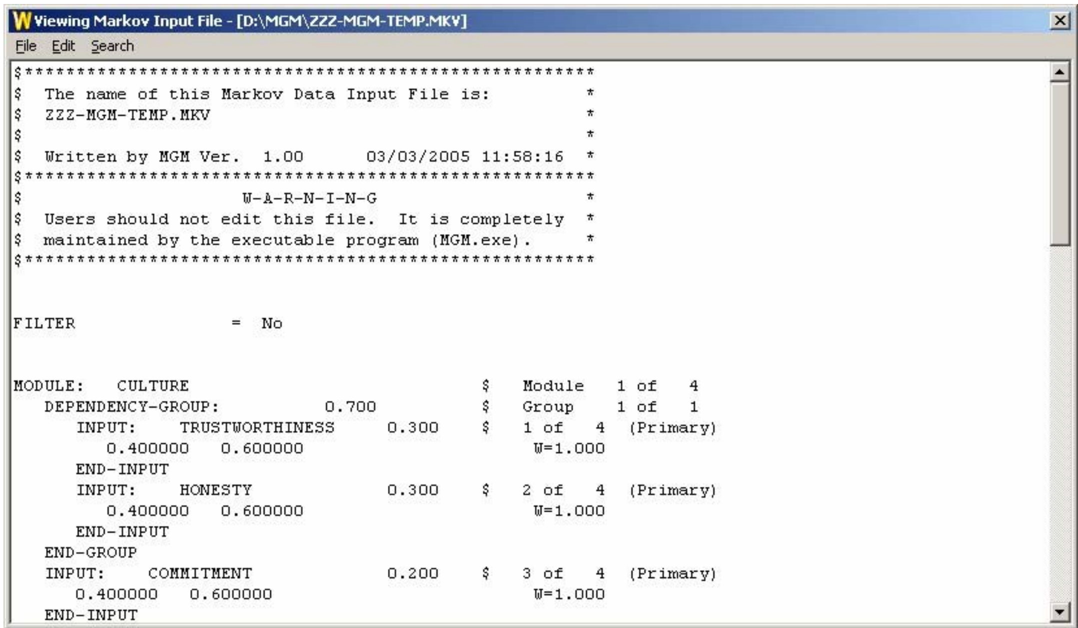


Figure 3: View Menu

View > Markov Input File

This option will display a working copy of the current Mgmt. Markov study file in read-only mode. An example of this option is shown below.

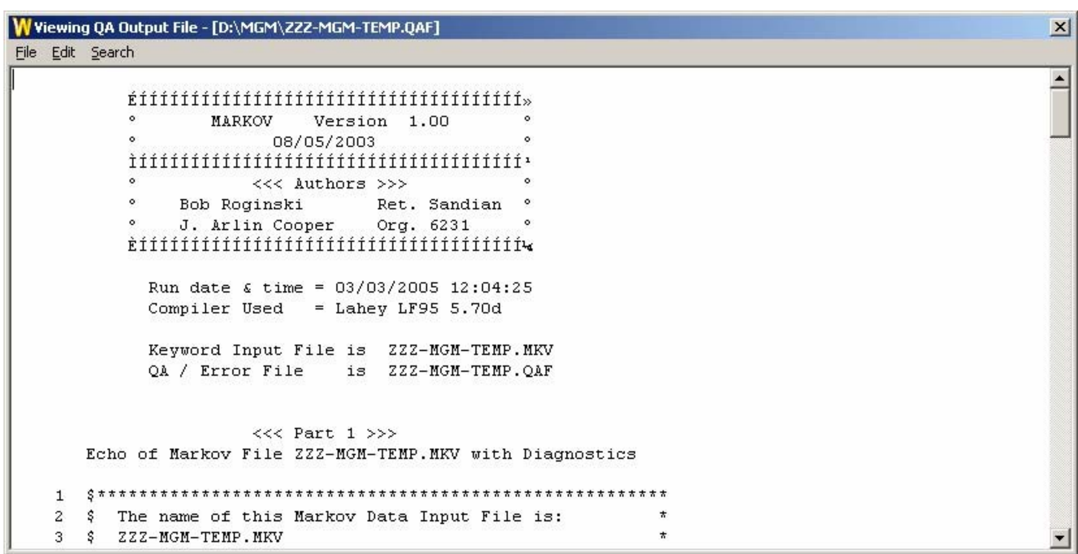


```
Viewing Markov Input File - [D:\MGM\ZZZ-MGM-TEMP.MKV]
File  Edit  Search
$*********************************************************
$  The name of this Markov Data Input File is:           *
$  ZZZ-MGM-TEMP.MKV                                      *
$                                                        *
$  Written by MGM Ver.  1.00      03/03/2005 11:58:16    *
$*********************************************************
$                     W-A-R-N-I-N-G                      *
$  Users should not edit this file.  It is completely    *
$  maintained by the executable program (MGM.exe).       *
$*********************************************************


FILTER              =  No


MODULE:   CULTURE                           $   Module   1 of   4
   DEPENDENCY-GROUP:          0.700         $   Group    1 of   1
      INPUT:    TRUSTWORTHINESS      0.300  $   1 of   4  (Primary)
         0.400000   0.600000                     W=1.000
      END-INPUT
      INPUT:    HONESTY              0.300  $   2 of   4  (Primary)
         0.400000   0.600000                     W=1.000
      END-INPUT
   END-GROUP
   INPUT:    COMMITMENT              0.200  $   3 of   4  (Primary)
      0.400000   0.600000                        W=1.000
   END-INPUT
```

