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The Markov Latent Effects Approach to Safety Assessment and Decision-Making

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The Markov Latent Effects Approach to Safety Assessment and Decision-Making

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Key words: safety analysis, root causes, organizational factors, soft aggregation, decision analysis

Abstract

The methodology in this report addresses the safety effects of organizational and operational factors that can be measured through “inspection.” The investigation grew out of a preponderance of evidence that the safety “culture” (attitude of employees and management toward safety) was frequently one of the major root causes behind accidents or safety-relevant failures. The approach is called “Markov latent effects” analysis. Since safety also depends on a multitude of factors that are best measured through well known risk analysis methods (e.g., fault trees, event trees, FMECA, physical response modeling, etc.), the Markov latent effects approach supplements conventional safety assessment and decision analysis methods. A top-down mathematical approach is developed for decomposing systems, for determining the most appropriate items to be measured, and for expressing the measurements as imprecise subjective metrics through possibilistic or fuzzy numbers. A mathematical model is developed that facilitates combining (aggregating) inputs into overall metrics and decision aids, also portraying the inherent uncertainty. A major goal of the modeling is to help convey the top-down system perspective. Metrics are weighted according to significance of the attribute with respect to subsystems and are aggregated nonlinearly. Since the accumulating effect responds less and less to additional contribution, it is termed “soft” mathematical aggregation, which is analogous to how humans frequently make decisions. Dependence among the contributing factors is accounted for by incorporating subjective metrics on commonality and by reducing the overall contribution of these combinations to the overall aggregation. Decisions derived from the results are facilitated in several ways. First, information is provided on input “Importance” and “Sensitivity” (both Primary and Secondary) in order to know where to place emphasis on investigation of root causes and in considering new controls that may be necessary. Second, trends in inputs and outputs are tracked in order to obtain significant information, including cyclic information, for the decision process. Third, Early Alerts are provided in order to facilitate pre-emptive action. Fourth, the outputs are compared to soft thresholds provided by sigmoid functions. The methodology has been implemented in a software tool.

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Historical Background

This project began in late 1997 to investigate mathematical methodology for assessing the effects of organizational and operational factors on high consequence system safety. For example, determining the safety status of a system operation might depend on measuring factors such as accident/incident statistics, maintenance personnel/operator competence and experience, scheduling pressures, and safety “culture” of the organization. Many of the potential metrics on such individual parameters are difficult (and generally uncertain) to determine. Also, there may be ill-defined interrelations among the contributors. This focus was made for two main reasons. First, a preponderance of evidence was accumulating that the safety “culture” (attitude of employees and management toward safety) was frequently one of the major root causes behind accidents or safety-relevant failures [Refs. 1, 2]. Second, nearly all high consequence operations have some sort of independent assessment review process, and there is a correlation between the extent of this process and the success of the resultant operational safety [Ref. 3.]. Neither of these appeared to be amenable to conventional mathematical analyses, so management judgment initially determined the level of each that was appropriate as well as what the response should be to identified weaknesses. While there is undeniable benefit to management judgment, a mathematical structure as an adjunct and contributor to judgment has significant value. For example, a mathematical analysis helps organize thinking by systematically processing data. It can help focus priorities and payoffs through quantification. It can be automated. And it contributes to *defensible* decision-making.

The effort was initially sponsored by the Federal Aviation Administration Aviation Safety Risk Analysis Section, Airport and Aircraft Safety Research Engineering and Development Division (FAA/AAR-424). Since October 1998 it has had the additional support of the Sandia National Laboratories LDRD (Laboratory Directed Research and Development) program. The initially developed approach and methodology was described in a previous report [Ref. 4]. The information in this report depends somewhat on the previous report, but there have been sufficient developments that the material is significantly improved. For example, a new architecture was developed based on another FAA/AAR-424-sponsored project called ASRATS (Aviation Safety Risk Analysis Technical Support). An improved soft aggregation process has been developed. An improved treatment of dependence has been developed. The metrics for Importance and Sensitivity were improved and supplemented by Secondary Importance and Secondary Sensitivity. The software implementation has also changed from an initial Windows version to a Web-based version, supplemented by a Fortran 77 routine that has been used for accuracy checks and simulations.

The methodology is called “Markov latent effects” analysis in honor of A. A. Markov, who was one of the first scientists to stress the formal mathematical role of a chain of occurrences in determining subsequent events [Ref. 5]. Since safety also depends on a multitude of factors that are best measured through well known risk analysis methods (e.g., fault trees, event trees, FMECA, physical response modeling, etc.), the Markov latent effects approach supplements conventional safety assessment and decision analysis

methods. A top-down mathematical approach was developed for decomposing systems, for determining the most appropriate items to be measured, and for expressing the measurements as imprecise subjective metrics through possibilistic or fuzzy numbers. A mathematical model was developed that facilitates combining (aggregating) inputs into overall metrics and decision aids, also portraying the inherent uncertainty. A major goal of the modeling was to help convey the top-down system perspective. Metrics were weighted according to significance of the attribute with respect to subsystems and were aggregated nonlinearly. Since the accumulating effect responds less and less to additional contribution, it is termed “soft” mathematical aggregation, which is analogous to how humans frequently make decisions. Dependence among the contributing factors was accounted for by incorporating subjective metrics on commonality and by reducing the contribution of these combinations to the overall aggregation. Decisions corresponding to the results were facilitated in several ways. Information was provided on input “Importance” and “Sensitivity” (both Primary and Secondary) in order to know where to place emphasis on investigation of root causes and in considering new controls that may be necessary. Trends in inputs and outputs were tracked in order to obtain significant information, including cyclic information, for the decision process. Early Alerts were provided in order to facilitate pre-emptive action. The results were compared to soft thresholds provided by sigmoid functions.

Overarching Development Strategy

A systemic approach that is applicable to safety analysis in general was specifically chosen for the overarching strategy behind this project.

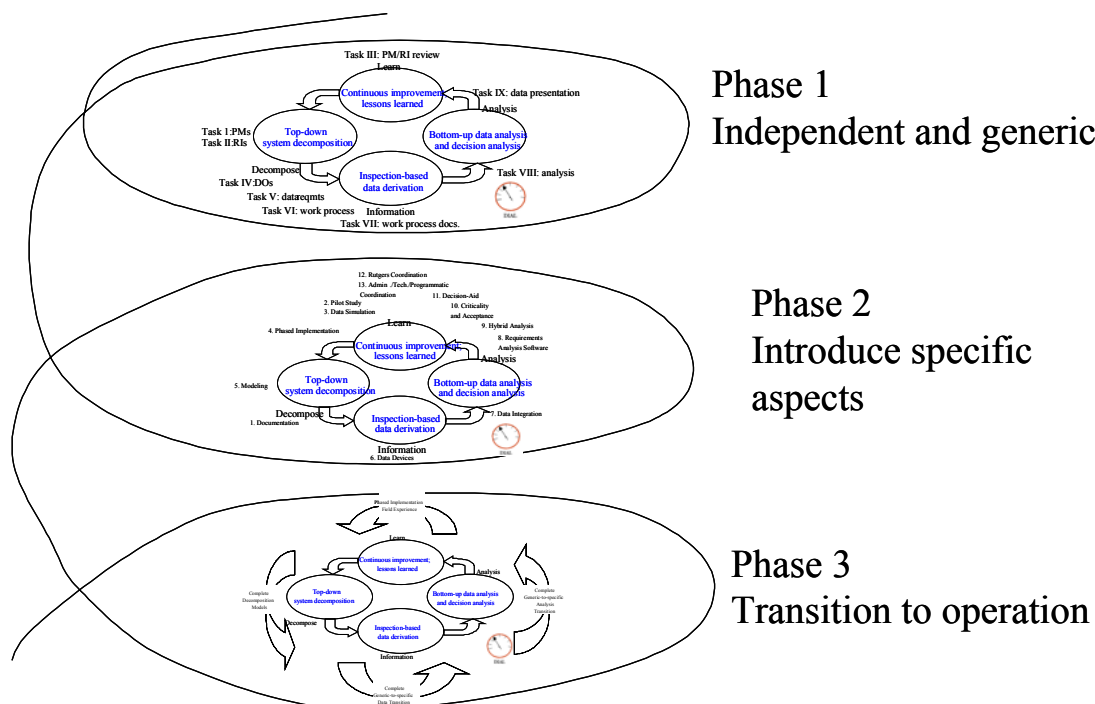


Figure 1. Three-Phase Strategy

The approach is based on tasks that follow a multi-phase process guided by a structure common to each phase. The tasks are not independent, but rather were chosen to synergistically support a planned implementation of the results over a particular period of time. In Fig. 1, a strategic plan for a three-phase project is shown.

The first phase is an independent assessment of what is needed for an optimum approach. The basic tasks (from ASRATS) are indicated in Fig. 2 (also see the Glossary).

Within each indicated loop is a circuit around a “DIAL” process (Decompose, Inform, Analyze, Learn, detailed later), which provided the structure for the tasks. The second phase is a more detailed trip around the DIAL process, with developments aimed at adding specific aspects to the generic process. The third phase is intended to transition toward operational status, aiming toward enhanced decision-making wisdom. At the culmination, there was intended to be a capability to decompose any system of interest using any or all of the methodologies.

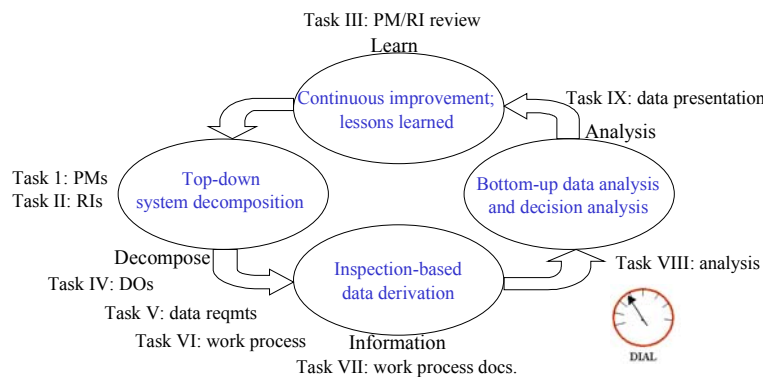


Figure 2. The DIAL Process, Showing Phase 1 Tasks

The nine tasks for Phase 2 are portrayed in Fig. 3 on the DIAL structure.

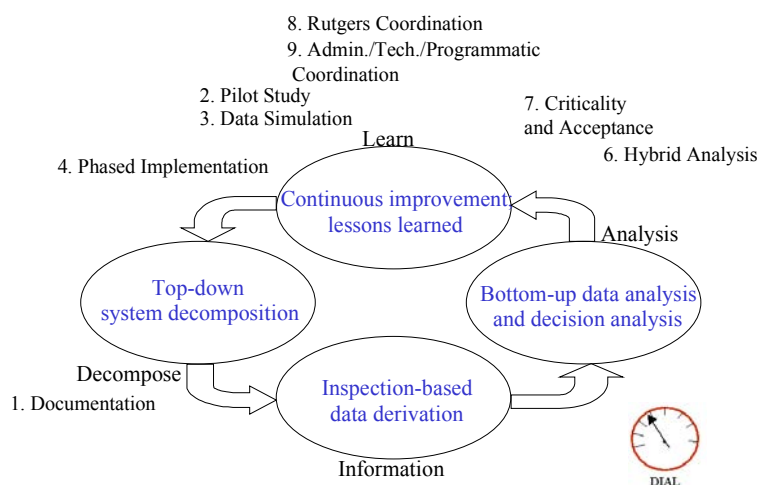


Figure 3. Phase II Tasks Shown in DIAL Structure

The general plan of tasks for Phase 3 is shown in Fig. 4 on the DIAL structure.

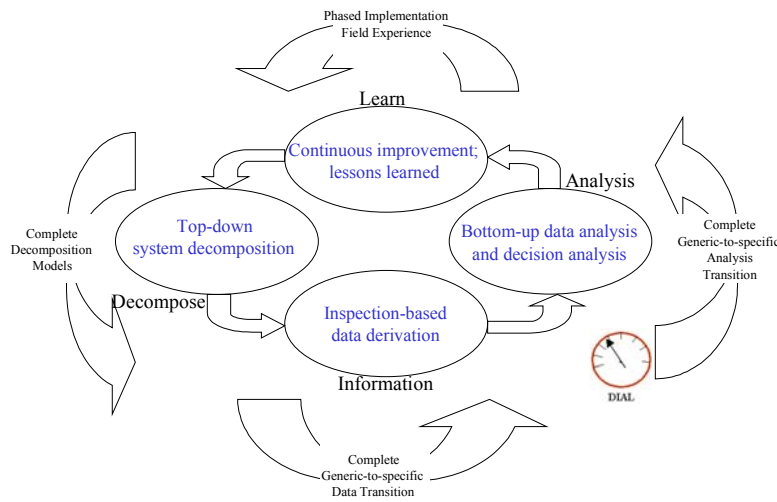


Figure 4. General Phase 3 Plan

Most operational high consequence systems have been developed to a high level of safety because of the potential consequences. However, there is always a desire to improve safety, especially if it can be done efficiently, aided by the utilization of improved decomposition and analysis methodologies. The Gore Commission recommendation to reduce the air transportation accident rate by a factor of five by 2007 provides an example of such desires. High consequence systems also benefit from meaningful analysis in the design, implementation, operations, and disposal phases. There can be significant improvements in the conventional methodologies currently used. This is necessary for efficiently gathering data and analyzing those data to provide information and knowledge that could contribute to defensible (wise) decisions about the safety of high consequence systems. In order to meet these objectives, one can take an independent top-down system view. The resultant structure is the DIAL process, described above in conjunction with the overall plan, and shown again in Fig. 5 in its basic form.

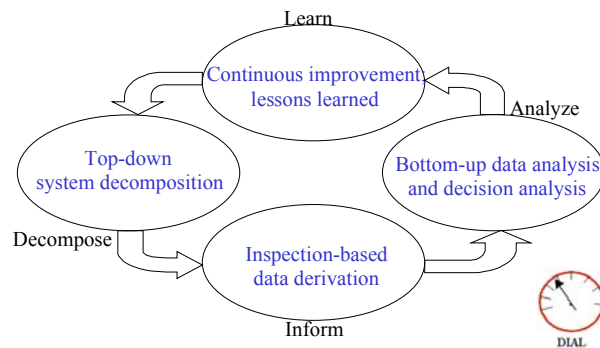


Figure 5. The DIAL Process (Decompose, Inform, Analyze, Learn)

As indicated, a complex system can be decomposed to facilitate meaningful analysis, then data can be gathered as the first step leading to information, then these data and information can be aggregated through analysis to create the knowledge needed to make better decisions, and throughout the process lessons learned and expert judgments can be sought and used in feedback to improve the wisdom necessary to good decision-making.

A detailed breakdown of the strategy is shown in Fig. 6. Beginning in the upper left part of the figure is the first step in risk analysis, decomposition of the system. Over the years, many risk analysis methodologies have been developed for many purposes, because no single method is ideal for all situations. In accordance with this experience, hybrid combinations of methodologies are generally needed to optimally analyze any reasonably complex system. The general concept is illustrated by the orthogonal axes for “compliance” and “commitment” in the upper left part of the figure. This indicates that compliance with laws, policy, and regulation is not sufficient for safety; even in the presence of compliance, lack of commitment is risky. Driving a car provides an informative analogy. It is important to place controls on how a car must be driven (e.g., traffic laws), but while these are indeed important, optimally safe driving requires many other considerations that transcend controls. For example, defensive driving requires an anticipatory and cultural focus on actions that are being taken by other drivers. Driving on icy roads requires skills that can only be learned through experience, which in turn requires commitment to skill development. This helps explain why no single decomposition approach is sufficient. It is the basic reason that a hybrid decomposition was used in the Markov latent effects model development.

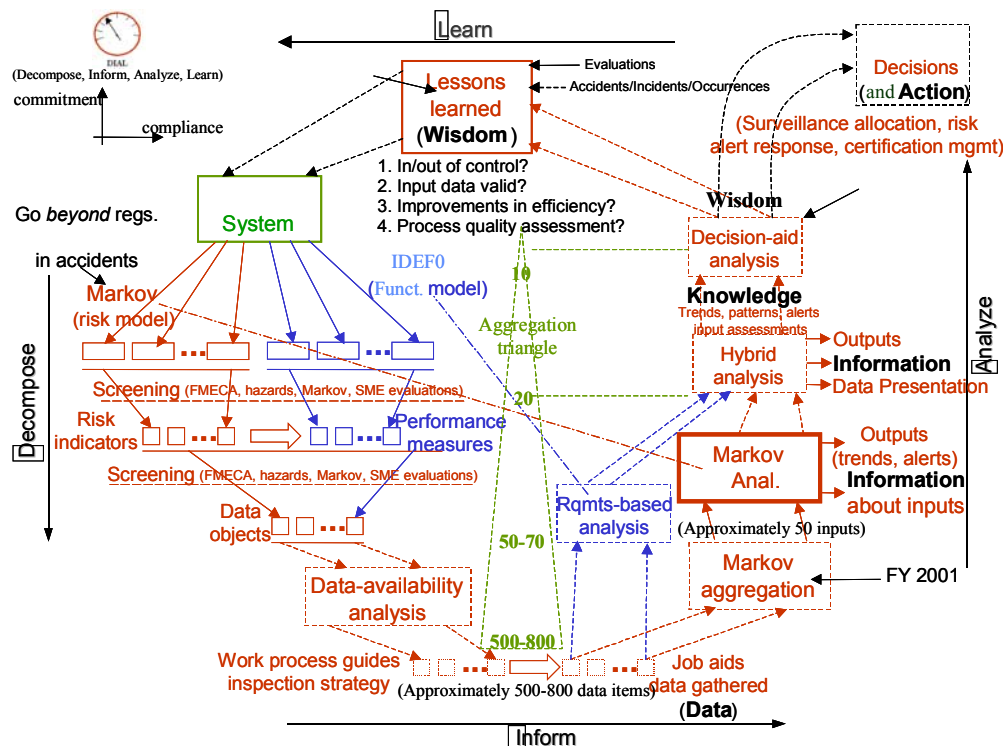


Figure 6. DIAL Strategy Components

Complex systems must generally be decomposed (but without sacrificing interrelations that are part of the top-down system view or losing track of the interrelations among subsystems) in order to make analysis both feasible and meaningful. Multiple decompositions (e.g., functional, risk-based) are generally required if comprehensive benefits are to be derived. In order to further demonstrate the need for multiple decompositions, note that functional decompositions are essential for describing intended operations, but these focus on management, activity execution, and providing resources for the operation. Functional decomposition is especially well suited to assuring adherence to safety requirements, which are often negotiated to what can be done rather than what is desired at the outset of design. Also, safety requirements are often retroactive as they depend largely on lessons learned (the “fly-fix-fly” approach), rather than proactive so as to prevent some unwanted loss in the future.

Although appropriate and necessary to describe general functionality, restricting decompositions to this approach would be more likely to result in missing important failure-drivers such as the inherent environment (e.g., financial and legal constraints), the need for a specific safety function in any high consequence operation, the roles of self-assessment and independent assessment, and the need to foster a safety culture.

Risk models such as the Reason model [Ref. 1] have a safety-focused approach built around the timing of latent effects, first recognizing the environmental constraints and threats, then the management safety philosophy that is established within that environment, then the working conditions affecting safety, and finally the safety risks inherent in actual operation. This approach helps better identify safety risks, but more importantly, helps determine *why* safety problems might arise (a forward-looking approach) and helps identify what can be done to improve overall safety (similar to an in-depth root cause and correction analysis, but also accommodating hypothetical events).

Both of these types of decompositions are indicated in Fig. 6, where the system is decomposed into subsystem modules by a Markov (risk model) decomposition [Ref. 4] and a functional requirements decomposition [Ref. 6].

Adjunct decompositions are also useful. For example, organizational decomposition guides where and how measurements should be made for a specific organization.

The selected process was to systematically decompose a system using first risk and then functional models in ways that facilitate the identification of meaningful measurements relevant to safety. The resultant risk categories help derive the corresponding performance categories, first at a high level, and then at more detailed levels. When the categories are sufficiently detailed, they facilitate derivation of metrics. The results are then organized for use in analysis. This general strategy is outlined in Fig. 7.

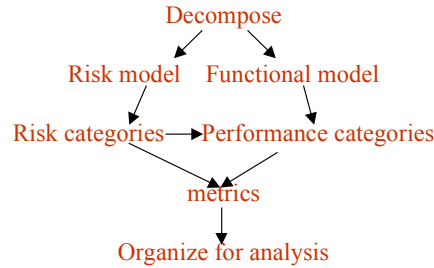


Figure 7. Hybrid Decomposition Strategy

Among the specific methods used for identifying risk categories are: examination of the particular inputs, outputs, functions, and interface transfers associated with the Markov risk model; FMECA (Failure Modes, Effects, and Criticality Analysis); existing lessons-learned programs (accident/incident/occurrence information); root cause analysis (of real and hypothetical incidents), and hazards databases.

Decomposition Approach

Decomposition is a technique for partitioning a complex system into more manageable, more meaningful, and more analyzable subsystems. It is helpful in apportioning team effort and contributes to understanding. However, it is important to not lose sight of the interactions of subsystems in contributing to system performance. It is essential that the top-down system consideration not be lost through the decomposition mechanism.

Risk Decomposition. The most productive decomposition found in this study was a Markov latent effects decomposition. This is because in order to make long-term improvements in safety, it is essential to affect root causes that occur early in a chain of influences. Addressing the results of these influences is less effective in the long run, as Reason and many others (e.g., Ref. 2) have pointed out. The basic structure for the first level of risk decomposition is shown in Fig. 8.

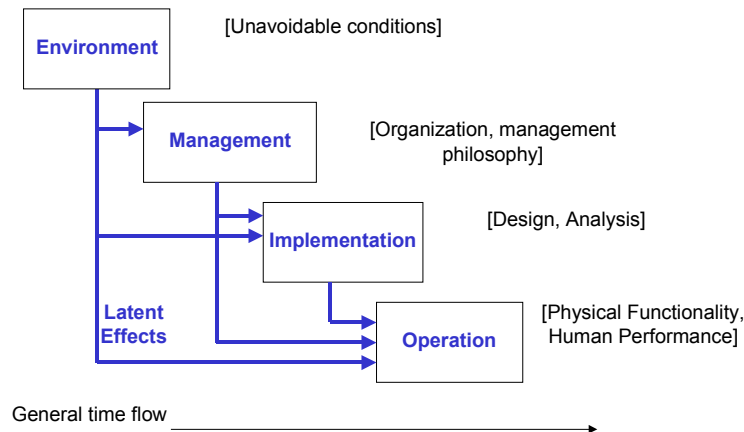


Figure 8. Basic Risk Decomposition

The effects depicted in Fig. 8 begin with the inherent environment. The environment establishes the operating conditions (financial, legal, competition, labor unions, weather, international, etc.). An organization is established to operate within this environment. The organization first establishes an operating philosophy and exerts influence over ethics, culture, communication style, and basic policy. Then implementation takes place, where decisions and designs are made, analysis and assessment are performed, purchases are made, facilities and resources are provided, and the general working conditions are established. The actual operation is the performance of the functions that are of the most *immediate* safety criticality, although many of these may have been somewhat preordained (or at least strongly influenced) by the conditions established earlier. This is why the approach is called a “latent effects” model.