Figure 4: View > Markov Input File

View > QA Output File

This option will display the QA Output File generated from the working copy of the current Mgmt. Markov study file in read-only mode. All Markov results calculated by the program can be found in Part II of this file. Result values are shown using more significant digits than indicated on the corresponding plot. An example of this option is shown below.



```
Viewing QA Output File - [D:\MGM\ZZZ-MGM-TEMP.QAF]
File  Edit  Search
           ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»
           º       MARKOV    Version  1.00       º
           º             08/05/2003              º
           ÌÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¹
           º           <<< Authors >>>           º
           º    Bob Roginski        Ret. Sandian º
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           ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼

             Run date & time = 03/03/2005 12:04:25
             Compiler Used   = Lahey LF95 5.70d

             Keyword Input File is  ZZZ-MGM-TEMP.MKV
             QA / Error File    is  ZZZ-MGM-TEMP.QAF


                       <<< Part 1 >>>
       Echo of Markov File ZZZ-MGM-TEMP.MKV with Diagnostics

     1  $*********************************************************
     2  $  The name of this Markov Data Input File is:           *
     3  $  ZZZ-MGM-TEMP.MKV                                      *
```

Figure 5: View > QA Output File

View > Capture File

If a Capture File has been specified (using Edit > Capture Filename) this option will display the User's Capture File generated from the working copy of the current Mgmt. Markov study file in read-only mode. An example of this option is shown below.

```
Viewing Capture File - [D:\MGM\ZZZ-CAPTURE.DAT]
File  Edit  Search
04/21/2004 10:42:21
   16   Primary Inputs
TRUSTWORTHINESS      1  0.300 0.400 0.400 0.600 0.600
HONESTY              1  0.300 0.400 0.400 0.600 0.600
COMMITMENT           0  0.200 0.400 0.400 0.600 0.600
USE-OF-FEEDBACK      0  0.200 0.400 0.400 0.600 0.600
COMMUNICATION        0  0.161 0.400 0.400 0.600 0.600
BUDGET-PLAN          0  0.161 0.400 0.400 0.600 0.600
STRATEGIC-PLAN       0  0.161 0.400 0.400 0.600 0.600
GUIDANCE             0  0.161 0.400 0.400 0.600 0.600
WELCOME-DISSENT      0  0.151 0.400 0.400 0.600 0.600
IND-ASSESS-STAT      0  0.151 0.400 0.400 0.600 0.600
TECH-UNDERSTAND.     0  0.075 0.400 0.400 0.600 0.600
ACCOUNTABILITY       0  0.151 0.400 0.400 0.600 0.600
NON-AMBIGUITY        0  0.072 0.400 0.400 0.600 0.600
LT/ST-BALANCE        0  0.072 0.400 0.400 0.600 0.600
EXPL.-DECISIONS      0  0.145 0.400 0.400 0.600 0.600
FAIRNESS             0  0.145 0.400 0.400 0.600 0.600
    5   Secondary Inputs
CULTURE              0  0.355
STRATEGY             0  0.320
CULTURE              0  0.152
```