Functional Decomposition. Another necessary model is a carefully developed functional decomposition. Understanding functionality is a necessary basis for system analysis. A widely used form of functional decomposition is called IDEF0. The basic IDEF0 decomposition strategy [Ref. 6] is shown in Fig. 9.

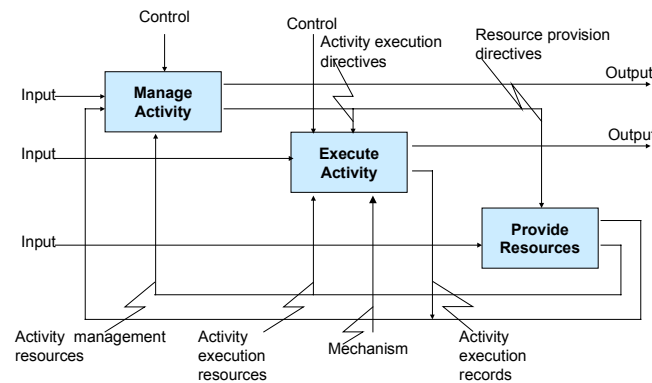


Figure 9. Basic Functional Decomposition

The top-level module functions are management, activity execution, and resource provision. Each module has inputs, outputs, and functionality that is supported by “mechanisms” and governed by “controls.” All modules can similarly be decomposed to any level of detail desired.

With the guidance of the risks previously identified as described above, requirements are identified that could be associated with each function (as well as inputs, outputs, controls, mechanisms, supports, and interface transfers) to address the risks directly associated with functions. This helps determine performance categories. At this point, there is a feedback assessment in order to eliminate risk categories that are duplicates of performance categories. This is done to maintain the association of risk indicators with potential problems not explicitly associated with requirements.

Organization for Analysis. Although functional and risk decompositions guide identification of potential safety problems, individual sources of safety concern at the most basic level of decomposition are often global in nature (apply at many places in the system decomposition). High-level examples are culture, management style, training

process, communication philosophy, and documentation, for which effects can be seen throughout an organization. For most effective analysis, it is useful to organize the derived data by these broad categories, which become more specific at lower levels of decomposition. An example is shown in Fig. 10, where a file drawer analogy is drawn. The file-drawer-level of decomposition is termed “Factors,” and these are subdivided into drawer sections termed “Characteristics,” each of which can be divided into folders termed “Sub-Characteristics,” etc.

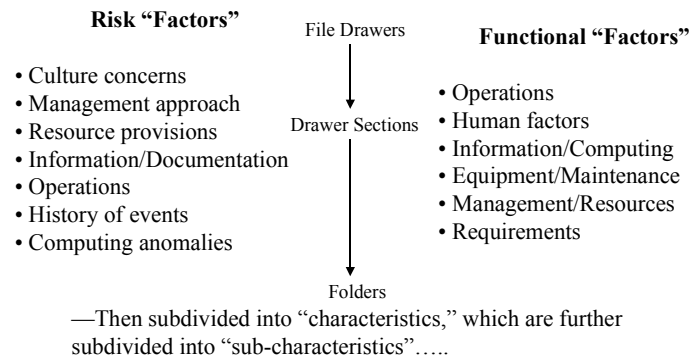


Figure 10. Basic Characteristics Decomposition

Approach Used for Determining Risk Metrics and Performance Metrics. The methodology begins with the development of safety-relevant risk categories, most of which are derived from risk models, and none of which are derived explicitly from system requirements. Basically, risk categories of a system point to areas that might need to be changed to make the system safer. Using the earlier driving example, a driver who has a poor safety culture might violate speed laws when thought to be under no threat of being apprehended (e.g., on a private road). Changing this behavior through improved culture makes driving safer, because sooner or later, any bad habits formed will influence behavior when adherence to good habits matters most. Some risk categories might lead to concerns even if changes are not feasible. For example, a history of events tells us that inexperienced drivers are generally less safe than experienced drivers. Although inexperienced drivers are not necessarily restricted from driving, the value is that one can learn where to be the most vigilant. All of these safety concerns are first developed at a high system level, and through decomposition they are gradually made more detailed until risk metrics can be identified. The derivation of Risk Indicators (RIs) and Performance Measures (PMs) is indicated in the center left decomposition portion of Fig. 6.

At each level of decomposition, the risk categories are used along with the appropriate level of a functional decomposition in order to derive performance categories. Performance categories are used to measure safety-related requirements that are in place so that adequacy of or changes in requirements can be considered. For example, the risk of inexperienced drivers is reduced by placing age limits on qualification for a driver’s license. As the decomposition becomes more detailed, these performance categories

become more detailed until performance metrics can be identified, nearly always influenced by risk considerations. This strategy is diagrammed in Fig. 11.

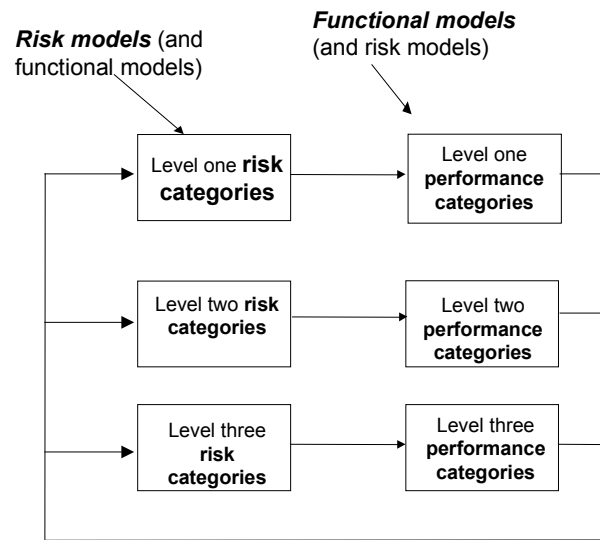


Figure 11. Risk-Driven Decomposition Strategy

An objective is to derive performance metrics and risk metrics that can be used to efficiently and accurately aggregate information through analysis and to contribute toward assessing important system operations and risk.

Screening. Obtaining insufficient numbers of metrics would not allow meaningful analysis. It is important to try to assure that nothing is missed. However, it is relatively easy to identify so many metrics that it isn't feasible to gather or analyze them. In order to address this problem, it is helpful to be conservative on the high side during the identification process, but then to systematically screen for safety criticality at every level of decomposition. The screening process depends on hazards analysis, FMECA, risk analysis, and feedback from subject matter experts. This screening is depicted in Fig. 12. In Fig. 6, screening is indicated between subsystem components and RIs/PMs, and between RIs/PMs and DOs.

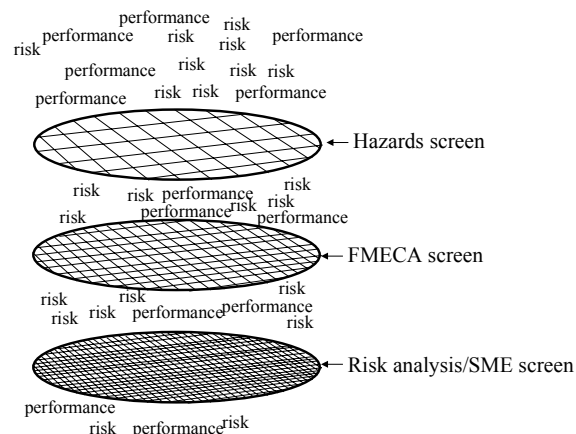


Figure 12. Multiple Screens Strategy

Input Capture

The Markov inputs have been selected to range between 0 (very bad) and 1 (excellent). The major challenges associated with the inputs are reducing the subjective variation to a minimum (similarly qualified people should generate similar inputs), and to represent any remaining uncertainty in an informative manner.

Types of Metrics. In the information process, there have been three types of metrics identified as the most useful. These are quantitative, multiple choice, and qualitative. The process is diagramed in Fig. 13, which also indicates measurement guidance.

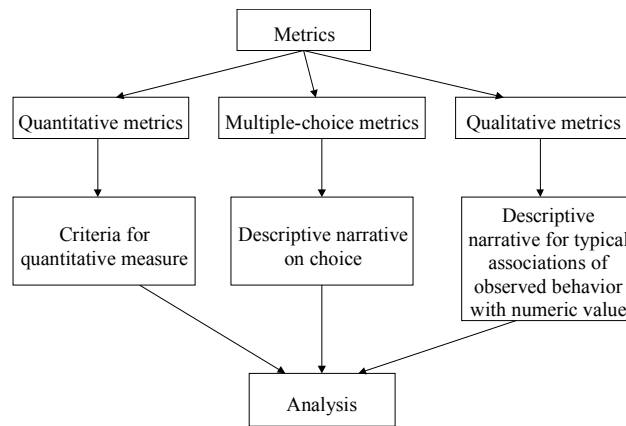


Figure 13. Handling Different Types of Metrics

In order to be useful in analysis, both the multiple choice metrics and 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. In order to make the process 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 is part of the data-availability analysis, indicated at the lower left of Fig. 6 in the beginning of the Inform process.

Work process guidance and inspection strategy analyses are also shown at the bottom of Fig. 6. For illustration, an example of methodology for deriving numeric representations of qualitative characteristics is shown below in Fig. 14. The qualitative metric desired (as an example) is “Is there a connection between training and needs for that training?” A number between zero and 10 is sought, where zero represents as little connection as possible, and 10 represents as great a connection as possible. The Markov implementation was similar, but used numbers between 0 and 1.

Qualitative question: Is there any relationship between
training provided and needs for training?

[Enter any number or range of numbers between 0 and 10 to indicate a qualitative judgment (or range of possible judgments) of the quality of the relationship. 0 represents extremely poor, and 10 represents extremely good]

Score

- | | |
|---------|---|
| 0 to 1 | If there is no apparent relationship, or if personnel in charge of training are not aware of any specific needs for relationship, an appropriate entry is in the range of 0 to 1. |
| 1 to 3 | If there are minor relationships, and if concerned personnel are somewhat aware of needs for relationship, but you don't believe that the relationship is very effective, an appropriate entry would be in the range of 1 to 3. |
| 3 to 7 | If the relationship appears to be about average, and the involved personnel are paying about average heed to needs, an appropriate entry would be between 3 and 7. |
| 7 to 9 | If the relationship is somewhat above average, and if the involved personnel reflect this awareness, an appropriate entry would be between 7 and 9. |
| 9 to 10 | If the relationship is outstanding, and the involved personnel appropriately embrace the need for the relationship, an appropriate entry would be in the range 9 to 10. |

Figure 14. Example Numeric Representation of a Qualitative Metric

The results obtained at this point provide the beginning of the data-information-knowledge-wisdom-action chain, as indicated by the data in the lower right of Fig. 6. Information depends on beginning to aggregate data through analysis.

The metrics must also be tested for effectiveness. This isn't a formal screening process, since modification is more common than rejection. The qualities sought are sensitivity (responds to process changes), stability (stable if process is stable), reliability (same results in same situation), validity (representative of measurement intent), feasibility (data are obtainable), efficiency (measurement is cost-effective), comparability (sensitive to changes under different factors and conditions), and usability (can be correctly used).

Number of Inputs. Since the purpose of the Markov Latent Effects Tool is to facilitate for inspection and analysis personnel a fairly efficient evaluation of an operation, the number of inputs used must be constrained. There is a tradeoff inherent in this limitation, however. In general, less detailed inputs mean less specific explicit guidance for deriving inputs. Much of the input guidance was placed in an adjunct called the "Pre-Markov aggregation" process (Appendix A). This gives the user the option of developing Markov inputs through pre-Markov aggregation, or of entering the inputs with less specific (and possibly more intuitive) guidance. The 1998 Markov architecture had 45 inputs (along with a number of other input features, such as Early Alert logic). The new architecture has 119 inputs (also Early Alert logic and dependence groups). For comparison, there were 277 DOs identified in ASRATS, out of several thousand possible (see Fig. 15).

The descriptions of the 119 inputs is given in Appendix B.

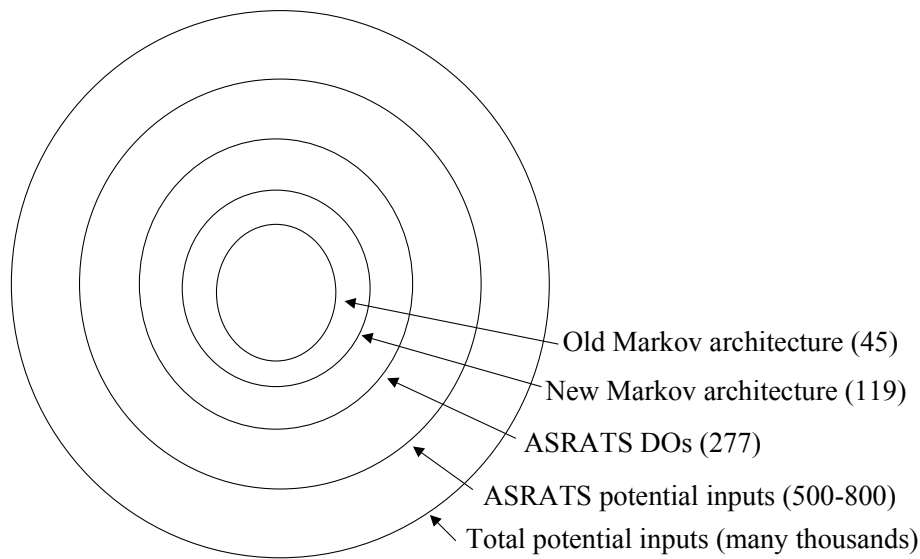


Figure 15. Subsets of Potential Inputs

Uncertainty. There are two main sources of uncertainty inherent in the Markov inputs. One is that a person entering an input may be unsure of the precise value to enter and might prefer entering a range of values. Another is that a collection of people collaborating on input entry may not agree on exactly the same value regardless of the amount of guidance provided.

Since this input entry process represents subjective judgment, possibilistic and fuzzy representations were investigated, and the methodology to support such mathematics was generated. However, the Web-based software implementation restricted uncertainty to intervals (upper and lower bounds), which are a subset of the FORTRAN methodology. The complete approach will be described; the interval implementation follows.

First, assume that there is a range of abscissa values representing some resultant uncertainty. Then assume an ordinate representing “level of presumption,” where 0 is the absolute minimum level of presumption (widest credible range) and 1 is the absolute maximum level of presumption (smallest credible range). A linear representation of these possibilities yields a trapezoid in general, although it may be restricted to a triangle, square, or point value, depending on the amount of uncertainty represented.

An example helps clarify these concepts. Assume that an inspection value uncertainty range is judged to be as large as 0.4 to 0.6 (least level of presumption), or as small as 0.45 to 0.55 (greatest level of presumption). Alternatively, assume that the lowest value obtained from a collection of personnel is 0.4 and the highest is 0.6; while the average of the lowest bound values obtained from the collection of personnel is 0.45 and the average of the highest bound values is 0.55. Either way, the uncertainty function is a trapezoid, as shown in Fig. 16.

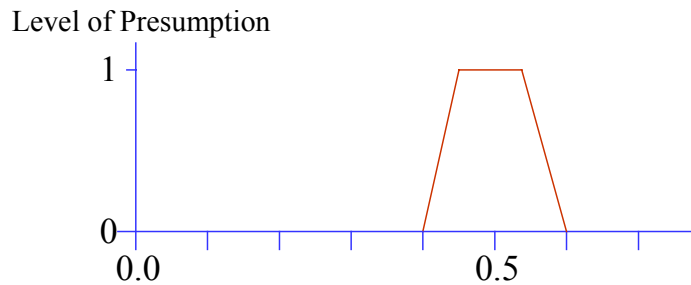


Figure 16. Trapezoidal Uncertainty Function

If the uncertainty range at the highest level of presumption were reduced to a point, the function would be triangular. If the lower bound and the upper bound were the same at all levels of presumption, the function would be square (representing an interval). If there were no uncertainty, the function would be a delta function (a point at all levels of presumption). All four representations of uncertainty were implemented in the FORTRAN software. Responding to the desires of potential users, only the interval uncertainty and point capability was implemented in the Web-based software.

Data Aggregation

Data aggregation allows observed metrics to be combined to derive various sorts of information, such as combined ratings of subsystems or the entire system, and trends information. The strategy extends naturally to decision analysis, where decision aids must be developed concerning acceptability of system safety or concerning the need for operational restrictions; and also to selection among alternative approaches or forensic hypotheses.

The overall objectives include:

- Deriving safety performance metrics of subsystems and the overall system
- Facilitating decision analysis about robustness of the operation
- Prioritizing examination of safety hazards, where limited resources must be expended in a cost-effective manner
- Facilitating investigations (root cause in response to incidents or hypothetical causes during assessment)
- Prioritizing hazard controls, where corrective actions must be taken
- Helping determine the most effective response actions

Analysis. Since measurements can lead to assessments when compared to norms or acceptance margins, subsequent analytical methodology and information presentation can contribute to a structured approach for defensible safety decision-making. The data are rolled up to higher levels utilizing various forms of analysis methodologies as indicated along the right side of Fig. 6. The analysis methodologies help to assess system safety

and can be used to derive information about the inputs that will help guide safety-relevant decisions.

Soft Aggregation Computation. Each group of input values is aggregated by a modified weighted sum to provide an assessment score for each module, and this process continues until an overall assessment score is derived. Input uncertainty (possibilistic or interval functions for each input) is allowed, and the results reflect this uncertainty. The modification of the weighted sum process is called soft aggregation and is derived according to the nonlinear expression in Eq. 1.

$$y = \frac{1}{1 + e^{-5.5(\sum_{i=1}^n w_i x_i - 0.5)}} \quad (1)$$

where the x_i values are the individual inputs, the w_i are the corresponding weights, and y is the result. This expression was based on, but is slightly different than the soft aggregation expression used in the 1998 computation package. The change was made to optimize the tradeoff between soft aggregation and suppression of extreme (high or low) scores as the number of levels of computation grows.

A plot of the function is shown in Fig. 17, where the weighted sum is the abscissa, and the ordinate is y .

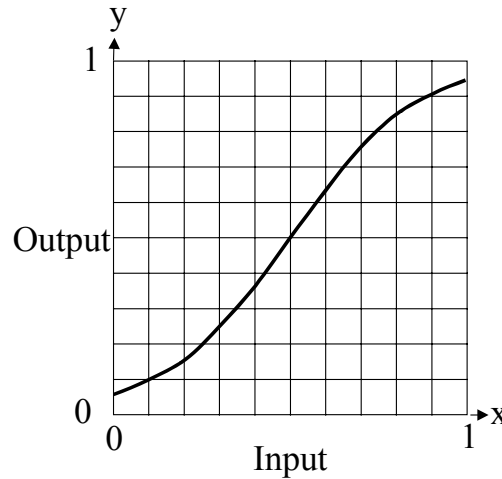


Figure 17. Soft Aggregation Response

Analysis Architecture. The overall Markov architecture is structured in two parts, corresponding to the two most significant decompositions used; one is risk-oriented, following the Markov latent effects structure; the other is performance-oriented, following the IDEF0 structure. This is because in any safety system, there are two major concerns: 1) “Is there adherence to the functional requirements (i.e., regulations, rules)?” and 2) “Is there a cultural commitment to safety that transcends requirements?”. The

assessment “grades” for each of these considerations are combined in a soft-aggregation weighted sum (details to be discussed in a later section). The architecture and the weights for the combination are shown in Fig. 18. No inputs or any other weights are shown in the figure, because these are given in the subsequent breakdown figures. The individual modules in the “Risk” category correspond to the seven risk “Factors” identified in the ASRATS project. These are grouped in the figure according to the three basic Markov categories. The modules in the “Performance” category correspond to the six performance Factors identified in the ASRATS project. These are grouped in the figure according to the five basic IDEF0 categories. The architecture shown depicts the most significant latent effects paths identified.

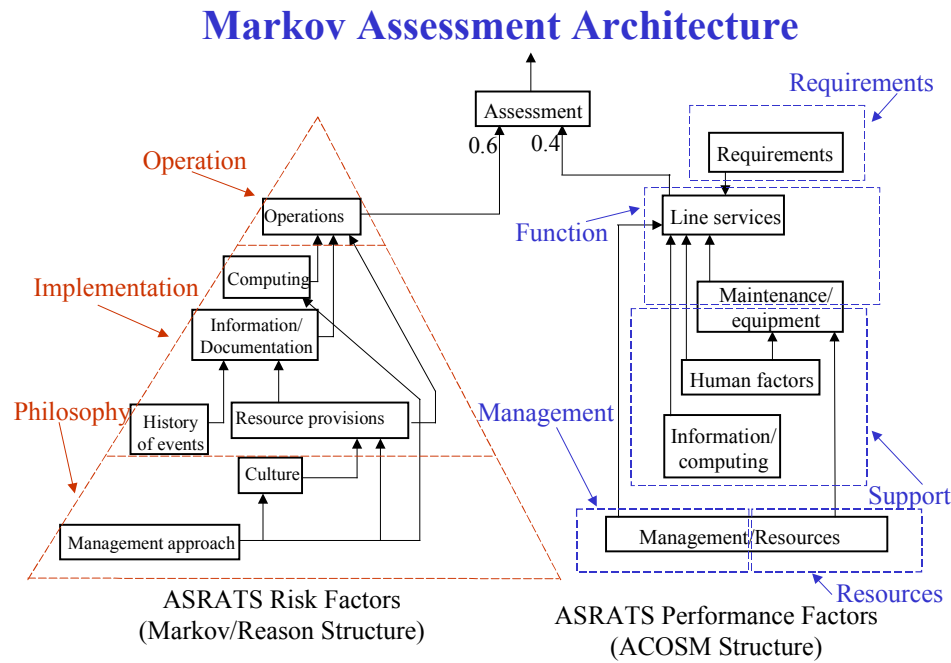


Figure 18. Overall Markov Architecture

Risk Culture. The structural breakdown for Risk Culture is shown in Fig. 19. Note that all of the pertinent inputs are shown. Also shown are groups of dependent inputs, with an indication of the assumed degree of independence ($d = 0$ would represent independence; $d = 1$ would represent complete dependence). Most of the inputs shown are equivalent to ASRATS “Characteristics;” in two cases the module inputs are at the Sub-Characteristic level.

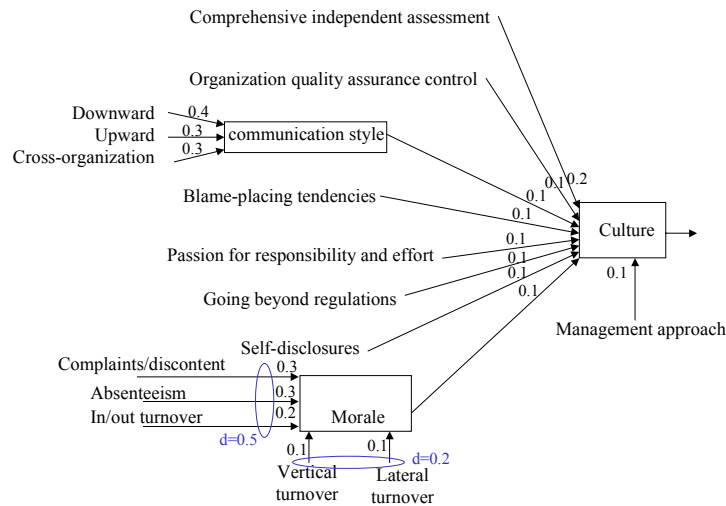


Figure 19. Risk Culture Breakdown

Risk Management Approach. Figure 20 shows the breakdown for the Risk Management Approach. This completely defines the inputs necessary for this module. Note that there are latent effects connections shown in addition to inputs and dependence.

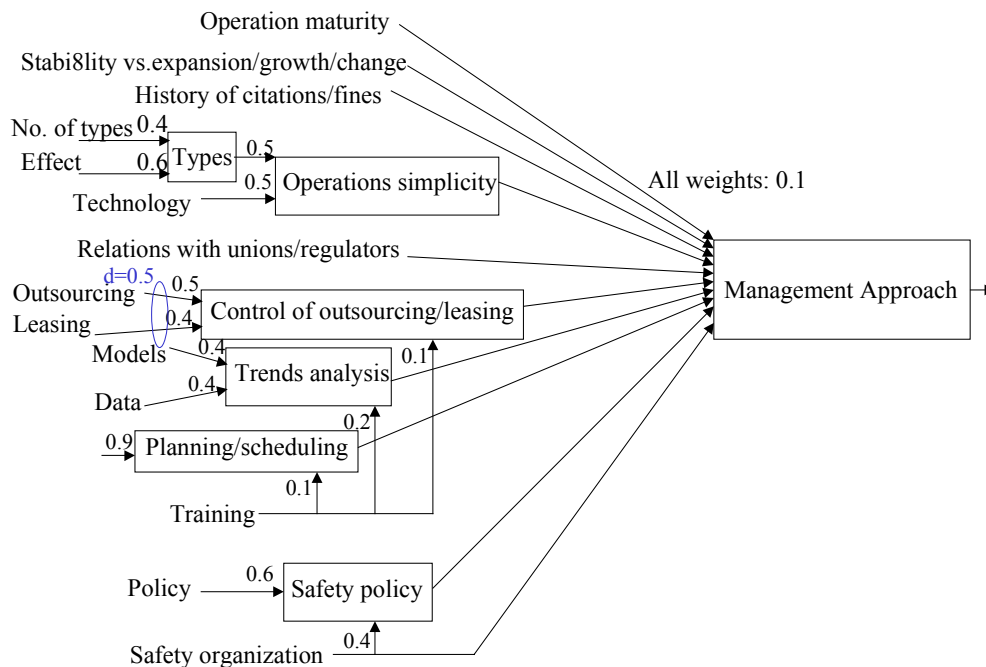


Figure 20. Risk Management Approach Breakdown

Risk Resource Provisions. Figure 21 shows the breakdown for Risk Resource Provisions. Note the dependence between the two latent effects (secondary) inputs.

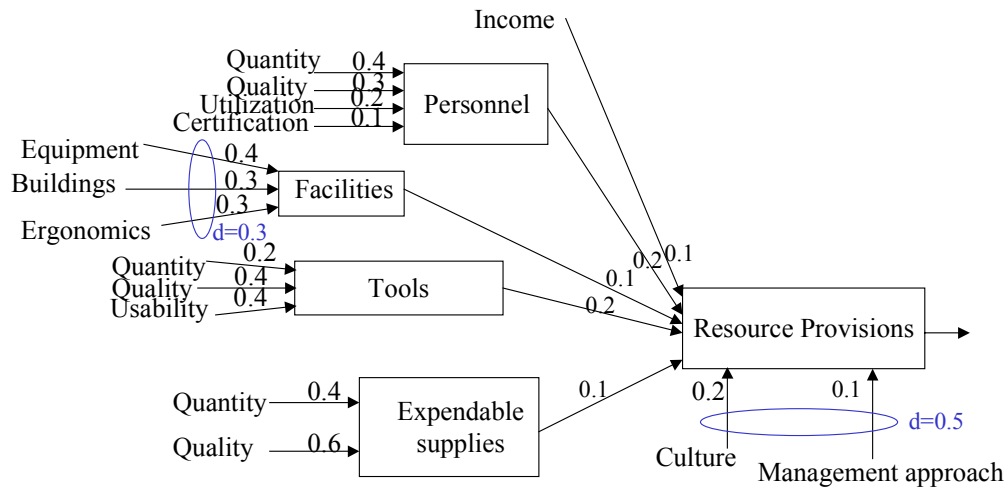


Figure 21. Risk Resource Provisions Breakdown

Risk Information/Documentation. Fig. 22 shows the breakdown for Risk Information/Documentation.

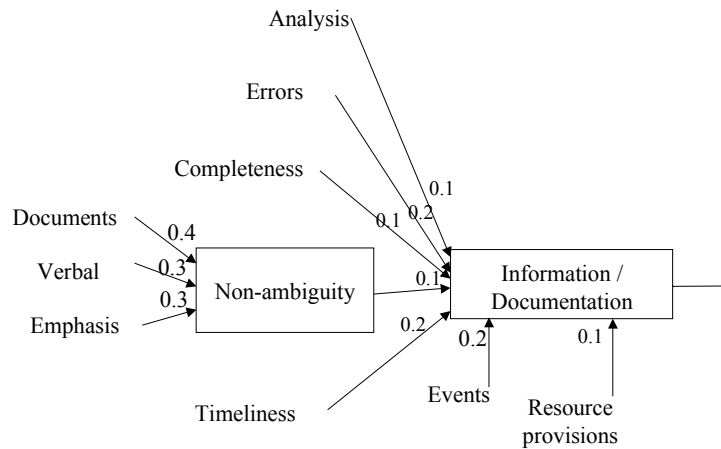


Figure 22. Risk Information/Documentation Breakdown

Risk Operations. Fig. 23 shows the details of the Risk Operations breakdown. Here there are inputs at the Sub-Characteristic level.

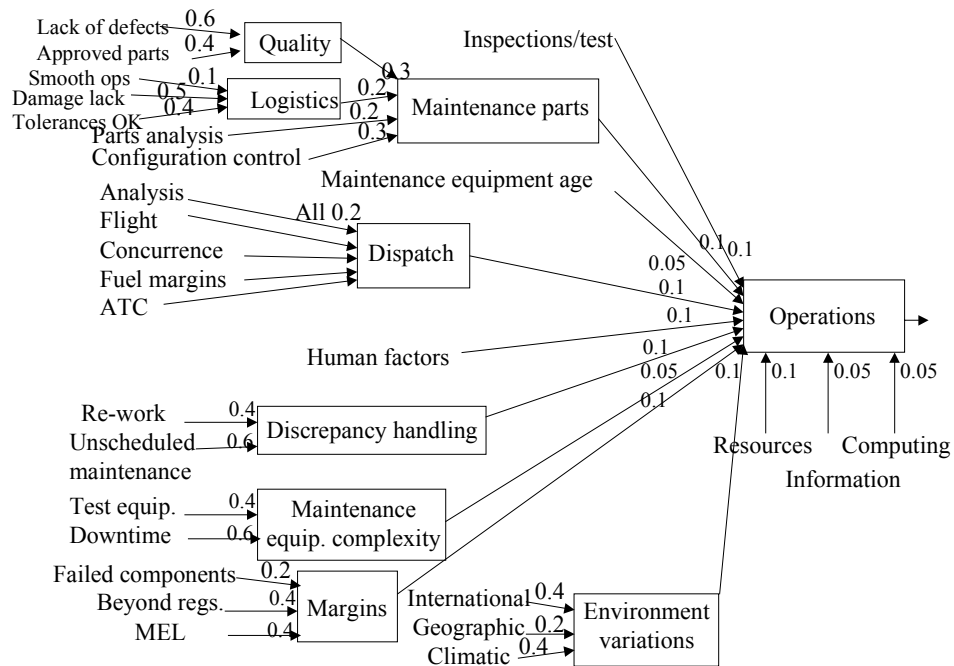


Figure 23. Risk Operations Breakdown

Risk History of Events. Fig. 24 shows the breakdown for Risk History of Events. Note that all inputs are positive, i.e., lack of events helps the safety assessment score.

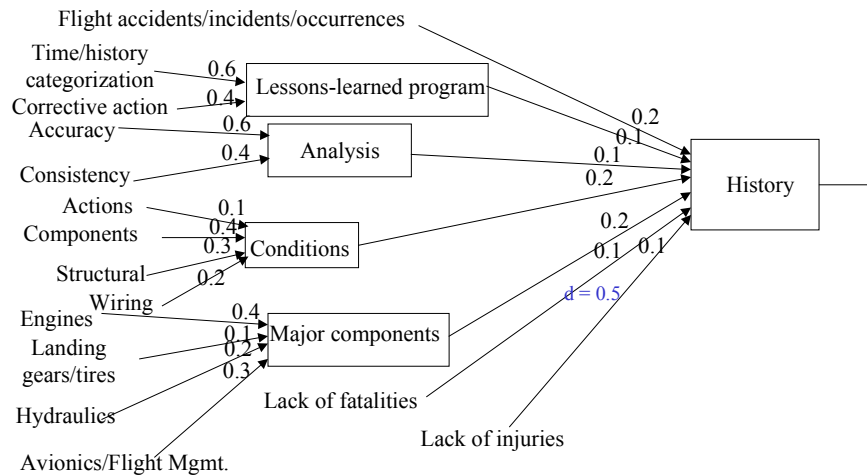


Figure 24. Risk History of Events Breakdown

Risk Computing. Fig. 25 shows the Risk Computing breakdown.

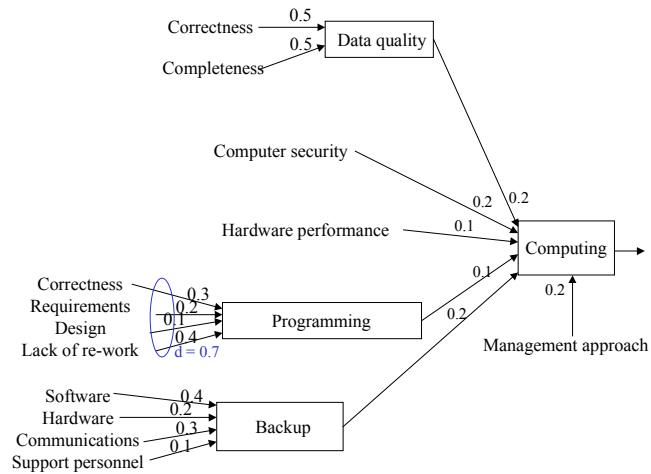


Figure 25. Risk Computing Breakdown

Performance Line Services. Fig. 26 shows the Performance Line Services breakdown.

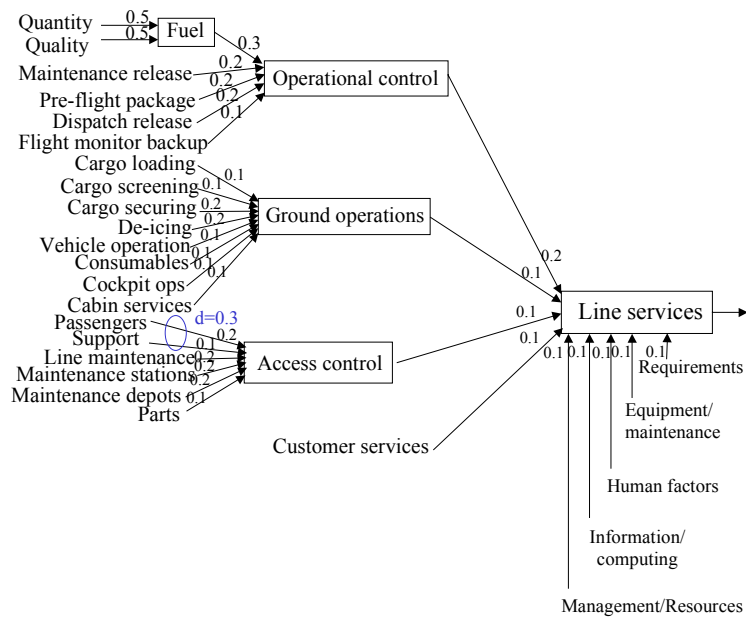


Figure 26. Performance Line Services Breakdown

Performance Human Factors. Fig. 27 shows the Performance Human Factors Breakdown. All of the Performance inputs relate to requirements (e.g., regulations, laws, policies).

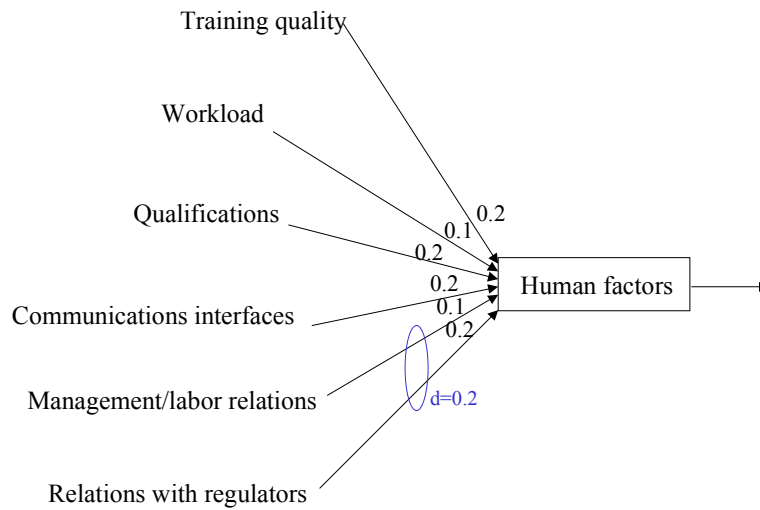


Figure 27. Performance Human Factors Breakdown

Performance Information/Computing.

Fig. 28 shows the Performance

Information/Computing Breakdown.

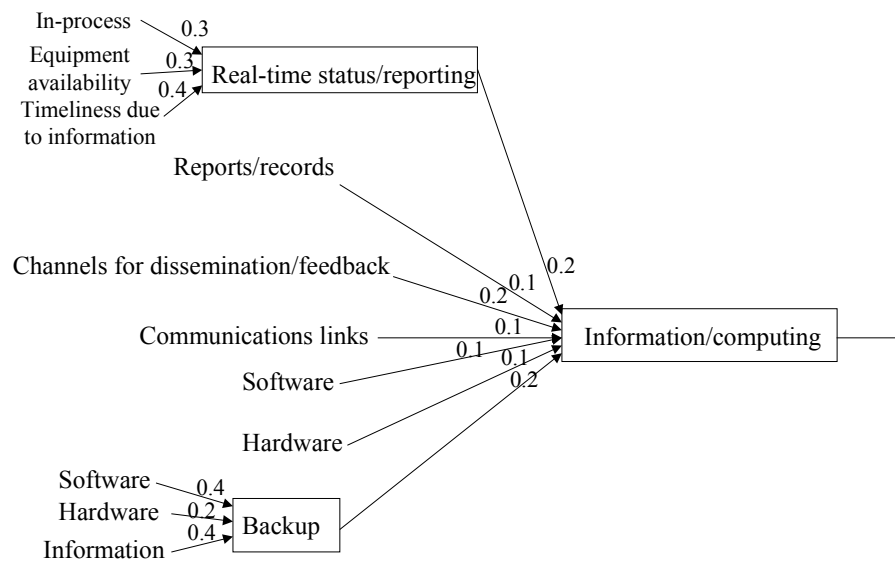


Figure 28. Performance Information/Computing Breakdown

Performance Equipment/Maintenance.

Fig. 29 shows the Performance

Equipment/Maintenance breakdown.

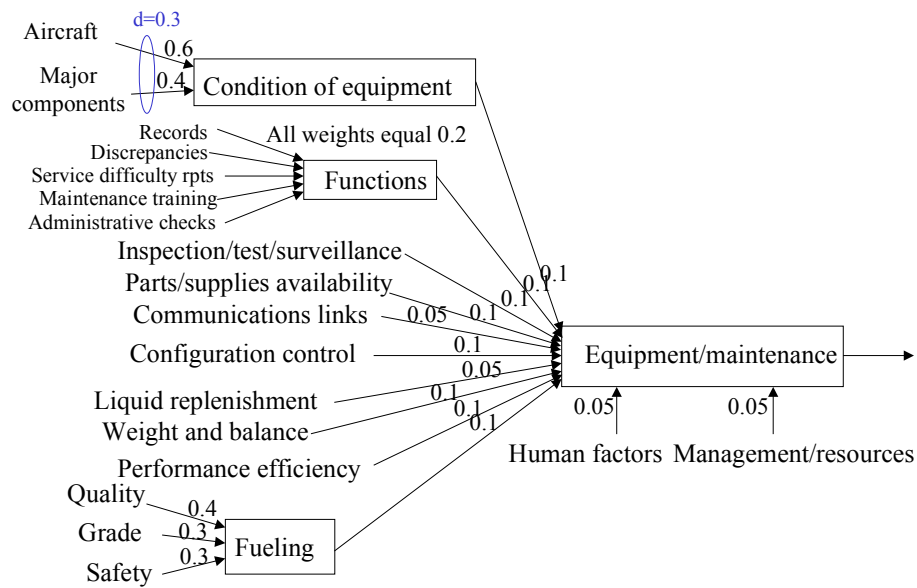


Figure 29. Performance Equipment/Maintenance Breakdown

Performance Management/Resources.

Fig. 30 shows the Performance

Management/Resources Breakdown.

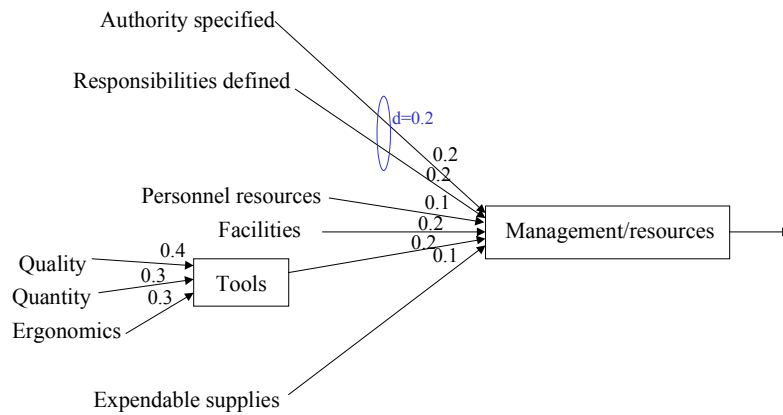


Figure 30. Performance Management/Resources Breakdown

Performance Requirements. Fig. 31 shows the Performance Requirements breakdown.

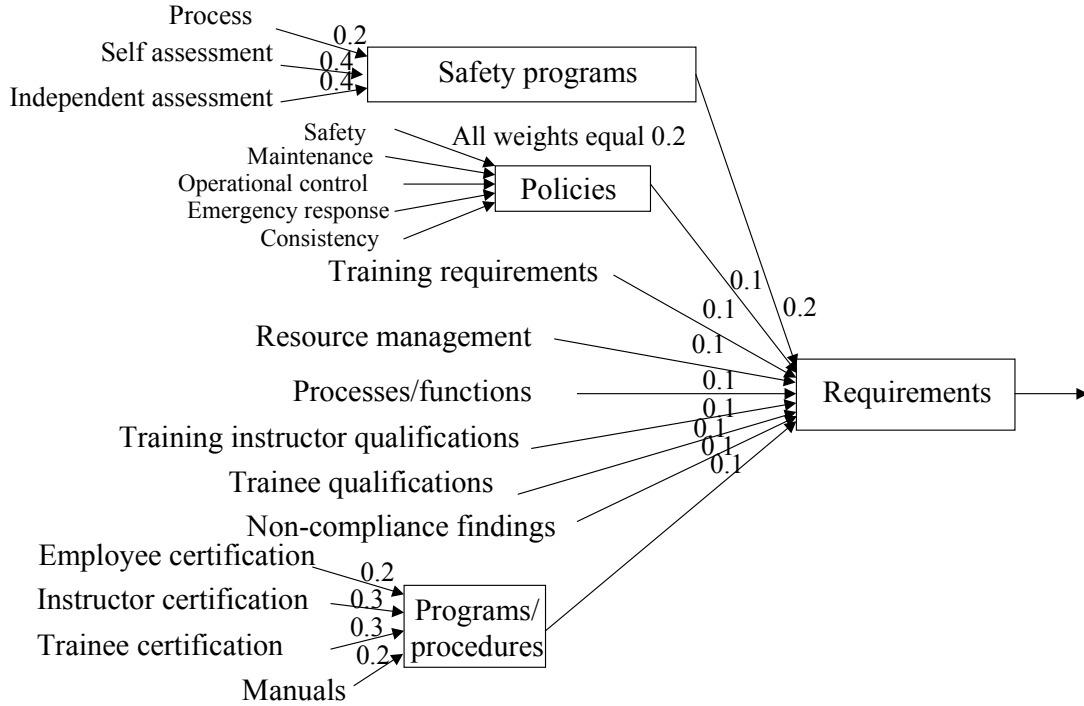


Figure 31. Performance Requirements Breakdown

Dependence Methodology

Accounting for dependence is important, because it is very difficult to find independent parameters contributing to an overall assessment. The 1998 Markov architecture had a bi-valued computation because of the use of positive and negative assessment variables. The new architecture has only positive variables. As before, dependence among any group (i) of variables can be specified by a parameter d_i , where $d_i = 0$ signifies complete independence and $d_i = 1$ specifies complete dependence, and any value in between these extremes may be entered. The dependence parameter is used as a ratio between the score that would be obtained by crediting only the minimum assessment score and the count that would be obtained by crediting the sum of all scores. This is defined for the weighted sum of each group of dependent variables in Eq. 2.

$$\sum_{j=1}^r x_j w_j \Leftarrow (1 - d) \sum_{j=1}^r x_j w_j + dx_{\min} \sum_{j=1}^r w_j \quad (2)$$

where $\sum_{j=1}^r x_j w_j$ represents the independent calculation for the weighted sum of the group dependent inputs, \Leftarrow means “is replaced by,” d is the dependence parameter for the group, and x_{\min} is the minimum input in the group. This has the effect of reducing the credit given for a group of dependent inputs in all cases except that for which all inputs are equal. The reduction could have been made applicable to all cases. However, since there is already some reduction in credit for multiple inputs because of the limit on how much weight can be associated with each input (more inputs to a module must share the same total weight), the model given by Eq. 2 was chosen.