Figure 6: View > Capture File

View > Filter File

If a Capture File has been specified (using Edit > Capture Filename) this option will display the temporary Filter File generated by the program's filtering routine. An example of this option is shown below.

```
Viewing Filter File - [D:\MGM\FILTERED-MARKOV-DATA.DAT]
File  Edit  Search
   10   (No. of Plot Segments to follow)
Plot Segment     1 averages    41 Days:  09/04/2004 - 10/14/2004
   16  Pri-Inputs  (1)   (2)    (3)    (4)      Imp.       Sens.
TRUSTWORTHINESS   0.400 0.400 0.600 0.600  0.10       3.42E-02
HONESTY           0.400 0.400 0.600 0.600  0.10       3.42E-02
COMMITMENT        0.400 0.400 0.600 0.600  4.60E-02   7.40E-02
USE-OF-FEEDBACK   0.400 0.400 0.600 0.600  4.60E-02   7.40E-02
COMMUNICATION     0.400 0.400 0.600 0.600  1.22E-02   1.97E-02
BUDGET-PLAN       0.400 0.400 0.600 0.600  1.22E-02   1.97E-02
STRATEGIC-PLAN    0.400 0.400 0.600 0.600  1.22E-02   1.97E-02
GUIDANCE          0.400 0.400 0.600 0.600  1.22E-02   1.97E-02
WELCOME-DISSENT   0.400 0.400 0.600 0.600  2.61E-02   4.19E-02
IND-ASSESS-STAT   0.400 0.400 0.600 0.600  2.61E-02   4.19E-02
TECH-UNDERSTAND.  0.400 0.400 0.600 0.600  1.32E-02   2.12E-02
ACCOUNTABILITY    0.400 0.400 0.600 0.600  2.61E-02   4.19E-02
NON-AMBIGUITY     0.400 0.400 0.600 0.600  3.14E-02   5.05E-02
LT/ST-BALANCE     0.400 0.400 0.600 0.600  3.14E-02   5.05E-02
EXPL.-DECISIONS   0.400 0.400 0.600 0.600  6.21E-02   0.10
FAIRNESS          0.400 0.400 0.600 0.600  6.21E-02   0.10
    4  Module Outputs
CULTURE           0.366 0.366 0.634 0.634
STRATEGY          0.351 0.351 0.649 0.649
IMPLEMENTATION    0.339 0.339 0.660 0.660
OPERATION         0.332 0.332 0.668 0.668
```

Figure 7: View > Filter File

Plot Menu

Once the User has loaded a Markov study file (using either the File > New or the File > Open option) the Plot Menu will be enabled. This menu option will allow the User to plot (in bar graph format) any of the eight categories of Markov results.

As indicated in the figure that follows, four of the eight categories have sub categories that allow the User to select a specific module or input as a plot object. (Early alerts will be implemented in a future version). The number of different plots is too large to provide an example of each one in this document. However, examples of the Plot > Primary Importance and the Plot > Module Outputs options are respectively shown in Figures 9 and 10.

The User should be aware that no plot is initially displayed when a Markov study file is loaded. But once a plot type has been selected via the Plot Menu, it will continue to be displayed until such time as a different plot type is chosen.

If the User elects to modify any of the primary input values (using the Edit > Primary Inputs menu option), the Markov results are immediately recalculated, and the <u>most recently selected</u> plot type is redisplayed using the new values. This feature gives the User a nearly instantaneous update of the graphical results without destroying any of the original input values; these remain unchanged (in the Mgmt. Markov study file) until the File > Save option or the File > Save As option is executed.