A catalog of the complete collection of mathematical equations implemented in software for soft aggregation and dependence is given in Appendix D.

Sigmoid Decision Threshold

There is a temptation to treat thresholds of concern, such as probabilistic safety requirements, as firm, whereas their source of derivation is not firm. For example, if there is a requirement that a system must maintain safety from catastrophic failure to a probability of one in a million, the implication is that an analysis that derived a system safety measure of 1×10^{-6} would be indicative of a satisfactory system (meets the requirement) and an analysis that derived a system safety measure of 1.1×10^{-6} would be indicative of an unsatisfactory system (fails to meet the requirement).

In order to more realistically portray the comparison of information aggregation with a threshold of concern, a mathematically constructed non-abrupt transition was developed. This function is termed a “sigmoid,” and is expressed with an exponential constituent so that the abscissa value transitions gradually from zero to one as the ordinate value, f , increases through a decision threshold, with the transition rate determined by a constant, q . Figure 32 shows an application of this approach.

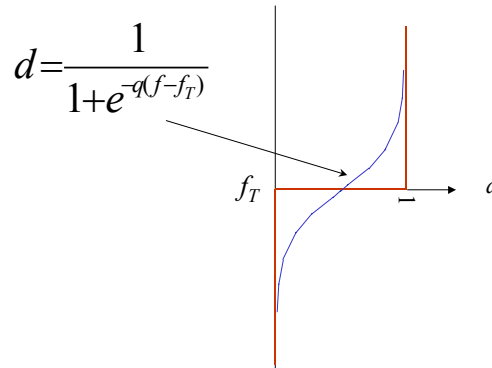


Figure 32. Sigmoid Decision Transition Function

The sigmoid transition has the same effect as if a “warning light” were turned on gradually, rather than abruptly. This approach, which emphasizes soft transitions rather than abrupt was basic to the entire Markov project [Ref. 7].

Early Alerts Computation

Logic for Early Alerts is in terms of logical “ands” and “ors,” where the hierarchy of multiple operations is conventional (ands performed before ors when not overridden by parentheses). This allows for logical combination of assessment scores and module scores. The sense of the Early Alert inputs is inverse to that of the basic Markov inputs, because early alerts are intended to reflect proactive concern for potential developing problems, while Markov inputs are intended to measure credit to the system safety posture. For this reason, although Early Alert inputs are derived from the same set as Markov inputs, they are inverted by subtracting the entered value from one. This also causes the upper and lower bounds to invert. The combinational algebra of ands and ors is derived from basic propositional logic, where & is used to signify and, and | is used to signify or. The computation is according to basic min/max rules. That is:

$$X \& Y = \min(X, Y) \quad (3)$$

$$X | Y = \max(X, Y) \quad (4)$$

The expressions currently being used are shown below to illustrate the form Early Alerts can have.

$$\begin{aligned} E_1 (\text{Flight preparation}) &= x_{93} | x_{95} | x_{110} | x_{112} | x_{113} \\ E_2 (\text{Maintenance readiness}) &= x_{48} | x_{86} | x_{87} \\ E_3 (\text{Training posture}) &= x_9 \& (x_{76} | x_{78} | x_{86}) \\ E_4 (\text{Regulatory relations}) &= x_{81} \& (x_3 | x_{103}) \\ E_5 (\text{Personnel commitment}) &= y_2 \& (x_{14} | x_{16} | x_{17} | x_{19}) \\ E_6 (\text{Process control}) &= x_6 | x_7 | x_{12} | x_{21} | x_{24} \end{aligned} \quad (5)$$

There can be secondary inputs (module outputs) as well as primary inputs in the equation, as exemplified by the y_2 input into the E_5 early alert.

Trends, Cycles, and Filtering

Database capture allows tracking the results of system assessment, module (subsystem) outputs, and Early Alerts over time. If done consistently, this allows creating information on trends, cycles (e.g., seasonal and other variations unrelated to safety scores), and filtering (reducing variations due to human inconsistencies).

Trends. Static assessments need to be supplemented by multiple assessments over time, from which trends can be derived. The Markov inputs are stored in a database, so that historic information can be plotted to show trends over time. The process is also used

both for the overall result output, and for each subsystem output, as well as for Early Alerts.

An example trends plot is shown in Fig. 33. In the figure, the quantitative representation of a particular input (or output) is tracked over a period of time, during which multiple assessments are made. As is typical of such plots, there is some cyclic response and “noise” on the plot as trends develop. Also indicated (by the vertical spread, signifying interval uncertainty) is the uncertainty due to subjectively derived evaluations.

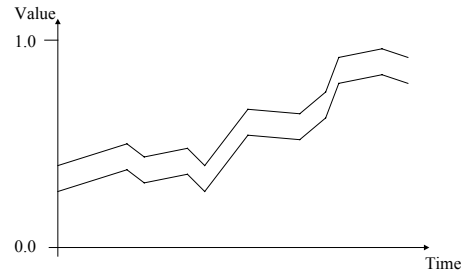


Figure 33. Example Trends Plot with Uncertainty

Cycles and Filtering. Filtering variations due to variance between individuals and variance from time to time for a particular individual can be helpful in suppressing “noise” surrounding desired information. It must be done very carefully, however, to prevent altering the information. Methodology incorporated in the FORTRAN implementation of the Markov Tool replaces a “window” containing a time series of points (inputs or outputs) with an average of points within the window, which is then plotted at the time mid-point of the window. The size of the window in time is specified, thereby controlling the amount of filtering. The time slip of the window position is also specified, thereby controlling the frequency of points plotted in the filtered collection. More specifically, for n data points (y_1, y_2, \dots, y_n) encompassed by a window of width

Δt , centered on t_1 , $\sum_{i=1}^n y_i / n$ is plotted at t_1 . The next plotted point will be at $t_1 + k$, where

Δt and k are the filtering parameters. Figure 34 shows an example of an unfiltered trend plot overlaid with a filtered trend plot.

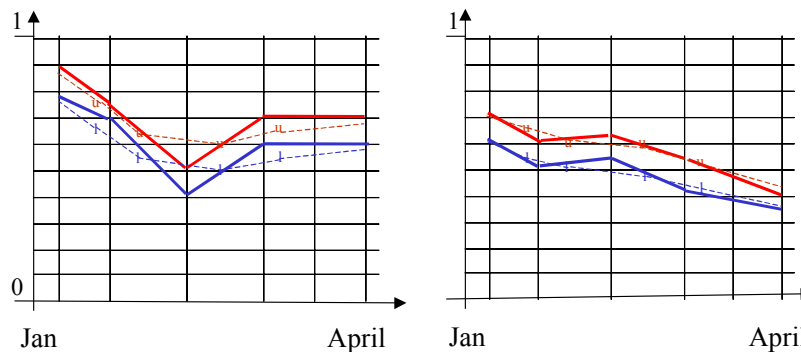


Figure 34. Effect of Filtering on Trends Plots

The solid lines show the raw data (upper and lower bounds); the dashed lines show the filtered data. The window size Δt was one month and the window was repositioned at half-month intervals (k).

Once filtered data are obtained, cycle removal may be desirable. This was discussed conceptually in Ref. 4, but the basic idea is outlined mathematically here. An identified cycle that must be removed to eliminate interference with the information sought is of the form $c(t) = m \sin(\omega t + \phi)$. The parameters m , ω , and ϕ can be identified from the cyclic behavior. Then $c(t)$ can be removed from the raw signal, $r(t)$, to give a processed signal, $p(t)$. This is specified mathematically as:

$$p(t) = r(t) - c(t) \quad (6)$$

Primary Importance and Sensitivity

Among the investigative features incorporated in the Markov Tool are the Importance and Sensitivity metrics associated with each input. When there are aggregated values that cause concern, Sensitivity is one of the features that enables one to look at the most significant contributors to that concern. When there are aggregated values that demonstrate success, Importance is one of the features that enables one to look at the most significant contributors to that success.

A useful analogy is to consider the various inputs as corresponding to leaves on a plant using chlorophyll to convert light energy to chemical energy as part of the nutrient process. All of the leaves contribute, but potentially in varying degrees. Furthermore, the contribution is not direct, but is delivered through a complex branching system in the plant structure. In order to find out which leaves contribute the most delivery through this structure-dependent aggregation process, something analogous to an Importance measure would be needed. In order to reveal the greatest potential for improvement, something analogous to a Sensitivity measure would be needed. This is the role of Importance and Sensitivity metrics.

The Importance and Sensitivity computations differ slightly from the 1998 Markov methodology. The changes were made for logical simplification (see Eqs. 7 and 8). The importance for an input measures the contribution of that input to the total result. This is computed by deriving the difference between the output value with the input as entered and the output value that would have been obtained if the input value had been zero. Where the input value is entered as uncertain over a range, the average value is used. Mathematically, the importance computation can be represented as:

$$I_n = O(i_n = \text{entered}, \dots) - O(i_n = 0, \dots) \quad (7)$$

where I_n is the importance measure for the input i_n , O is the output as a function of all of the inputs, $i_n = \text{entered}$ is the entered value for the input under consideration, and $i_n = 0$

is the input as if there had been a zero value entered. Importance values allow ranking the inputs in terms of their contribution to the overall output.

The sensitivity for an input measures the potential for that input to be improved with a resultant improvement in the total result. This is computed by deriving the difference between the output value with the input as entered and the output value that would have been obtained if the input value had been one (the maximum value). Where the input value is entered as uncertain over a range, the average value is used. Mathematically, the sensitivity computation can be represented as:

$$S = O(i_n = \text{entered}, \dots) - O(i_n = 1, \dots) \quad (8)$$

The Importance and Sensitivity measures allow ranking all inputs by Importance and to also rank them by Sensitivity. This is a form of prioritization on what the most productive inputs might be for investigation.

Secondary Importance and Sensitivity

During simulation studies (see Appendix C), it was found to be useful to add Secondary Importance and Sensitivity measures to the Markov Tool capabilities in order to trace back from a result to the most likely module root causes of that result. Following the plant analogy, this corresponds to starting at the plant root and tracing back initially to determine which branches deliver the most important nutrients and which could be most improved.

The difference between a secondary input and a primary input is that a secondary input is computed as the output from one module and becomes an input to another module. The following nomenclature uses secondary inputs to be general, but it is possible that some inputs to a module will be primary inputs. These latter will be treated in the same way as secondary inputs for the Secondary Importance and Sensitivity. In order to help the trace-back activity, the Secondary Importance is computed as:

$$I_s = O(y_n = \text{computed}, \dots) - O(y_n = 0, \dots) \quad (9)$$

where I_s is the Secondary Importance measure, O is the output as a function of all of the inputs, $y_n = \text{computed}$ is the computed value for the secondary input under consideration, and $y_n = 0$ is the input with a zero value computed.

$$S_s = O(y_n = \text{computed}, \dots) - O(y_n = 1, \dots) \quad (10)$$

The Secondary Importance and Secondary Sensitivity measures allow ranking secondary inputs by Importance and to also rank them by Sensitivity. This is a form of prioritization on what the most productive paths in the aggregation process are for investigation.

Conclusions

The non-traditional Markov model described in this report is especially useful in system safety analysis and decision support, because of its top-down perspective; the ability to track latent effects, cycles, and trends; its soft aggregation and dependence capabilities; and its portrayal of Early Alerts, Importance, and Sensitivity. Other attributes are the ability to mesh information derived about the inputs as well as the outputs with lessons-learned and root-cause-analysis functions. Another benefit is the straightforward software implementation, which has been demonstrated in various forums.

There is a description of how to make safety relevant decompositions that maintain a coordinated top-down system association, how this can help determine measurable parameters, and how these can be aggregated to provide support for defensible decision-making. The structure of the methodology is strategic, in that it follows the four-phase “DIAL” approach. The decompositions used are comprehensive, including a risk decomposition (latent effects) and a functional decomposition (IDEF0). The Latent Effects decomposition leads mainly to indicators of risk; these and the functional decomposition determine requirements measures. As gathered data are aggregated, there are also two analysis paths; one following the risk approach and one following the functional approach. Eventually, all of the analysis blocks are combined into a single hybrid analysis tool.

The types of decisions that must be made (involving surveillance allocation, response to risk alerts, certification, and certificate management) can be supported by a decision-aid analysis process, which can contribute to more defensible decisions.

Many of these techniques have been successfully applied to a variety of situations in weapons safety, air transportation safety, and rail transportation safety. The approaches that are described have significant advantages over more conventional approaches (such as more realistic portrayal of extremes and the inclusion of organizational factors), and therefore provide a viable methodology for use in high consequence system safety analysis.

Future Directions

Although a useful analysis tool has been developed, there are several activities that can contribute to the confidence in and usefulness of the methodology. The need to validate the Markov Model, the functional model, and PMs/RIs developed for ASRATS is recognized. Validation would ensure that the measures, and the way they are aggregated, actually do represent the level of safety state of health present in the organization. Validation of the models could occur through pilot testing, subject matter expert review, and comparison of ASRATS results with other safety metrics. To this point, the Markov project has concentrated on developing generic models and metrics. However, comprehensive implementation of the system would require that the metrics be customized to match each of the specific organizations in which it would be used.

It is useful for the outputs from the Markov analysis methodologies to feed into a comprehensive decision aid analysis. This would assist in making wise (correct) decisions for day-to-day operations, as well as decisions concerning abnormal or unexpected situations.

To facilitate the introduction of the Markov Tool into a surveillance program, it would be useful to coordinate with the people responsible for training, guidance concerning necessary database details for maintaining records of the data gathered, the data analyzed and the results. There will need to be further coordinated human factors studies/recommendations for implementation. Incorporation of additional decompositions could be appropriate.

A simulation project would support the Markov objectives by helping to demonstrate the properties of the analysis through Monte Carlo simulation, using a strategy based on experimental design methodology for improving the efficiency of the project activities. The Monte Carlo simulation needed requires an automated, accurate, and efficient routine. We already have such a routine (LHS) that can be adapted for generating Markov inputs. Each of 119 inputs would be provided 10,000 samples from one of the 45 distributions available in LHS (probably a bounded normal distribution). The size of the memory required for each run would necessitate implementing a dynamic memory switch. There would also be various quality checks instituted to assure that the developed program provides a highly accurate, bug-free implementation.

The simulation would utilize the following four phases: 1) A variance simulation would be done to relate input variability to output variability. This is intended to show how variations in inputs, such as might be the result of inspector uncertainty or variation in judgment from inspector to inspector (even using the same input guidance), map to output variation. The expectation is that variations will have a counter-intuitive cancellation tendency, as opposed to a more cumulative effect. 2) A test of the relation between Importance measures indicated by the Markov analysis, and actual variations in the values of the inputs (e.g., mean and variance) would be made. Possible options are to fix other inputs, while using probability distributions for the inputs under investigation, and/or to use variations described by distributions. We would also track the direction of greatest response of the output variance as a function of uniform increases in input variance. This would give a strong indicator of the value of Importance. 3) A test of the relation between Sensitivity measures indicated by the Markov analysis, and actual variations in the values of the inputs (e.g., mean and variance). This would be similar to the Importance investigation, but would involve examination of problem areas, as opposed to good practices. 4) A test of the relation between Early Alerts indicated by the Markov analysis, and actual variations in the values of the inputs (e.g., mean and variance). All four of these phases would follow a strategy developed under an experiment design approach for optimizing efficiency of the available time and resources.

Another important capability would be methodology for automating the process of converting inspection observations into data that can be automatically communicated to

the host computer used for the Markov Tool. The first phase would emphasize methodology for mode of entry of data gathered by inspection personnel into a device capable of accepting entries in a usable manner, storing the data in an organized form, and formatting it for transfer to a Web site where the Markov Tool resides. The pertinent considerations are the goals of the Markov data entry/transfer (e.g., Markov aggregation guidance, uncertainty, input descriptors, data/time/location capture, wireless or direct Web connection, etc.), usability¹ (environmental ruggedness, lighting restrictions, portability/pocket storage, etc.), and cost-effectiveness. A proof-of-principle demonstration would be made. Another need is to develop methodology or methodologies for transferring data from the entry device to the Web site where the Markov Tool resides. A study would include direct communication through Web-connected computers and wireless transmission. A proof-of-principle demonstration would be made. Since wireless transmission from within shielded areas² (such as hangars or buildings having extensive steel support structures) is dependent on location within the area, transmission enhancement must be considered. This can be done by incorporating translators or repeaters that provide external transmission of internally generated emanations. The methodology for accomplishing this should be investigated, with emphasis on cost-effectiveness of the desired performance enhancement. A proof-of-principle demonstration would be made.

An effort is also needed to develop methodology for facilitating the process of changing the architecture (modules, inputs, weights, interconnections, dependence, Early Alerts, and descriptive information) for the Markov Tool. The control of authorization for making changes would utilize an extension of the security methodology previously developed for the Markov Tool. The emphasis would be shifted to the identification of the persons who are permitted to make changes (e.g., analysts), rather than the persons who are permitted to make entries. The considerations are compatibility with the Web-based implementation of the Markov Tool and Windows-based menus and insertion/deletion capabilities. There is also intent to develop Windows-based methodology for making changes (in modules, inputs, weights, interconnections, dependence, Early Alerts, and descriptive information). There would also be methodology for capturing the date at which changes were introduced, which would be carried into the trends database. Since conflicts in user-entered changes are a potential hazard to the quality of the Markov Tool program, it is essential to include comprehensive checks that identify potential conflicts, advise the user of the problem, and facilitate correct resolution. There is intent to develop methodologies for providing checks and information to the user in an efficient and understandable manner.

The evaluation of the methodology obtained so far is discussed in Appendix E. Further and more comprehensive evaluation is needed.

¹ This addresses only capability. Selling users on the concept is another (out-of-scope) problem.

² This addresses only the capability for wireless transmission, not how it can be sold to potential users. For example, there might be reasons that the owner of a particular shielded area might not allow wireless transmission. Enhancing the ability to transmit Markov information enhances the ability to transmit other information. There could be operational or industrial information security issues.

References

1. Reason, James, *Managing the Risks of Organizational Accidents*, Ashgate, 1997
2. Long, R. L., and V. S. Briant, "Vigilance Required: Lessons for Creating a Strong Nuclear Culture," *Journal of System Safety*, Q4 1999
3. Schwoebel, Richard L., *Explosion Aboard the Iowa*, Naval Institute Press, 1999
4. Cooper, J. A., "Markov Modeling with Soft Aggregation for Safety and Decision Analysis," Sandia National Laboratories Report SAND99-2461, September 1999
5. Feller, William, *An Introduction to Probability Theory and its Applications*, John Wiley & Sons, 1957
6. O'Sullivan, David, *Manufacturing Systems Redesign: Creating the Integrated Manufacturing Environment*, Prentice-Hall 1994
7. Sandia National Laboratories Patent Application, SD-6449/S-92,433: *Latent Effects Decision Analysis*, Paul W. Werner and J. Arlin Cooper, September 25, 1999
8. Cooper, J. A., Invited Paper: "Decision Analysis for Transportation Risk Management," *Proceedings of the 2001 European Safety and Reliability Conference*, September 2001
9. Cooper, J. A., A. J. Johnson, and P. Werner, "Hybrid Safety Analysis Using Functional and Risk Decompositions," *Proceedings of the 2000 International System Safety Conference*, September 2000
10. Cooper, J. A., "Markov Modeling with Soft Aggregation for Safety and Decision Analysis," *Proceedings of the European Safety and Reliability Conference, Foresight and Precaution*, Balkema/Rotterdam/Brookfield Publishers, May 2000
11. Cooper, J. A., S. Ferson, and D. K. Cooper, "Constrained Mathematics for Calculating Logical Safety and Reliability Probabilities with Uncertain Inputs," *Journal of System Safety*: Vol. 36, No. 1, January 2000
12. Cooper, J. A., "Constrained Mathematics Evaluation in Probabilistic Logic Analysis," *Reliability Engineering and System Safety Journal*, Vol. 60, No. 3, June 1998
13. Cooper, J. A., "Hybrid Safety Analysis Using Subjective and Objective Components," *Proceedings of the 2001 Information Processing for Mining and Materials Conference*, July 2001
14. Cooper, J. A., "Hybrid Mathematics Aid for Safety-Relevant Decisions," *Proceedings of the 2001 European Safety and Reliability Conference*, September 2001

Glossary

DOs (Data Objects): Specific measurements that are derived from Performance Measures and Risk Indicators and that can be made by oversight personnel (usually quantitative or multiple choice, but potentially qualitative).

Factors: A categorization of metrics as applied to a high level (first level of decomposition) of the system.

Hybrid Analysis: This term describes combining analyses of various types (e.g., soft aggregation and propositional logic) for one purpose (e.g., making a decision).

Markov Latent Effects Model: A system model that can be used for cause and effect illumination, root cause analysis, and safety analysis. It is based on a concept wherein the causes for inadvertent operational actions are traced back through latent effects to the possible reasons undesirable events may have occurred. The approach is described in detail in Ref. 4. The Markov Latent Effects Model differs substantially from Markov processes, where events do not depend explicitly on past history, and Markov chains of arbitrary order, where dependence on past history is completely probabilistic.

Metrics: A data measurement that can be the beginning point of a process for converting data to information by using analysis.

PMs (Performance Measures): Measurable characteristics of a system pertaining to how it is intended to operate to meet safety requirements (FARs, laws, company policy and regulations).

RIs (Risk Indicators): Measurable characteristics of a system pertaining to safety concerns that are not explicitly related to requirements. These have a statistical correlation to safety.

Sigmoid: This is a mathematical non-abrupt depiction of passing through a “threshold” (decision-relevant) region.

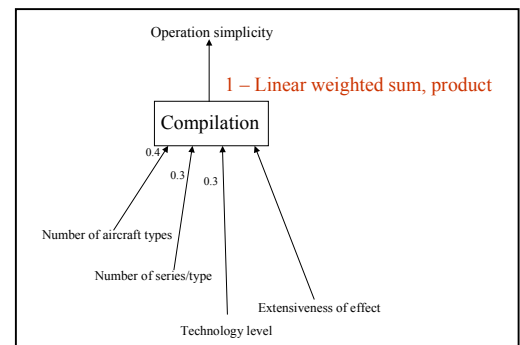
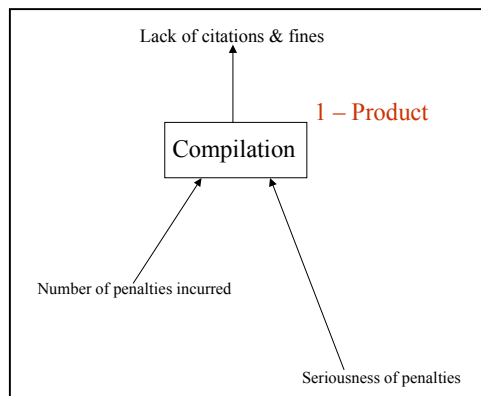
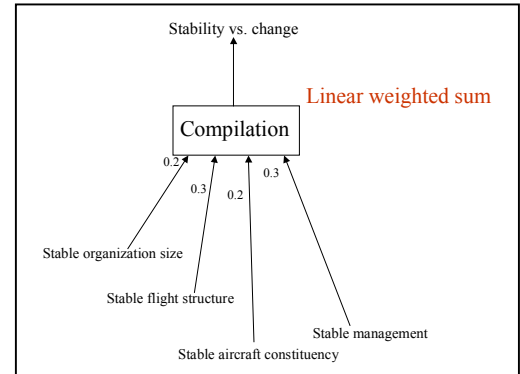
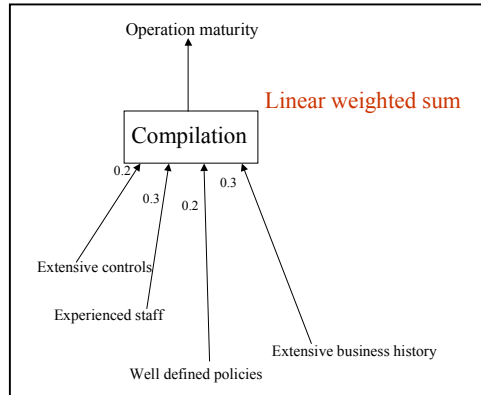
Soft Aggregation: A mathematical accumulation of evidence about an attribute that is nonlinearly accumulated so as to prevent reaching a limiting value.

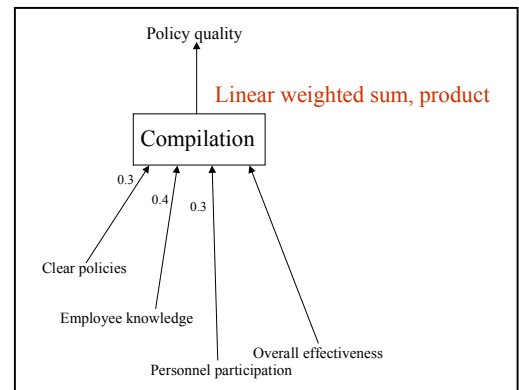
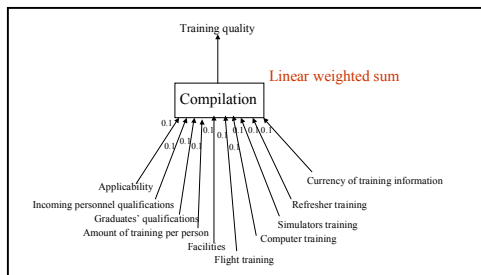
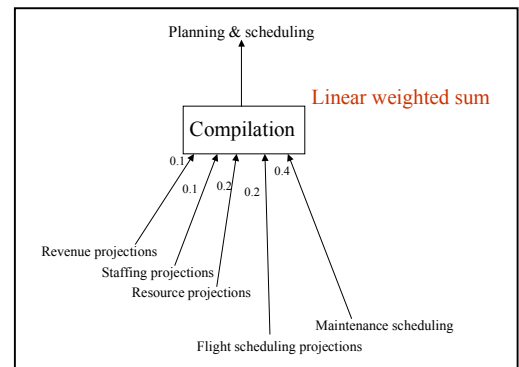
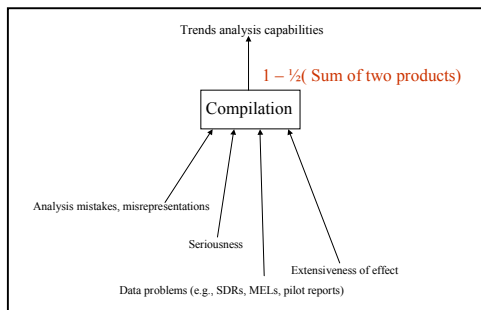
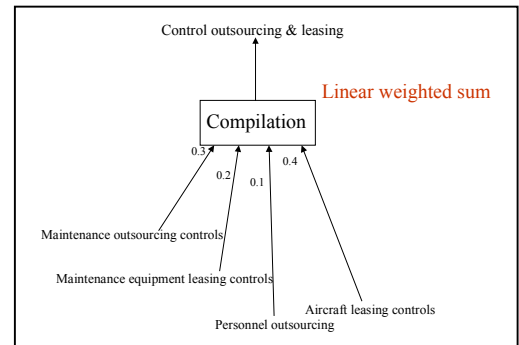
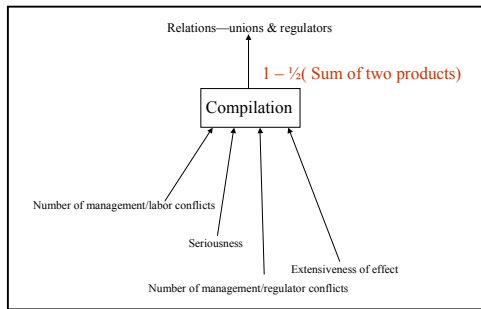
System: An interacting collection of entities intended to achieve a common goal.

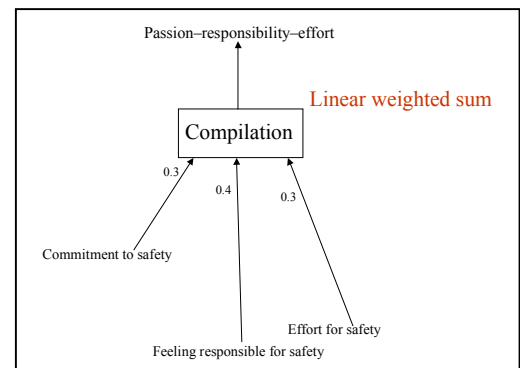
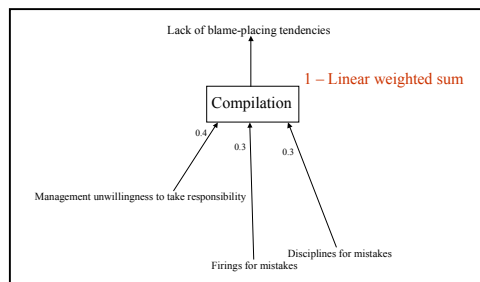
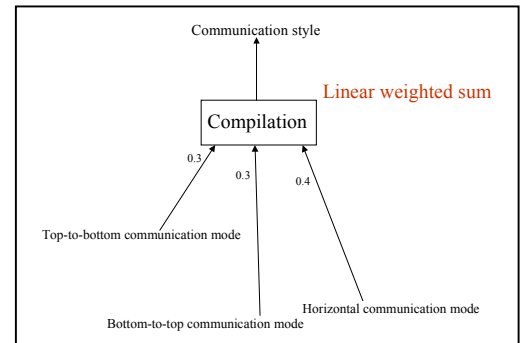
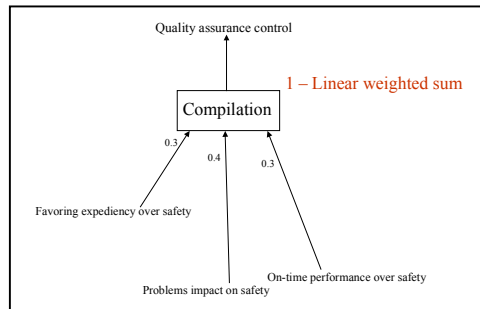
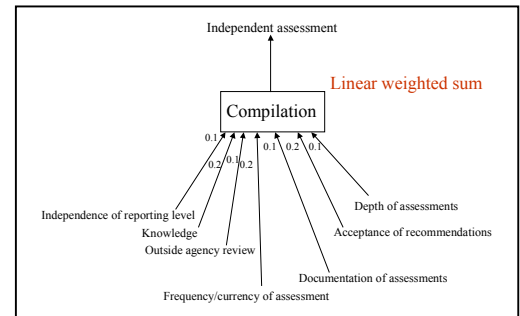
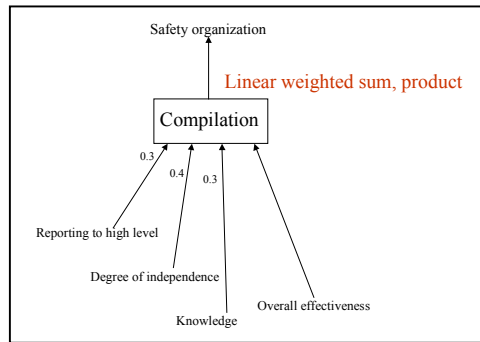
Appendix A: Pre-Aggregation for Markov Inputs

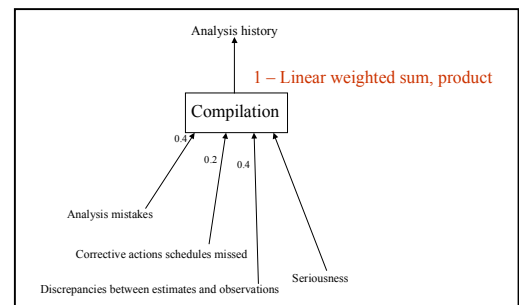
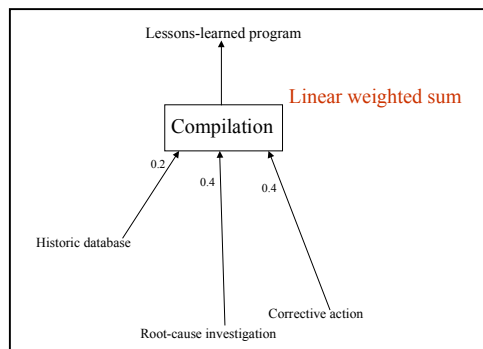
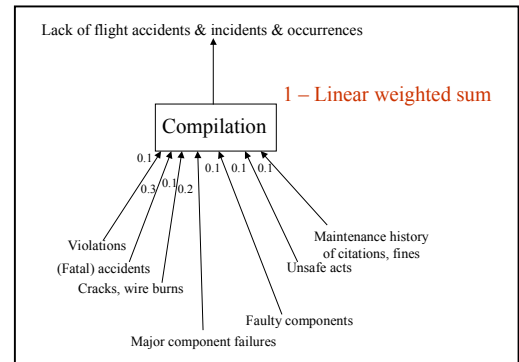
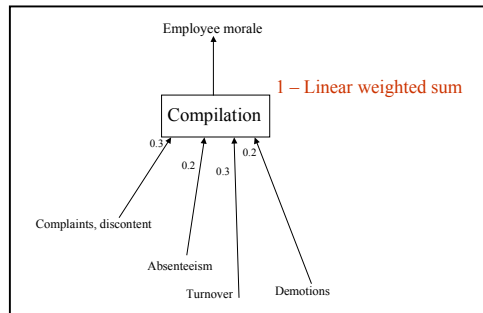
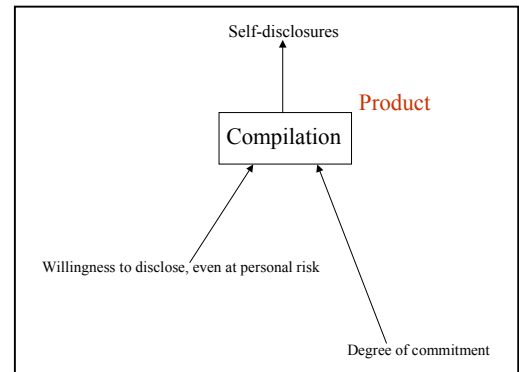
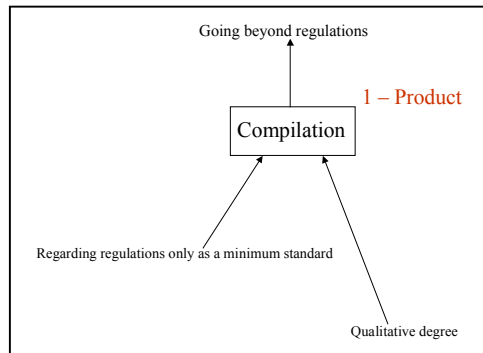
Although there are 119 inputs to the Markov Tool, the input descriptions are still broad enough that some users, particularly when first becoming familiar with the tool, will need additional guidance. To this end, aggregation guidance is provided for all 119 inputs. The aggregation is illustrated in the following 119 figures.

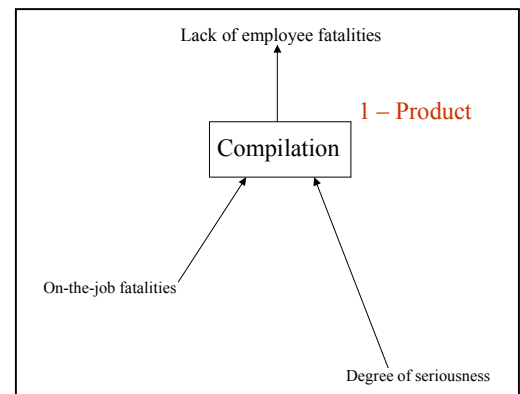
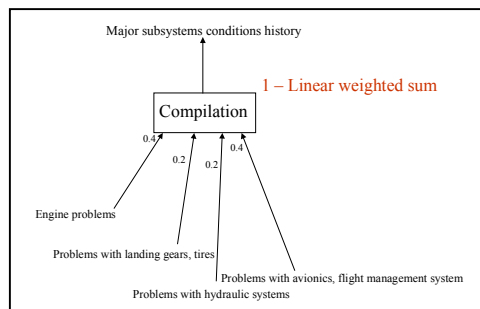
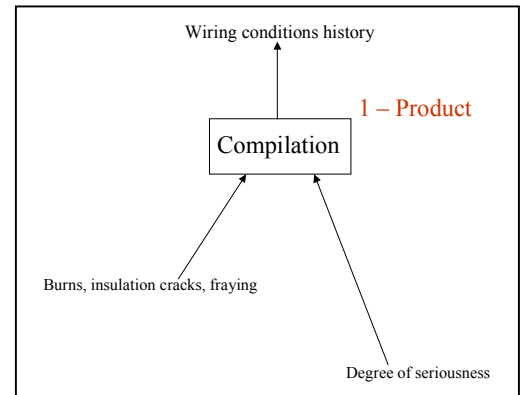
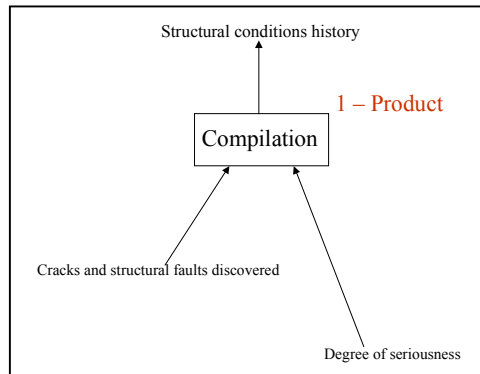
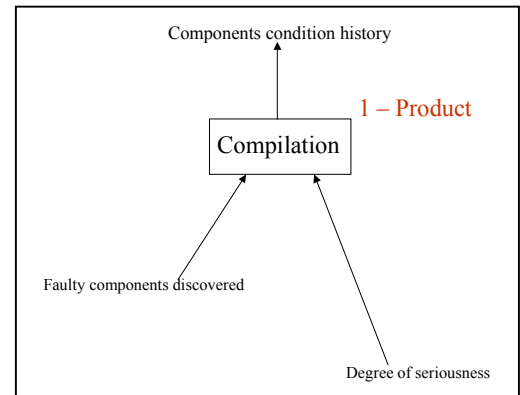
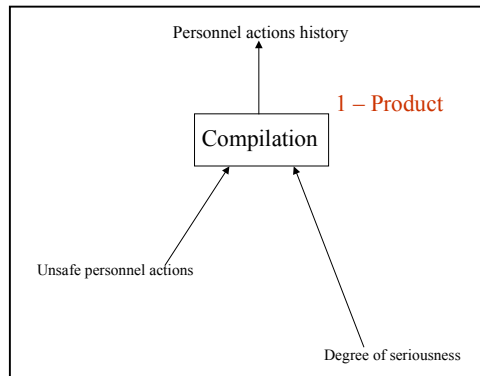
The indicated operations are simple, but would not be easily done by hand. Since it does not appear appropriate to include them in the Markov Tool (which would effectively increase the number of inputs to 375), it seems advisable that they be incorporated in a portable device (e.g., a palm-size computer or personal assistant).

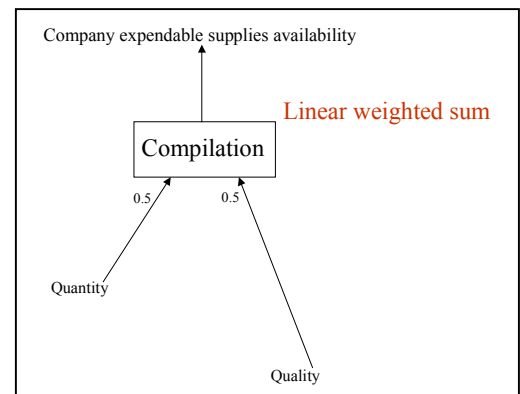
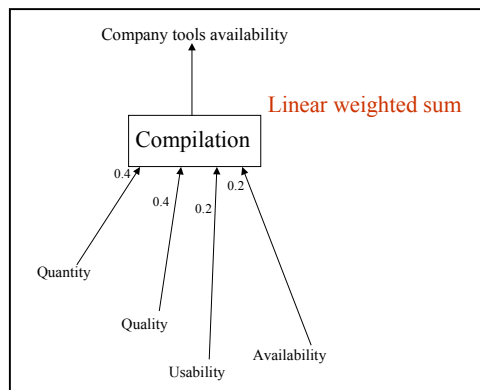
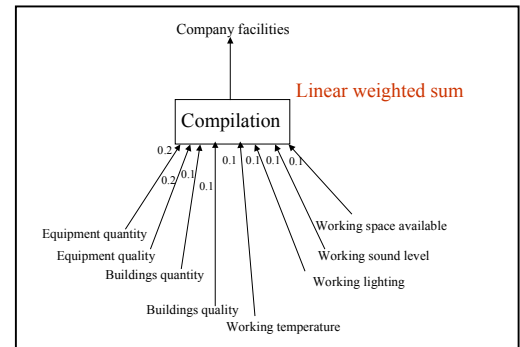
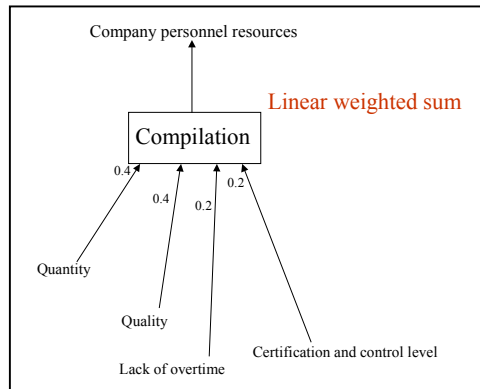
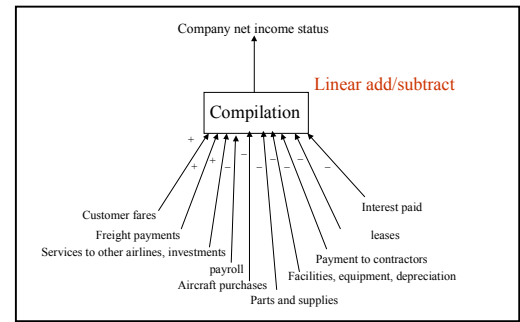
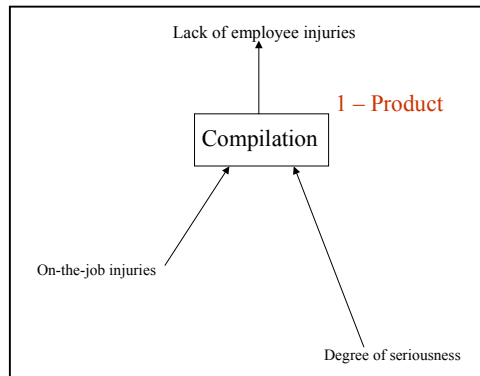


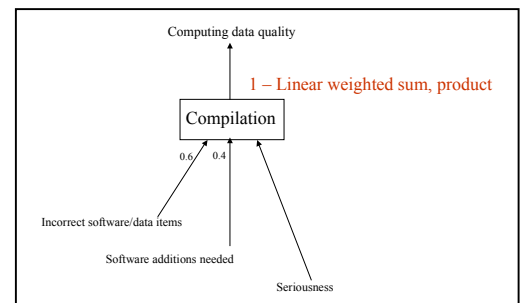
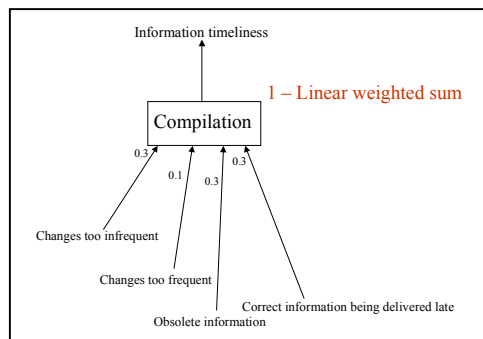
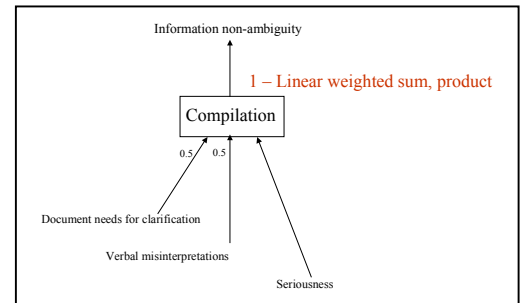
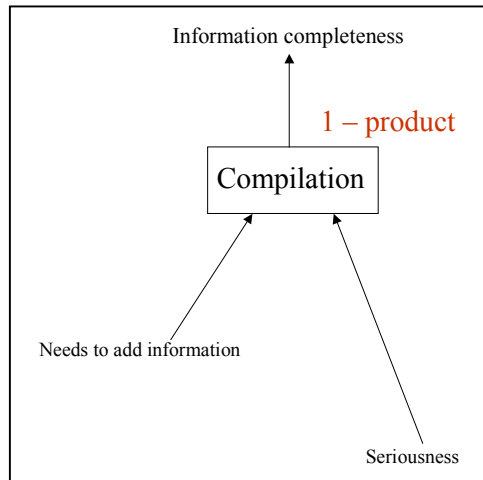
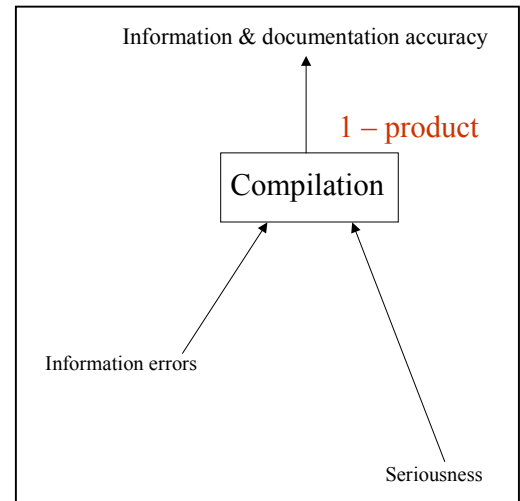
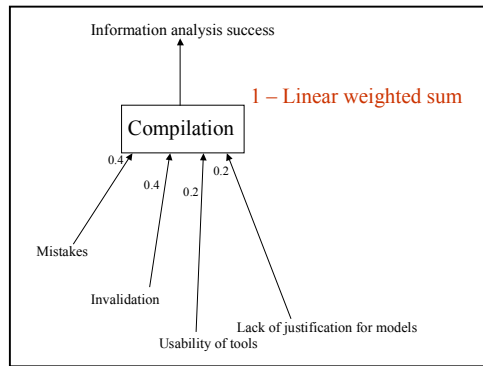