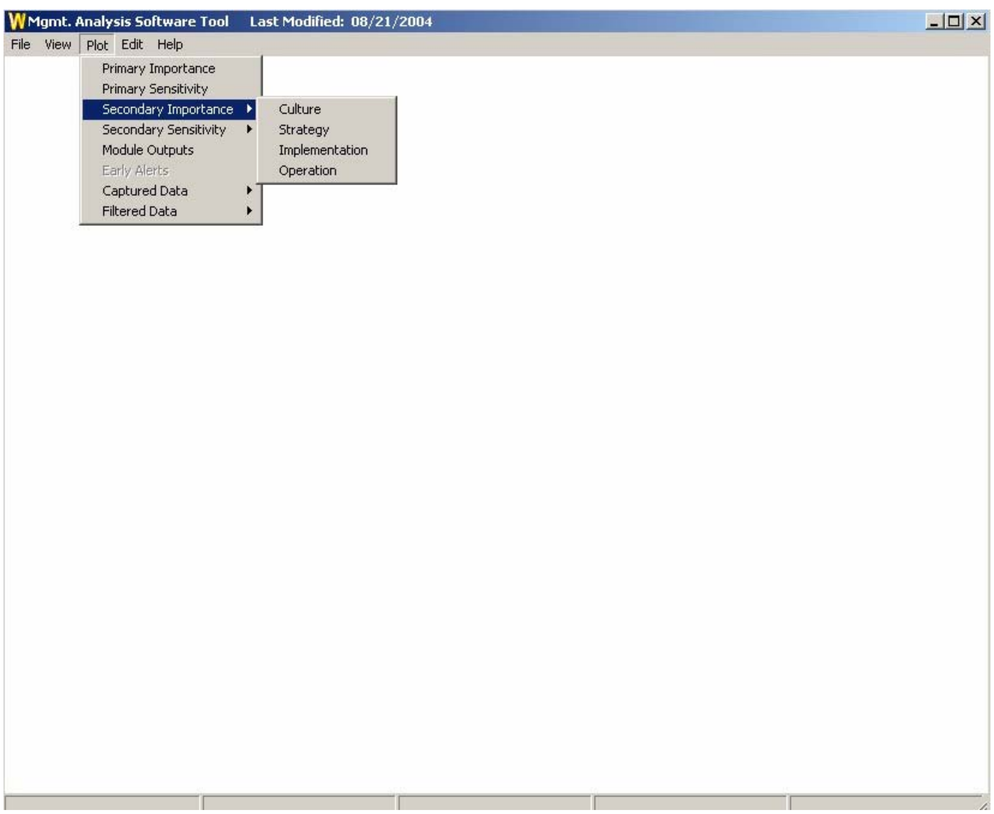

Figure 8: Plot Menu

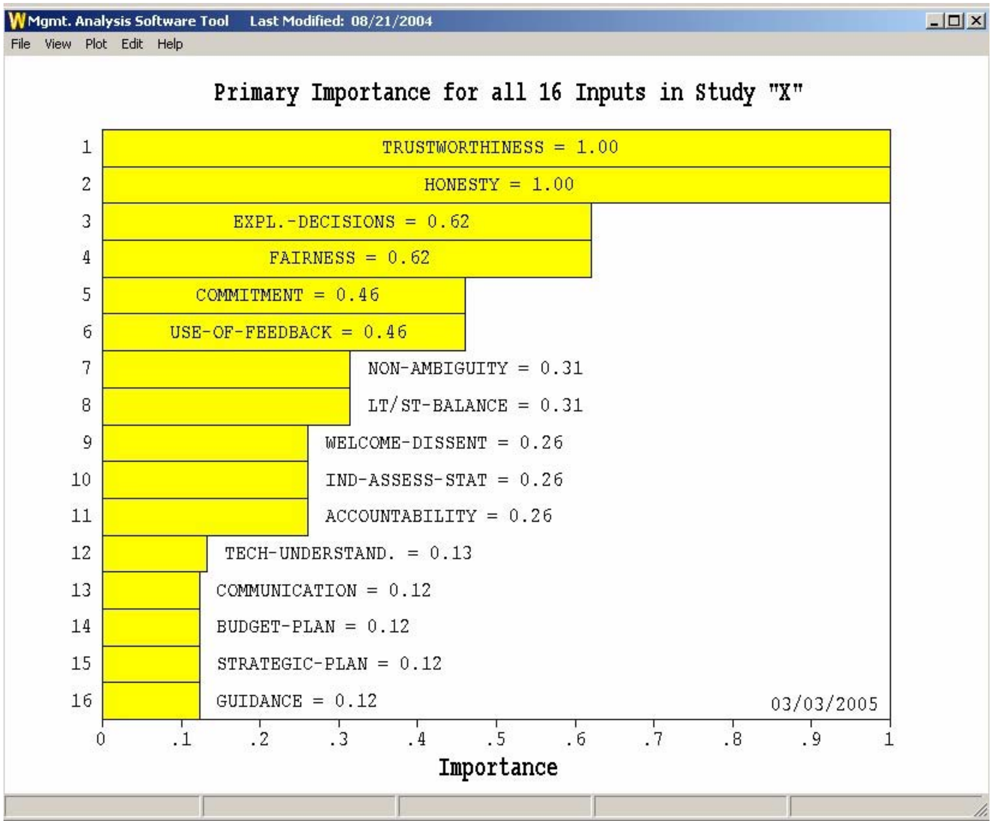

Figure 9: Plot > Primary Importance

Plot > Primary Importance

This option will plot a bar graph displaying the importance relative to the final output, of each defined primary input. The most important input or inputs will have a relative importance value of 1.0. As shown in the example in Figure 9 on Page `130, the bars representing these values are displayed in descending order of relative importance.