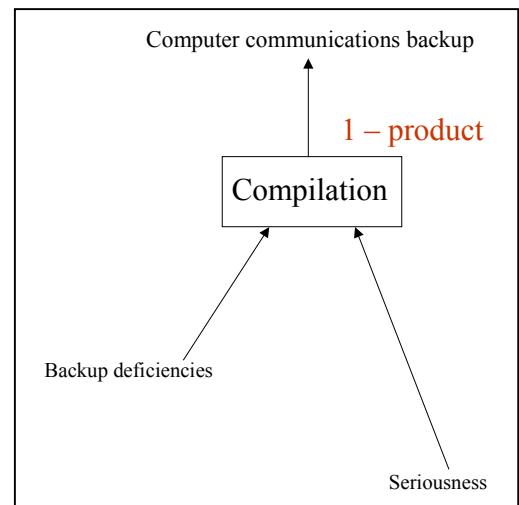
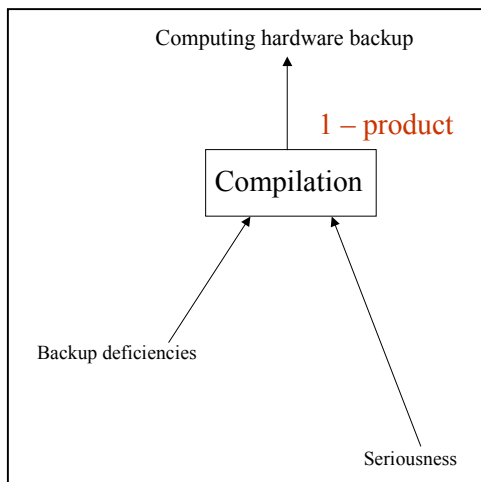
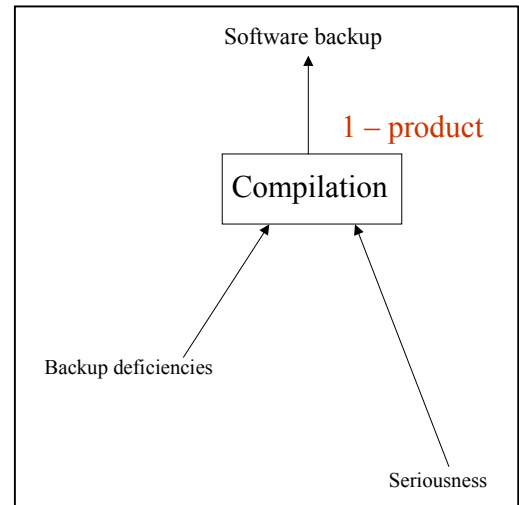
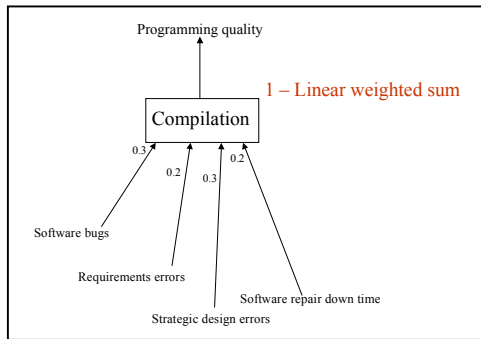
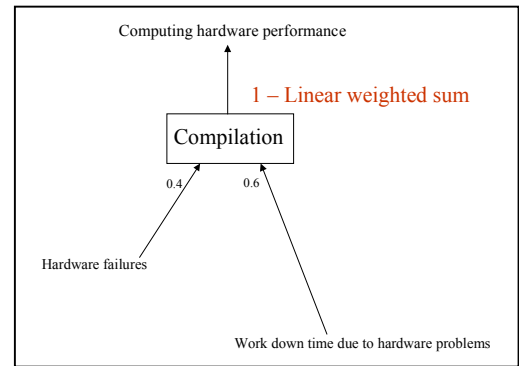
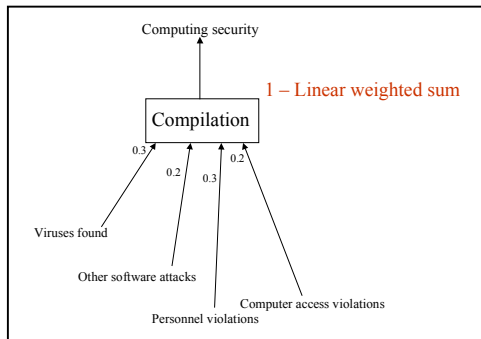


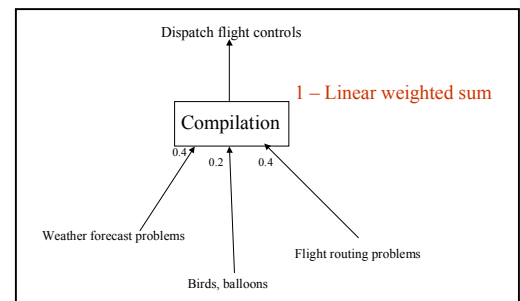
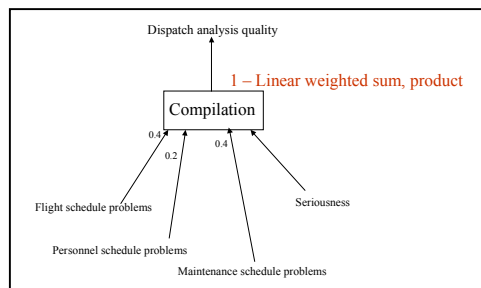
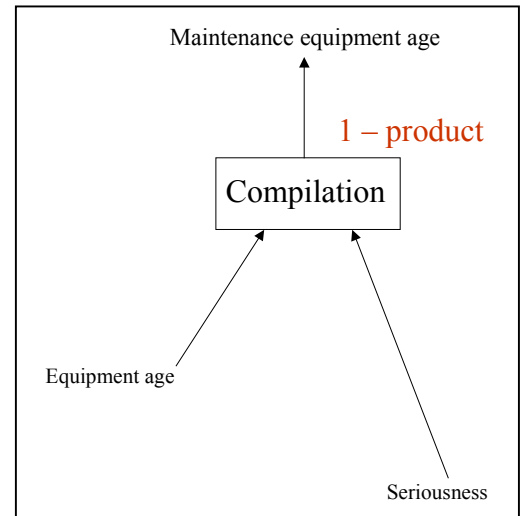
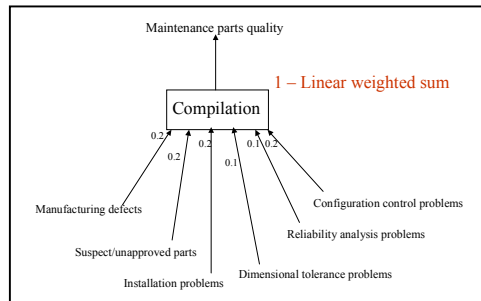
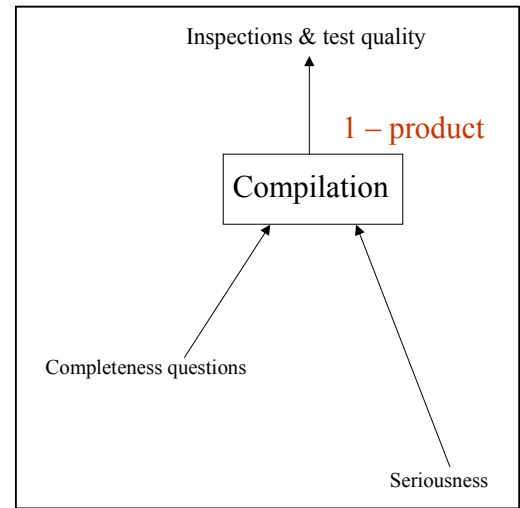
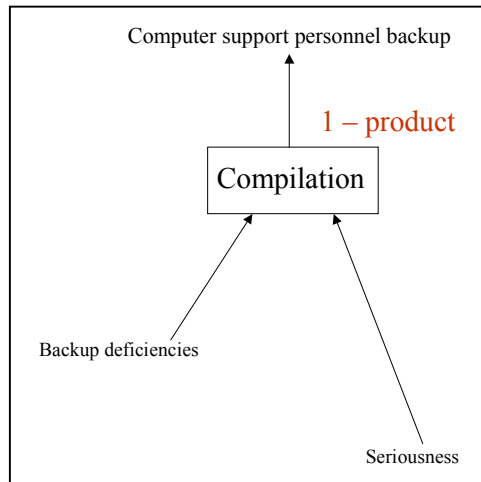


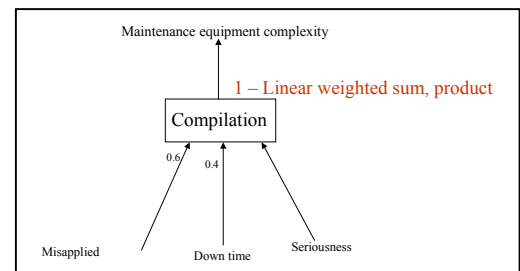
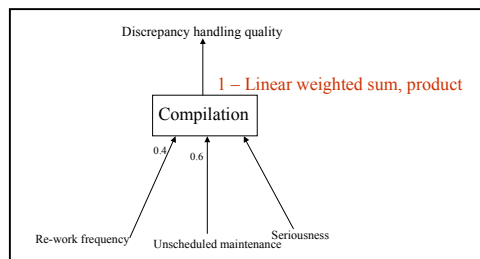
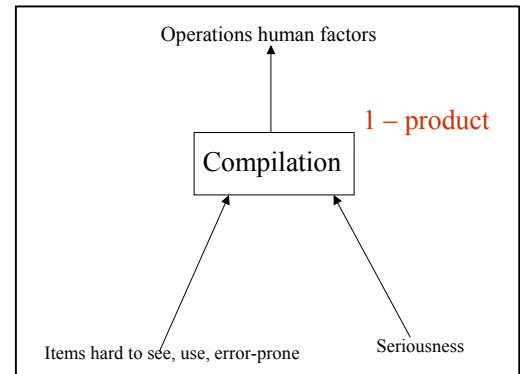
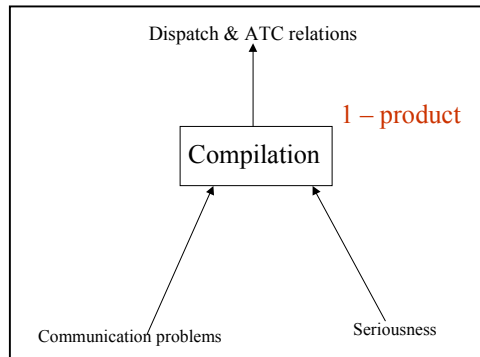
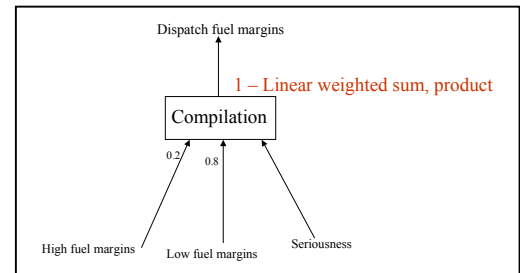
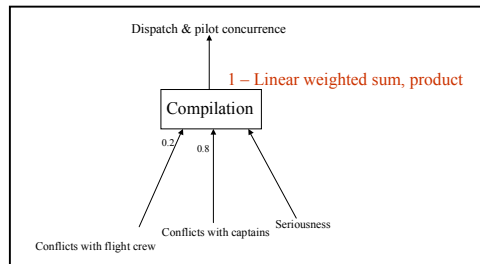


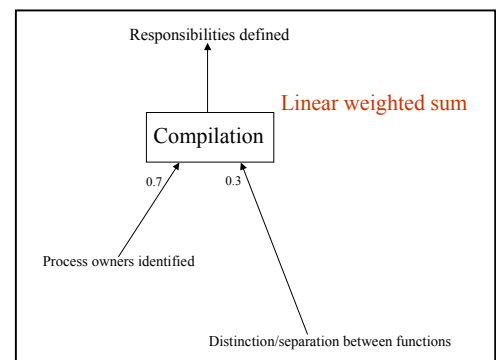
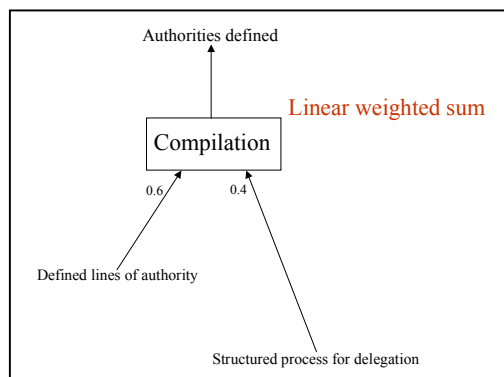
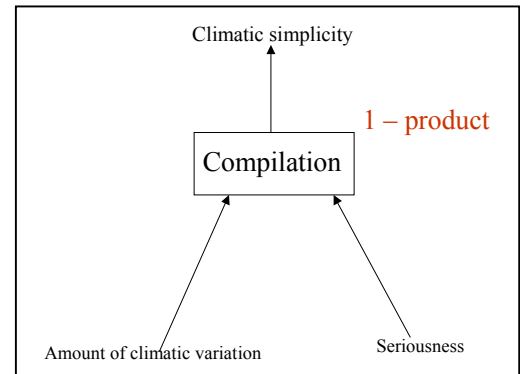
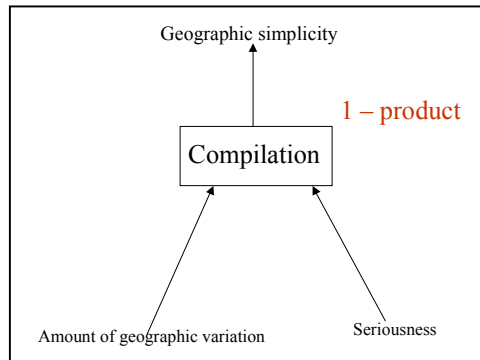
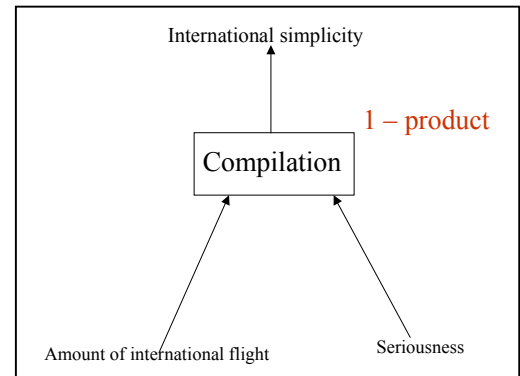
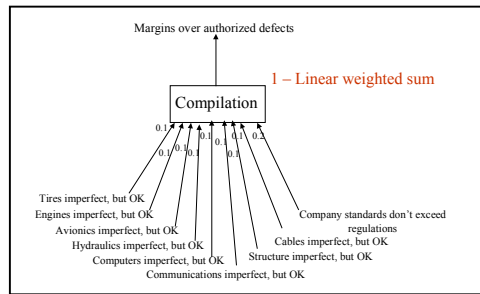


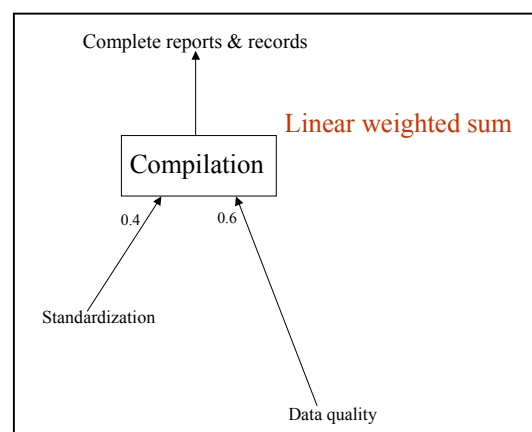
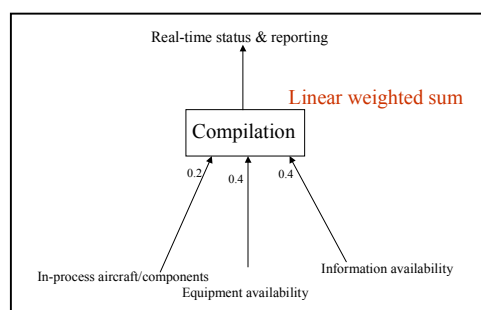
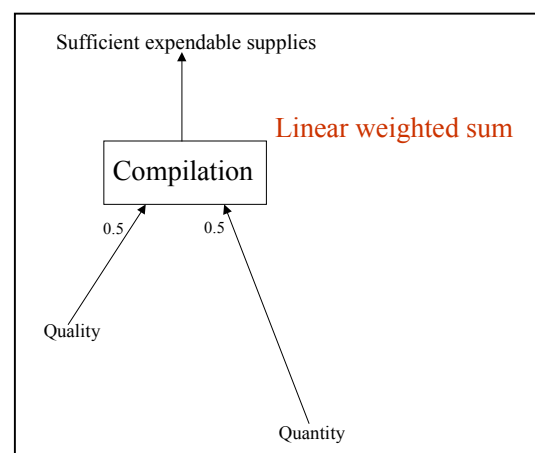
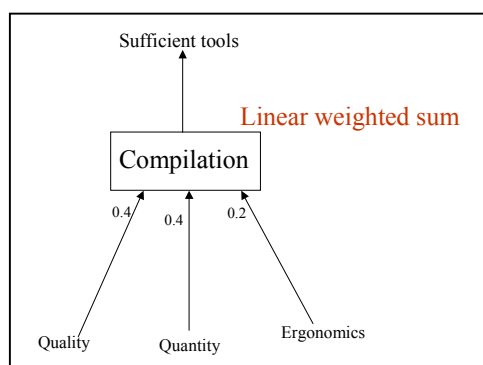
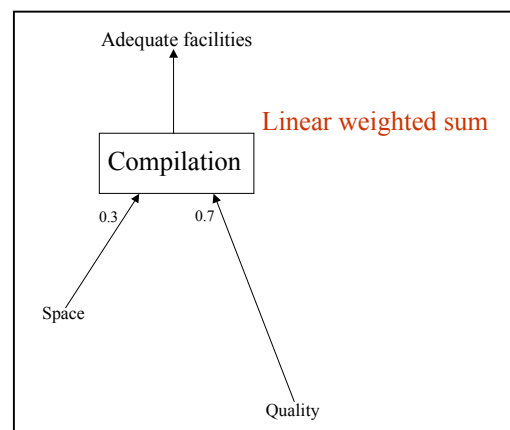
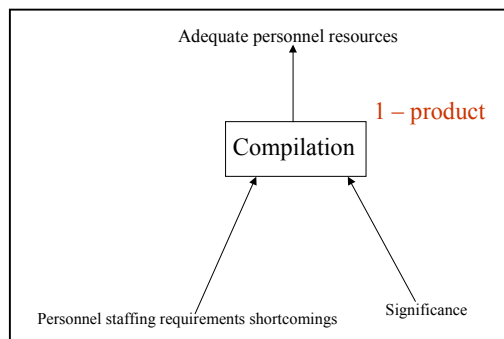


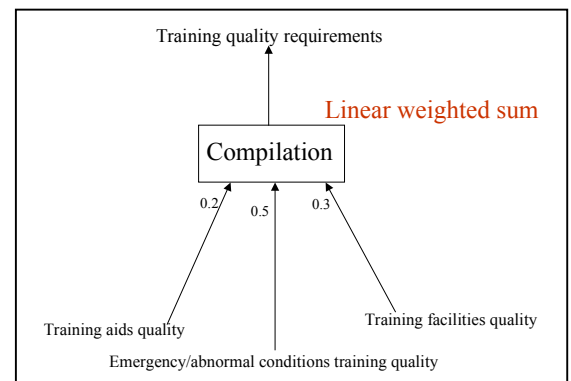
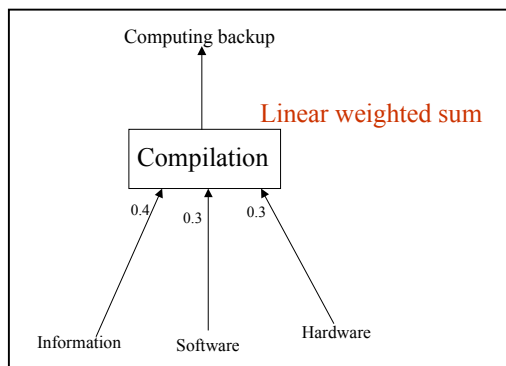
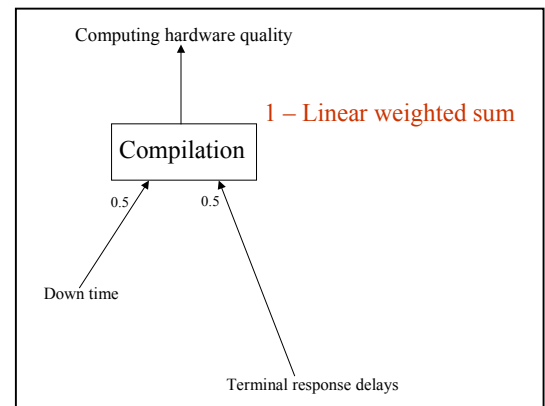
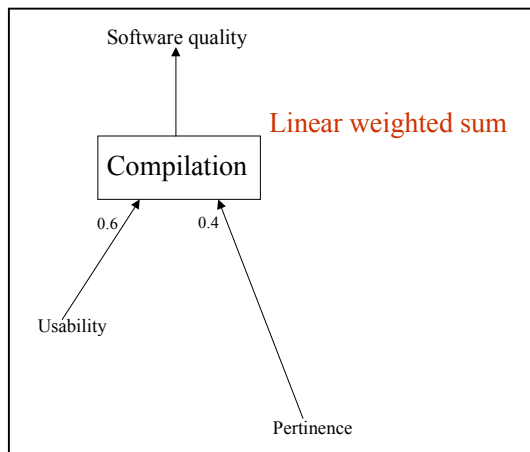
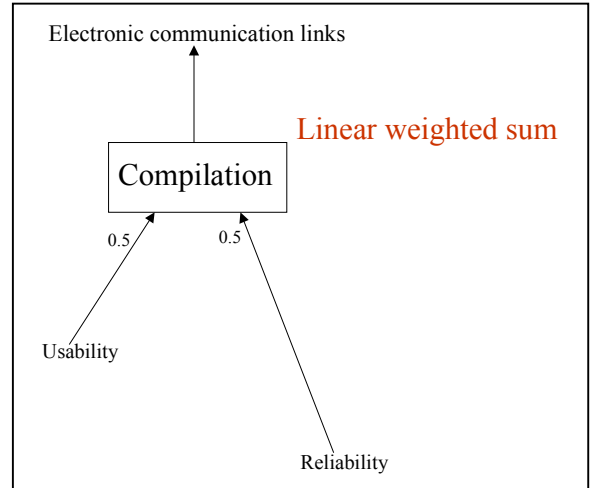
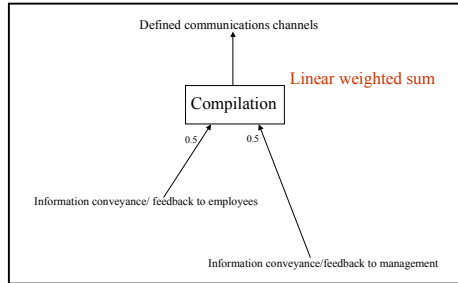