Plot > Primary Sensitivity

This option will plot a bar graph displaying the sensitivity relative to the final output, of each defined primary input. The most sensitive input or inputs will have a relative sensitivity value of 1.0. An example of this plot type is not shown. However, the display format is identical to that of the Plot > Primary Importance option. The bars representing the sensitivity values are displayed in descending order of relative sensitivity.

Plot > Secondary Importance

This option will plot a bar graph displaying the importance relative to the output of the User selected module, for each primary and secondary input defined for that module. The most important input or inputs will have a relative importance value of 1.0. An example of this plot type is not shown. However, the display format is identical to that of the Plot > Primary Importance option. The bars representing these values are displayed in descending order of relative importance.

Plot > Secondary Sensitivity

This option will plot a bar graph displaying the sensitivity relative to the output of the User selected module, for each primary and secondary input defined for that module. The most sensitive input or inputs will have a relative sensitivity value of 1.0. An example of this plot type is not shown. However, the display format is identical to that of the Plot > Primary Importance option. The bars representing these values are displayed in descending order of relative sensitivity.

Plot > Module Outputs

This option will plot a bar graph displaying the possibilistic number calculated for all modules. The range of this number is represented by the red portion of the bar representing a given module. The values of this range are also shown but are rounded to two decimal places.

The bars in this plot are also displayed in descending order, but in this case, it is the average of the range calculated by the program that is used for the sort. In other words, the sort key value is the center of the red portion of the bar along the abscissa.

An example plot is shown in Figure 10 on Page 131.

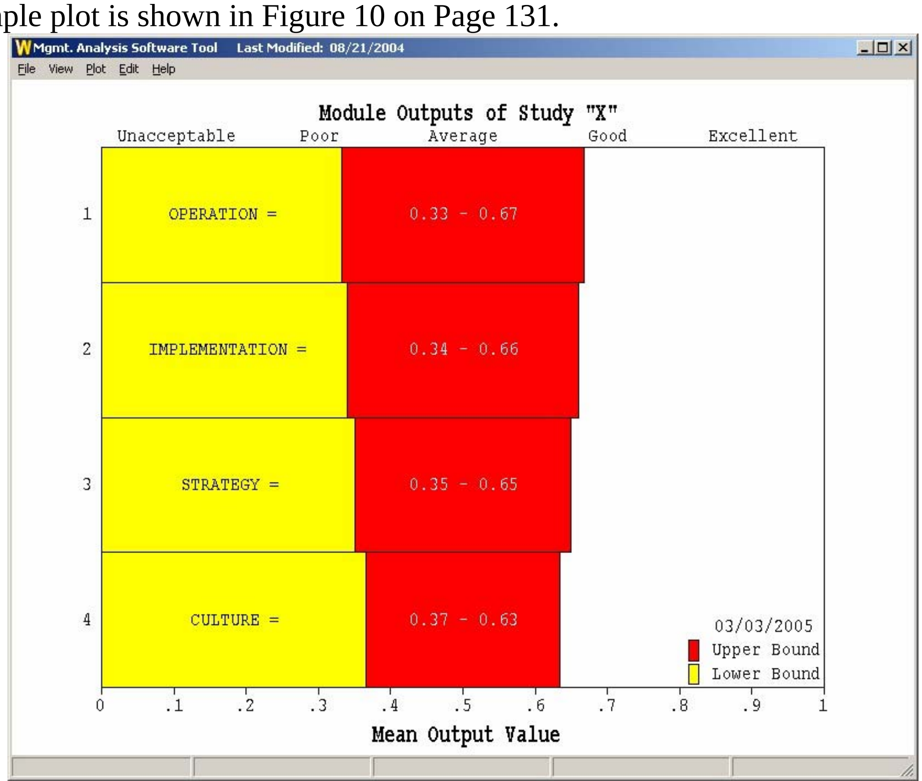

Figure 10: Plot > Module Outputs

Plot > Early Alerts

This future option will plot a bar graph displaying values calculated for the predefined early alert equations[27]. The effects of revising any of the primary input values will be reflected in the early alert results.

Plot > Captured Data

This option gives the User the opportunity to view data output trends graphically. Currently, there are two categories of data that can be plotted: Module Inputs and Module Outputs.

The lower and upper bounds of the data will be displayed as two sets of line segments with symbols representing the actual data values. The abscissa will be chronologically labeled for easy interpretation. In all three data categories, the ordinate (possibility) will be in the range of zero to one (0.0 to 1.0).

This plot option will not available until data capturing has been enabled by specifying a filename using the Edit > Capture File Name option. If desired, the Capture File can be examined by executing the View > Capture File option.

The User must also be aware that a plot of this type will not be meaningful until the program has been executed at least twice, and on different dates. The reason is that all the Markov data (inputs, outputs, etc.) are appended to the Capture File at the beginning of each execution, with a current date/time stamp header preceding each appended data segment. The time portion of this header is ignored, but when two or more identical dates are encountered, the values in the last segment for this date are assumed to be correct, and subsequently used in the plot. An example of this plot type is not shown.

Plot > Filtered Data

This option gives the User the opportunity to view the average of corresponding result values over the range of unique dates found in the date/time headers in the Capture File. If two or more dates are identical, then results for that date are averaged. Interim days in the chronological sequence are interpolated.

This option uses data from the User's Capture File as its input. For this reason, data capturing must be enabled by specifying a filename using the Edit > Capture File Name option. A number of program executions may be required to provide enough useful data for plotting. The output file (FILTERED-MARKOV-DATA.DAT) generated is used by this plotting option and is subsequently deleted. However, the file can be examined by executing the View > Filter File option.

---

[27] An early alert equation is combination of minimums and maximums of two or more module inputs or outputs. Its purpose is to determine a logical range of concern.

As in the Plot > Captured Data option, the two categories of data that can be plotted are Module Inputs and Module Outputs. An example of this plot type is not shown.

Edit Menu

The Edit Menu provides a means to revise the primary input values of any module, or to enable or disable Markov data capturing by revising the name of the User's Capture File. The Edit Menu is shown in Figure 11 on Page 134.

Edit > Module Input Values

This option allows the User to modify the input values of any primary input in any of the defined modules. When the User clicks this selection, the Edit Inputs Dialog appears on the CRT. The primary inputs of the first module are initially displayed, but the inputs of any module can be displayed by selecting its corresponding radio button.

Once the desired module is selected, its input values (shown in the grid control) can be revised. The dialog will perform error checking to ensure the validity of all modified values. The User can continue editing the input values of some other module (by selecting its radio button) or terminate the editing session by clicking the button labeled "Exit (End Revisions)". The Edit > Module Input Values dialog is shown in Figure 12 on Page 134.

The User should be aware that any changes made are not saved in the .MKV file until the File > Save or the File > Save As option is executed. This allows the User to view the results of a revision with the option to discard that revision. This is useful in the case where the results of the recent modification(s) are undesirable.