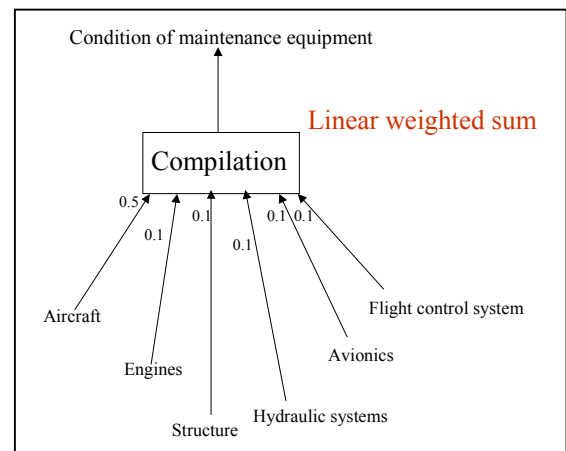
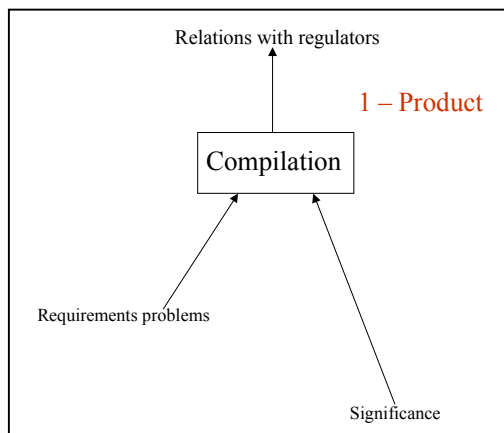
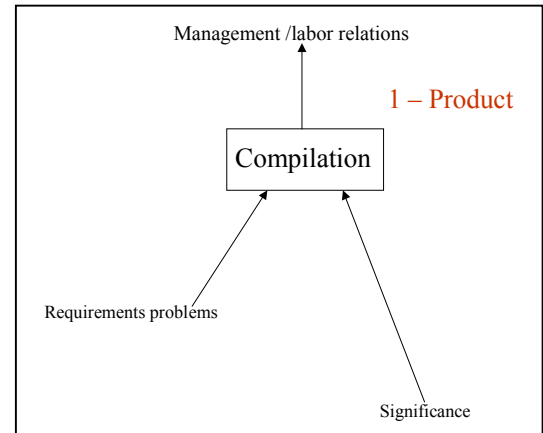
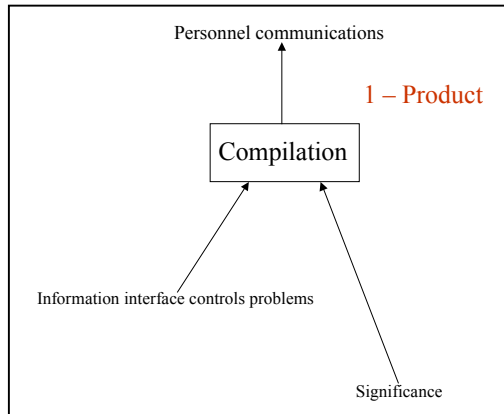
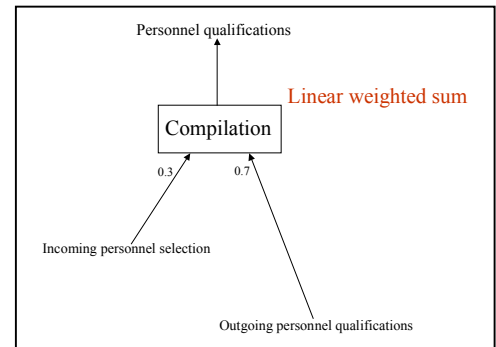
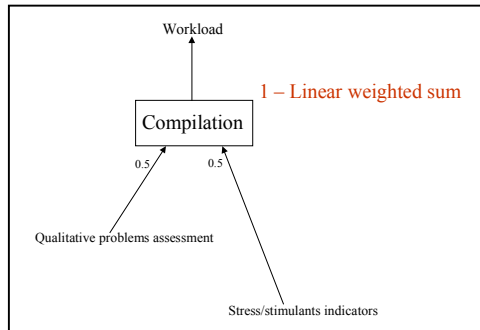


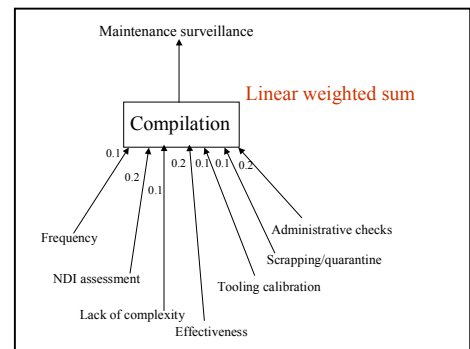
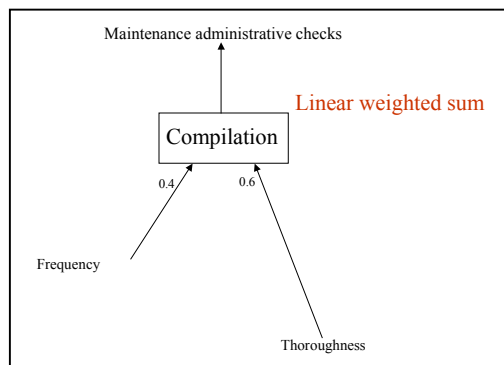
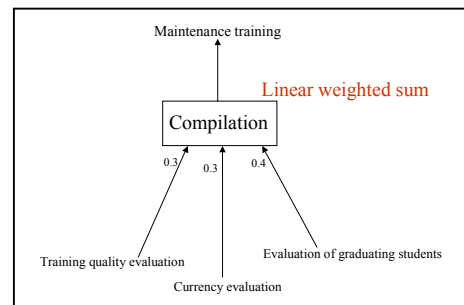
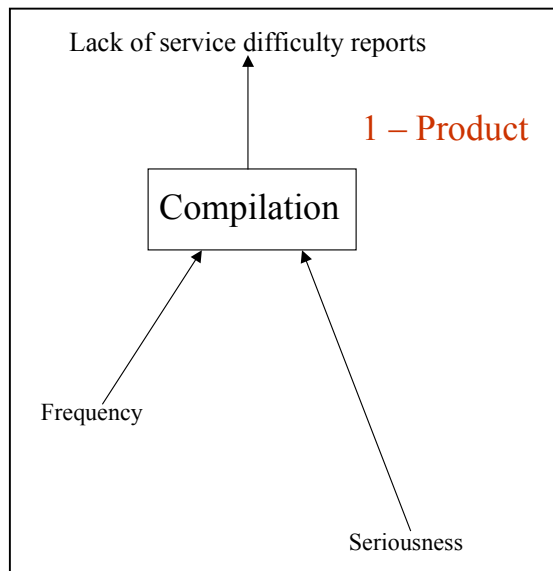
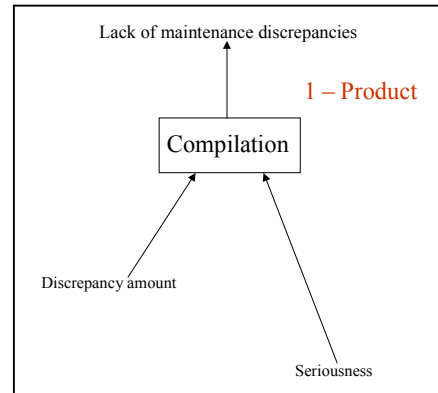
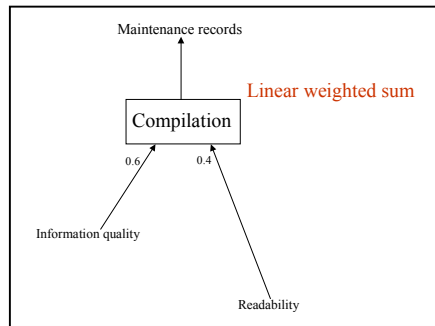


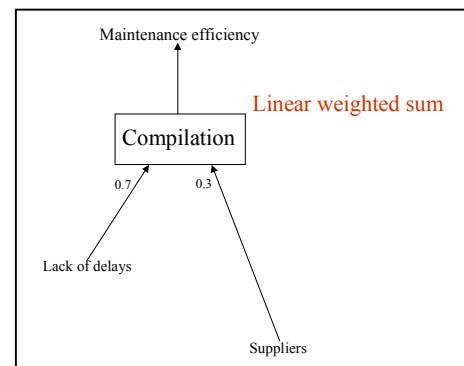
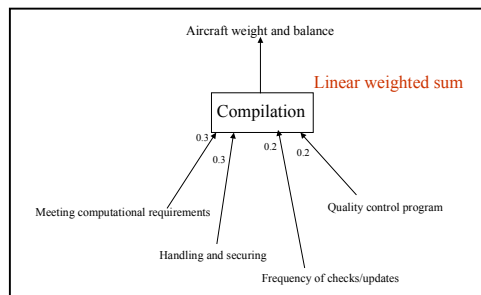
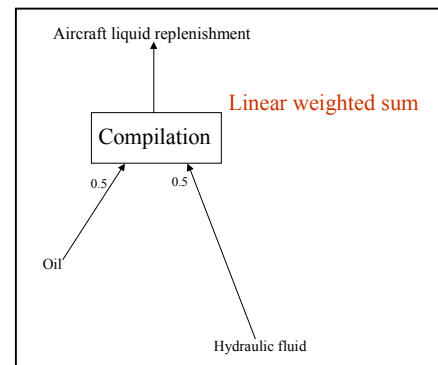
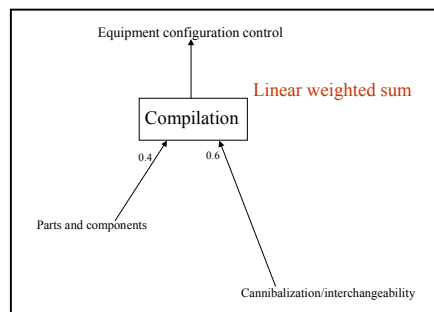
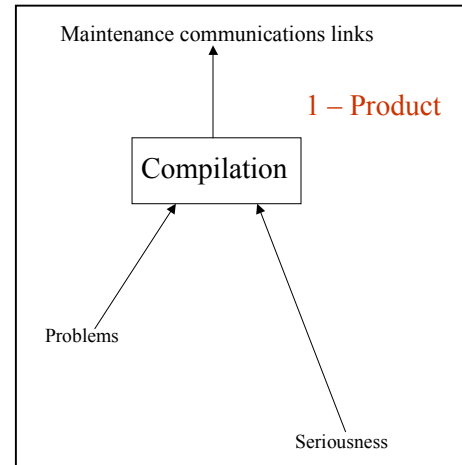
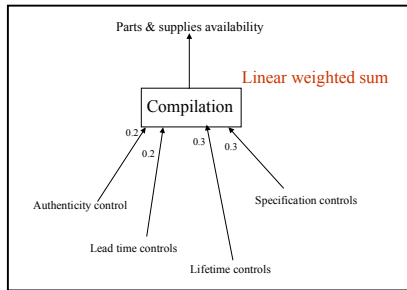


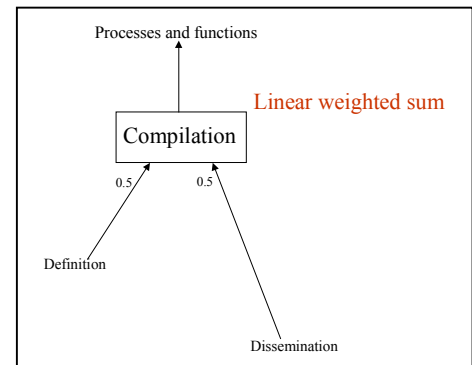
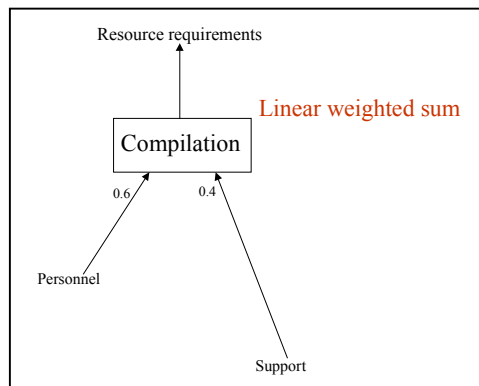
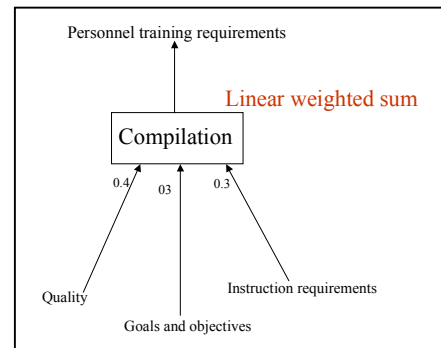
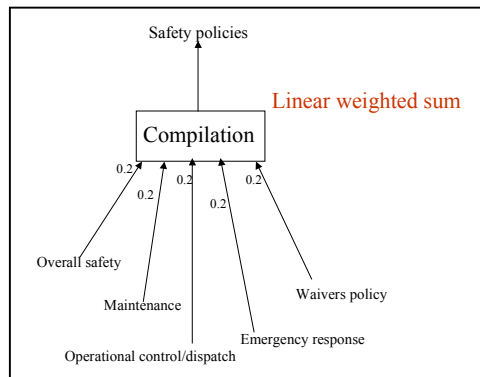
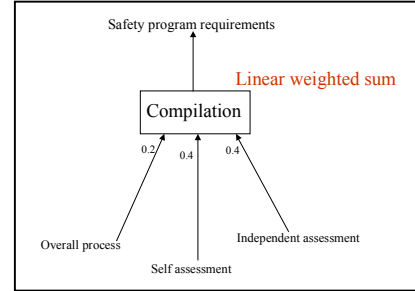
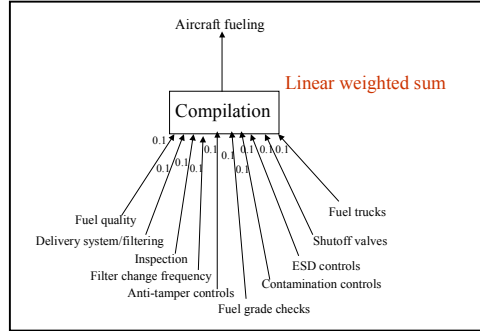


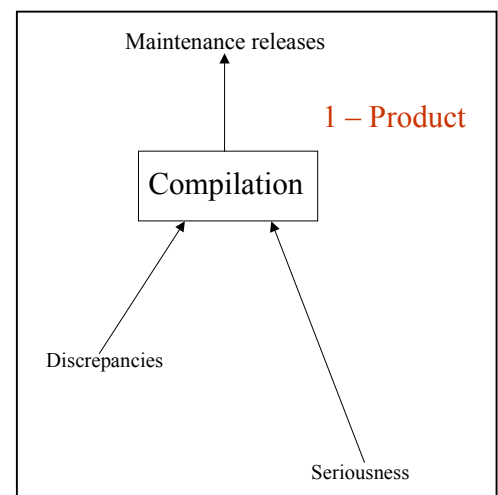
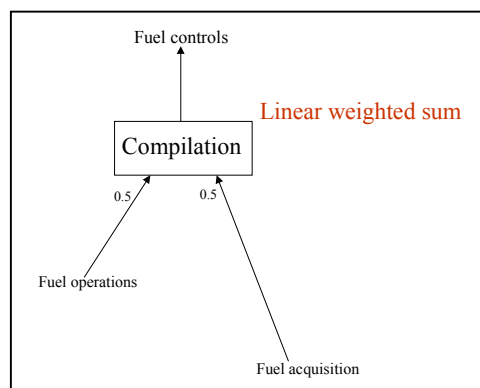
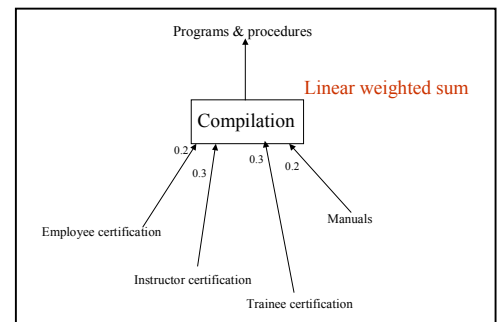
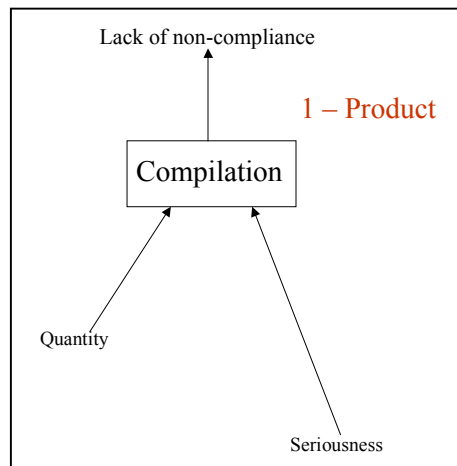
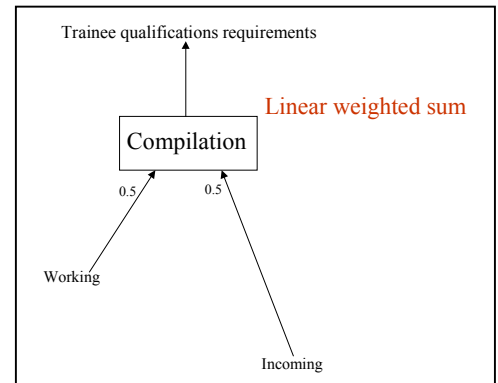
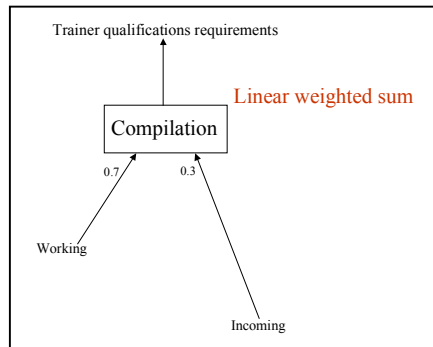


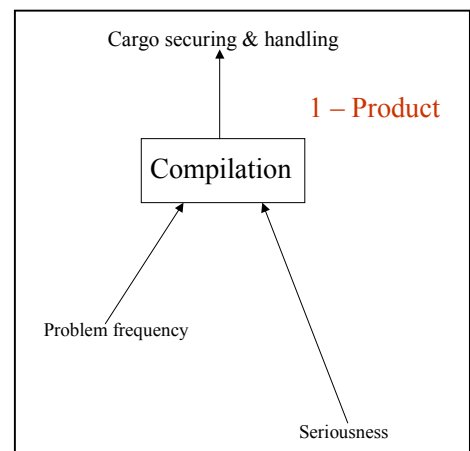
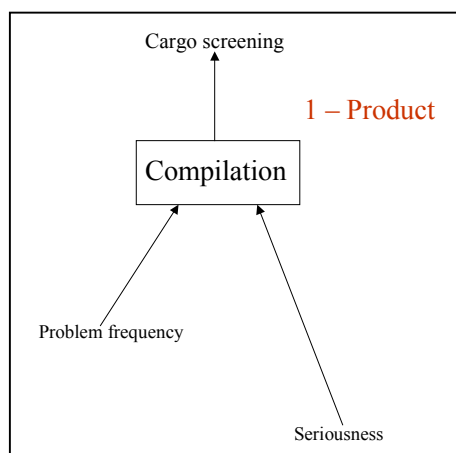
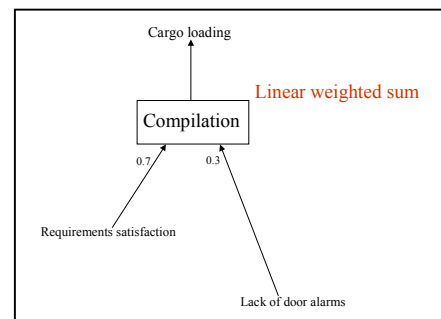
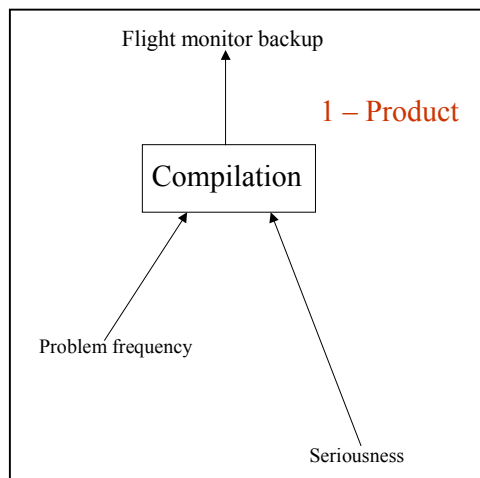
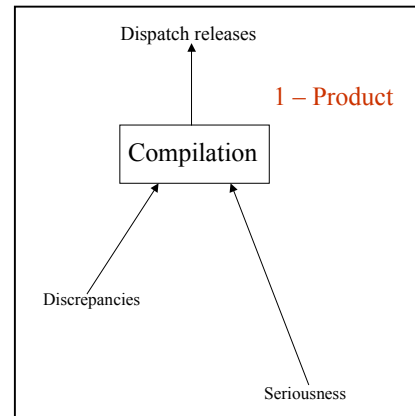
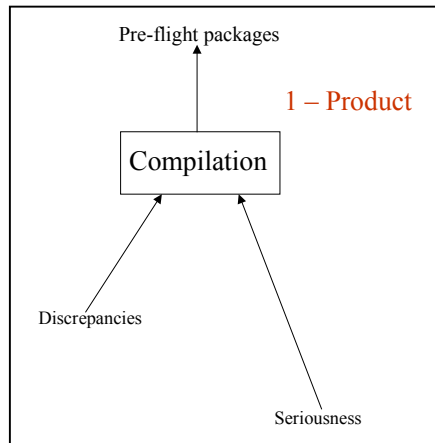