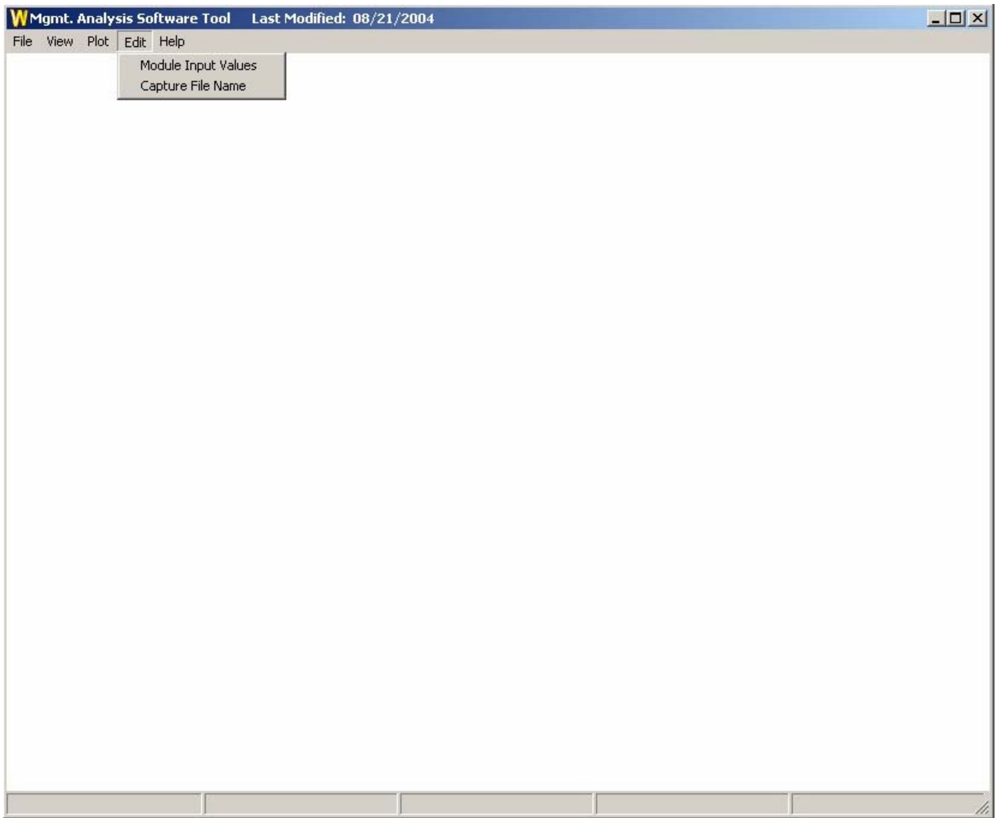

Figure 11: Edit Menu

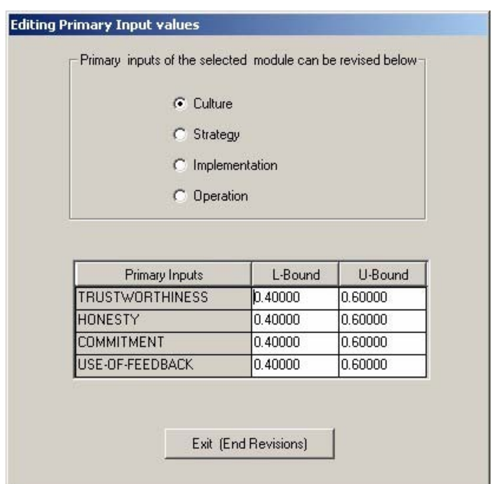

Figure 12: Edit > Module Input Values

Edit > Capture File Name

This menu option allows the User to enable capturing of Markov data and results for subsequent use in plots that indicate trends. This is accomplished by specifying a name for the Capture File when the dialog shown below appears on the CRT.

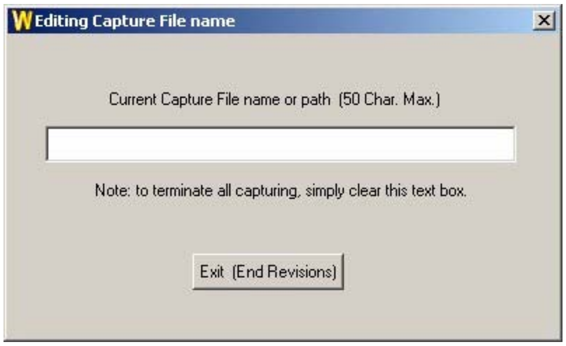

Figure 13: Edit > Capture File Name

As indicated in the dialog, capturing can be disabled at any time by simply clearing any Capture File Name currently in effect. However, capturing can be resumed at any time by entering the name of the desired Capture File. This can be the name of an existing Capture File if desired. If the file specified by the entry does not exist, then a new segment of data will be initialized (in that file) and identified by the current date/time in its header.

Help Menu

The Help Menu contains the single option Help > About. Additional help options may be added in future versions of the program.

Help > About

This option displays information regarding the program. An example is shown below.

Figure 14: Help > About

References

1. Cooper, J. A., “The Markov Latent Effects Approach for Safety Assessment and Decision-Making,” Sandia National Laboratories Report SAND2001-2229, September 2001.

2. Cooper, J. A., and Roginski, R. J., “Hybrid Processing of Measurable and Subjective Data.” Sandia National Laboratories Report SAND2001-3317, October 2001.

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