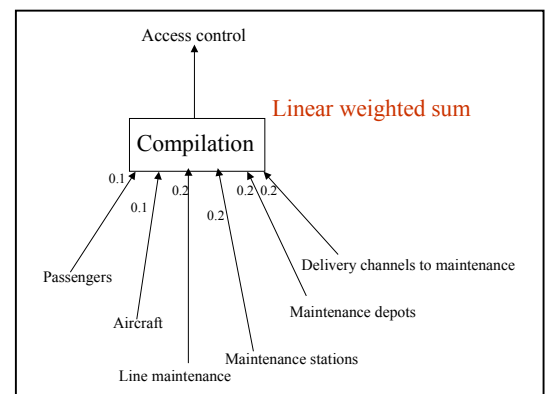
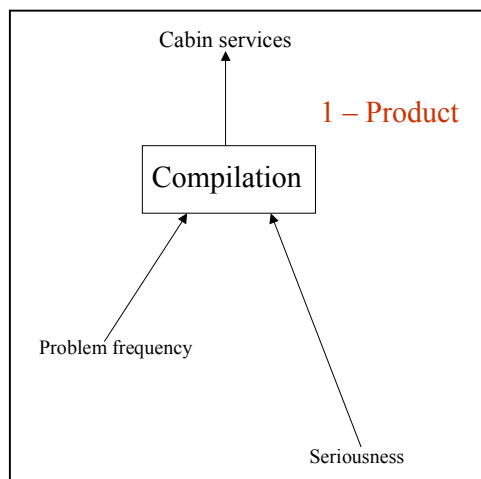
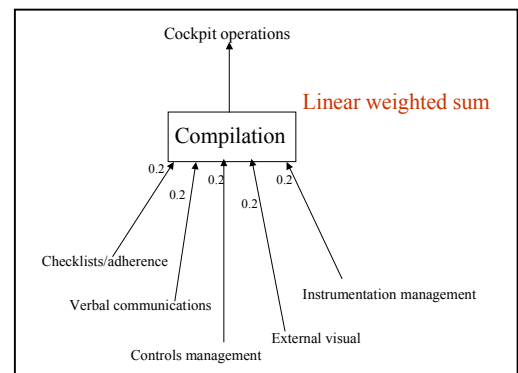
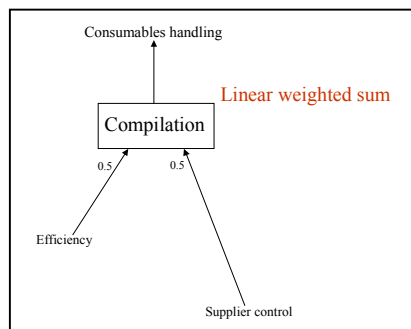
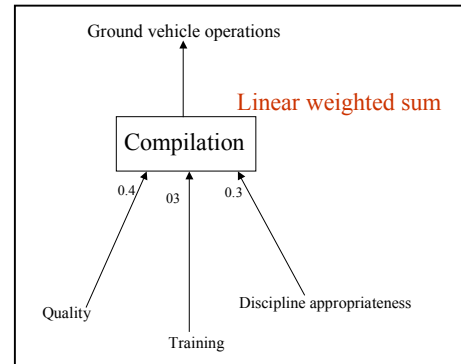
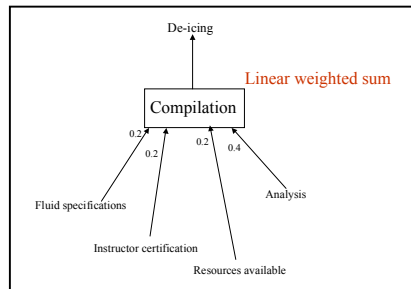


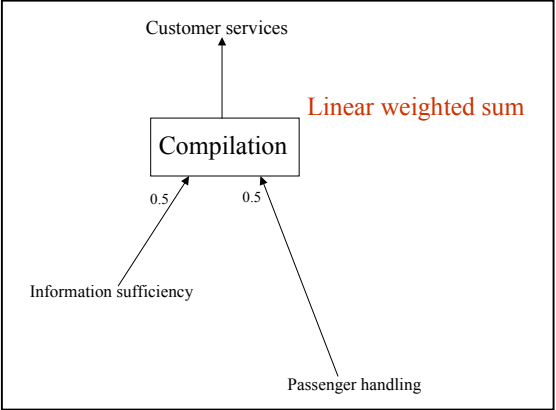












Appendix B: Input Descriptions

Risk Factors

Management Approach

1. Operation maturity: Indication that the organization (staff and infrastructure) is developed and stable (weight = 0.1)
2. Stability vs. change: Indication that the organization is not rapidly changing (e.g., rapidly growing, significantly changing flight structure, adding aircraft, changing personnel (especially management) (weight = 0.1)
3. Lack of citations and fines: Measure of the freedom from regulatory or legal violations (weight = 0.1)
4. Operation simplicity: Measure of freedom from complex variations in aircraft type and series, aircraft technology, etc. (weight = 0.1)
5. Relations—unions & regulators: Measure of freedom from significant conflicts with regulatory bodies and labor (weight = 0.1)
6. Control outsourcing and leasing: Extent of control over subcontracted activities such as maintenance, leased operations and equipment (weight = 0.9/Training 0.1; 0.1 into Management approach)
7. Trends analysis capabilities: Measure of ability to make decisions with confidence based on trends (freedom from information errors and ambiguity, ease of interpretation, etc.) (weight = 0.8/Training 0.2; weight = 0.1 into Management approach)
8. Planning & scheduling: Measure of capabilities to project revenue, staffing needs, resources, flight routes, etc. (weight = 0.9/Training 0.1; weight = 0.1 into Management approach)
9. Training quality: Measure of training attributes, such as applicability, trainer and trainee qualifications, graduate qualifications, facilities, and modes of instruction (weight = 0.1, 0.2, 0.1 in above three combinations)
10. Policy quality: Measure of policy clarity, understanding, and buy-in (weight = 0.6/Safety organization 0.4; weight = 0.1 into Management approach)
11. Safety organization: Safety attributes of the organization responsible for safety (weight = 0.4 above; weight = 0.1 into Management approach)

Culture

12. Independent assessment: Measure of the quality and value of the independent assessment being applied (weight = 0.2)
13. Quality assurance control: Measure of the safety quality as opposed to emphasis on profit and throughput (weight = 0.1)
14. Communication style: Effectiveness of top-to-bottom, bottom-to-top and horizontal communication (weight = 0.1)
15. Lack of blame-placing tendencies: Measure of willingness of upper management to assume blame when warranted (weight = 0.1)
16. Passion-responsibility-effort: Commitment and feeling of individual responsibility for safety (weight = 0.1)
17. Going beyond regulations: Measure of view that regulations are only a

minimum standard (weight = 0.1)

18. Self-disclosures: Willingness to disclose safety problems in the interest of helping overall safety posture (weight = 0.1)

19. Employee morale: Measure of employee job satisfaction (weight = 0.1)
[Management approach into Culture with weight = 0.1]

History of Events

20. Lack of flight accidents & incidents & occurrences: Measure of safety-relevant events observed/documented (weight = 0.2)

21. Lessons-learned program: Measure of documentation, root-cause investigation, and corrective actions (weight = 0.1)

22. Analysis history: Track record on use of and value of analysis (weight = 0.1)

23. Personnel actions history: Track record of freedom from unsafe personnel actions (weight = 0.1 into Conditions, which is weight = 0.2 into History)

24. Components condition history: Track record of freedom from faulty components (weight = 0.1 into Conditions, which is weight = 0.2 into History)

25. Structural conditions history: Track record of freedom from aircraft cracks and structural faults (weight = 0.3 into Conditions, which is weight = 0.2 into History)

26. Wiring conditions history: Track record of freedom from burns, insulation cracks, fraying (weight = 0.2 into Conditions, which is weight = 0.2 into History)

27. Major subsystems condition history: Track record of freedom from problems with major components, such as engines, landing gears, hydraulic systems, flight management systems, avionics, etc. (weight = 0.2)

28. Lack of employee fatalities: Track record of freedom from on-job fatalities (weight = 0.1, d = 0.5 with Lack of employee injuries)

29. Lack of employee injuries: Track record of freedom from on-job injuries (weight = 0.1, d = 0.5 with Lack of employee fatalities)

Resource provisions

30. Company net income status: Measure of financial health of organization (weight = 0.1)

31. Company personnel resources: Measure of adequacy of personnel resources (weight = 0.2)

32. Company facilities: Measure of adequacy of company equipment, building and office areas, and ergonomics (weight = 0.1)

33. Company tools availability: Measure of quantity, quality, and usability of proper tools (weight = 0.2)

34. Company expendable supplies availability: Measure of adequacy of expendable supplies (weight = 0.1) [Culture into Resource provisions with weight = 0.2, Management Approach into Resource provisions with weight = 0.1; d = 0.2 for these two secondary inputs]

Information/documentation

35. Information analysis success: Measure of information and information analysis tools quality (weight = 0.1)

36. Information & documentation accuracy: Measure of freedom from information/documentation errors (weight = 0.2)

- 37. Information completeness: Measure of completeness (weight = 0.1)
- 38. Information non-ambiguity: Measure of freedom from needs for clarification/interpretation (weight = 0.1)
- 39. Information timeliness: Measure of freedom from out-of-date information or information not available on time (weight = 0.2) [History of events into Information/documentation with weight = 0.2, Resource provisions into Information/documentation with weight = 0.1]

Computing

- 40. Computing data quality: Measure of quality of database, information, and software quality (weight = 0.2)
- 41. Computing security: Measure of quality of software, hardware, and personnel security (weight = 0.2)
- 42. Computing hardware performance: Measure of quality of computing hardware performance and availability (weight = 0.1)
- 43. Programming quality: Measure of quality of requirements, design, and reliability; and freedom from bugs (weight = 0.1)
- 44. Software backup: Measure of quality of software backup program (weight = 0.4 into Backup, which is weight = 0.2 into Computing)
- 45. Computing hardware backup: Measure of quality of computing hardware backup program (weight = 0.2 into Backup, which is weight = 0.2 into Computing)
- 46. Computer communications backup: Measure of quality of computer communications backup program (weight = 0.3 into Backup, which is weight = 0.2 into Computing)
- 47. Computer support personnel backup: Measure of quality of program to backup computer support personnel (weight = 0.1 into Backup, which is weight = 0.2 into Computing) [Management approach into Computing with weight = 0.2]

Operations

- 48. Inspections & test quality: Measure of quality of inspections and test program (weight = 0.1)
- 49. Maintenance parts quality: Measure of maintenance parts quality, including freedom from defects, freedom from suspect/unapproved parts, tolerances, configuration control, etc. (weight = 0.1)
- 50. Maintenance equipment age: Judgment concerning freedom from hazards from failure-prone, personnel-unfriendly, out-of-date equipment (weight = 0.05)
- 51. Dispatch analysis quality: Metric for freedom from dispatch personnel scheduling, dispatch/maintenance scheduling and dispatch flight scheduling problems (weight = 0.2 into Dispatch, which is weight = 0.1 into Operations)
- 52. Dispatch flight controls: Measure of freedom from problems concerning weather-related routing, flight path obstacles, and time-line control (weight = 0.2 into Dispatch, which is weight = 0.1 into Operations)
- 53. Dispatch & pilot concurrence: Measure of freedom from safety-relevant disagreements between pilots and dispatchers (weight = 0.2 into Dispatch, which is weight = 0.1 into Operations)
- 54. Dispatch fuel margins: Measure of freedom from errors in determining fuel margins (weight = 0.2 into Dispatch, which is weight = 0.1 into Operations)

- 55. Dispatch & ATC relations: Measure of freedom from problems involving ATC-Dispatch communication (weight = 0.2 into Dispatch, which is weight = 0.1 into Operations)
- 56. Operations human factors: Measure of freedom from items that are hard to use or error-prone (weight = 0.1)
- 57. Discrepancy handling quality: Measure of freedom from re-work problems, unscheduled maintenance, etc. (weight = 0.1)
- 58. Maintenance equipment usability: Measure of freedom from down-time, or other complexity-related sources of equipment unavailability (weight = 0.05)
- 59. Margins over authorized defects: Measure of discretion used in allowing fewer defective components on flying aircraft than allowed (weight = 0.1)
- 60. International simplicity: Measure of freedom from complications due to international flights (weight = 0.4 into Environment variations, which is 0.1 into Operations)
- 61. Geographic simplicity: Measure of freedom from complications due to geographic variations, such as mountainous regions, over-water flight, etc. (weight = 0.2 into Environment variations, which is weight = 0.1 into Operations)
- 62. Climatic simplicity: Measure of freedom from climatic variations (weight = 0.4 into Environment variations, which is weight = 0.1 into Operations) [Resource provisions into Operations with weight = 0.1, Information/documentation into Operations with weight = 0.05, Computing into Operations with weight = 0.05]

Requirements Factors

Management/resources

- 63. Authorities defined: Measure of definition quality, including defined authorities and delegation (weight = 0.2; 0.2 dependence with Responsibilities defined)
- 64. Responsibilities defined: Measure of definition quality, including process owners and separation of functions (weight = 0.2; 0.2 dependence with Authorities defined)
- 65. Adequate personnel resources: Measure of requirements for personnel resources (weight = 0.1)
- 66. Adequate facilities: Measure of requirements for facilities (weight = 0.2)
- 67. Sufficient tools: Measurement of requirements for tools quantity, quality, and ergonomics (weight = 0.2)
- 68. Sufficient expendable supplies: Measure of requirements for expendable supplies quality and quantity (weight = 0.1)

Information/computing

- 69. Real-time status and reporting: Measure of requirements, including in-process aircraft and components, equipment availability, and information availability (weight = 0.2)
- 70. Complete reports and records: Measure of requirements, such as for standardization and data quality (weight = 0.1)
- 71. Defined communications channels: Measure of requirements for information conveyance to management and employees (weight = 0.2)

- 72. Electronic communications links: Measure of requirements for computing communications links (weight = 0.1)
- 73. Software quality: Measure of requirements for computing software (weight = 0.1)
- 74. Computing hardware quality: Measure of requirements for computing hardware (weight = 0.1)
- 75. Computing backup: Measure of requirements for computing backup (weight = 0.2)

Human Factors

- 76. Training quality requirements: Measure of requirements for human factors aspects of training quality (weight = 0.2)
- 77. Workload requirements: Measure of requirements for human factors aspects of workload (weight = 0.1)
- 78. Personnel qualifications: Measure of requirements for personnel qualifications in human factors (weight = 0.2)
- 79. Personnel communications: Measure of requirements for communications interfaces aspects of human factors (weight = 0.2)
- 80. Management/labor relations: Measure of human factors requirements for relations between management and labor (weight = 0.1; d = 0.2 with Relations with regulators)
- 81. Relations with regulators: Measure of human factors requirements for relations with regulators (weight = 0.2; d = 0.2 with Management/labor relations)

Equipment/maintenance

- 82. Condition of maintenance equipment: Measure of requirements for condition of aircraft, engines, structure, hydraulic systems, avionics, flight control systems, etc. (weight = 0.1)
- 83. Maintenance records: Measure of requirements for records quality (weight = 0.2 into Functions; Discrepancies, Service difficulty reports, Maintenance training, Administrative checks all 0.2; Functions weight = 0.1 into Equipment/maintenance)
- 84. Lack of maintenance discrepancies: Measure of requirements for controlling discrepancies (weight = 0.2 into Functions; Records, Service difficulty reports, Maintenance training, Administrative checks all 0.2; Functions weight = 0.1 into Equipment/maintenance)
- 85. Lack of service difficulty reports: Measure of requirements for controlling service difficulty reports (weight = 0.2 into Functions; Records, Discrepancies, Maintenance training, Administrative checks all 0.2; Functions weight = 0.1 into Equipment/maintenance)
- 86. Maintenance training: Measure of requirements for evaluation of quality, currency, requirements for completion (weight = 0.2 into Functions; Records, Discrepancies, Service difficulty reports, Administrative checks all 0.2; Functions weight = 0.1 into Equipment/maintenance)
- 87. Maintenance administrative checks: Measure of requirements for frequency and quality of administrative checks (weight = 0.2 into Functions; Records, Discrepancies, Service difficulty reports, Maintenance training all 0.2; Functions weight = 0.1 into Equipment/maintenance)

- 88. Maintenance surveillance: Measure of requirements for frequency, NDI, complexity control, effectiveness, tooling calibration, scrapping and quarantine, etc. (weight = 0.1)
- 89. Parts & supplies availability: Measure of requirements for authenticity control, lead time controls, lifetime controls, specification controls, etc. (weight = 0.1)
- 90. Maintenance communications links: Measure of controls placed on maintenance communications links (weight = 0.05)
- 91. Equipment configuration control: Measure of requirements for configuration control of parts and components, cannibalization, and interchangeability (weight = 0.1)
- 92. Aircraft liquid replenishment: Measure of controls for replenishment of oil, hydraulic fluid, etc. (weight = 0.05)
- 93. Aircraft weight and balance: Measure of controls on computation methodology, handling and securing, frequency of checks/updates, quality control, etc. (weight = 0.1)
- 94. Maintenance efficiency: Measure of controls on internal delays and supplier delays (weight = 0.1)
- 95. Aircraft fueling: Requirements for fuel quality, delivery, filtering, inspection, security, contamination control, ESD control, etc. (weight = 0.1) [Human factors into Equipment/maintenance with weight = 0.05, Management/resources into equipment/maintenance with weight = 0.05]

Requirements

- 96. Safety program requirements: Requirements for safety processes, self assessment, independent assessment, etc. (weight = 0.2)
- 97. Safety policies: Requirements for policies for safety, maintenance, operations control/dispatch, emergency response, waivers, etc. (weight = 0.1)
- 98. Personnel training requirements: Controls on training quality, goals and objectives, instruction, etc. (weight = 0.1)
- 99. Resource requirements: Controls assessment relating to personnel and support (weight = 0.1)
- 100. Processes and functions: Controls on defining and disseminating information on processes and functions (weight = 0.1)
- 101. Trainer qualifications requirements: Controls on establishing qualifications for incoming and working instructors (weight = 0.1)
- 102. Trainee qualifications requirements: Controls on establishing qualifications for incoming and working trainees (weight = 0.1)
- 103. Lack of non-compliance findings: Controls on handling quantity and seriousness of non-compliance findings (weight = 0.1)
- 104. Programs & procedures: Controls on establishing programs and procedures for manuals, and certification of employees, instructors, and trainees (weight = 0.1)

Line services

- 105. Fuel controls: Requirements for operational control of fuel acquisition and fuel operations (weight = 0.3 into Operational control; weight = 0.2 for Maintenance release, weight = 0.2 for Pre-flight package, weight = 0.2 for Dispatch release, weight = 0.1 for Flight monitor backup; Operational control has weight 0.2 into Line services)

106. Maintenance releases: Requirements for operational control of maintenance release (weight = 0.2 into Operational control; weight = 0.3 for Fuel, weight = 0.2 for Pre-flight package, weight = 0.2 for Dispatch release, weight = 0.1 for Flight monitor backup; Operational control has weight 0.2 into Line services)
107. Pre-flight packages: Requirements for operational control of pre-flight package (weight = 0.2 into Operational control; weight = 0.3 for Fuel, weight = 0.2 for Maintenance release, weight = 0.2 for Dispatch release, weight = 0.1 for Flight monitor backup; Operational control has weight 0.2 into Line services)
108. Dispatch releases: Requirements for operational control of Dispatch release (weight = 0.2 into Operational control; weight = 0.3 for Fuel, weight = 0.2 for Maintenance release, weight = 0.2 for Pre-flight package, weight = 0.1 for Flight monitor backup; Operational control has weight 0.2 into Line services)
109. Flight monitor backup: Requirements for operational control of Flight monitor backup (weight = 0.1 into Operational control; weight = 0.3 for Fuel, weight = 0.2 for Maintenance release, weight = 0.2 for Pre-flight package, weight = 0.2 for Dispatch release; Operational control has weight 0.2 into Line services)
110. Cargo loading: Requirements for cargo loading (weight = 0.1 into Ground operations; weight = 0.1 for Cargo screening, weight = 0.2 for Cargo securing/handling, weight = 0.2 for De-icing, weight = 0.1 for Vehicle operations, weight = 0.1 for Consumables, weight = 0.1 for Cockpit operations, weight = 0.1 for Cabin services; Ground operations has weight 0.1 into Line services)
111. Cargo screening: Requirements for cargo screening (weight = 0.1 into Ground operations; weight = 0.1 for Cargo loading, weight = 0.2 for Cargo securing/handling, weight = 0.2 for De-icing, weight = 0.1 for Vehicle operations, weight = 0.1 for Consumables, weight = 0.1 for Cockpit operations, weight = 0.1 for Cabin services; Ground operations has weight 0.1 into Line services)
112. Cargo securing & handling: Requirements for cargo securing/handling (weight = 0.2 into Ground operations; weight = 0.1 for Cargo loading, weight = 0.1 for Cargo screening, weight = 0.2 for De-icing, weight = 0.1 for Vehicle operations, weight = 0.1 for Consumables, weight = 0.1 for Cockpit operations, weight = 0.1 for Cabin services; Ground operations has weight 0.1 into Line services)
113. De-icing: Requirements for de-icing (weight = 0.2 into Ground operations; weight = 0.1 for Cargo loading, weight = 0.1 for Cargo screening, weight = 0.2 for Cargo securing/handling, weight = 0.1 for Vehicle operations, weight = 0.1 for Consumables, weight = 0.1 for Cockpit operations, weight = 0.1 for Cabin services; Ground operations has weight 0.1 into Line services)
114. Ground vehicle operation: Requirements for vehicle operation (weight = 0.1 into Ground operations; weight = 0.1 for Cargo loading, weight = 0.1 for Cargo screening, weight = 0.2 for Cargo securing/handling, weight = 0.2 for De-icing, weight = 0.1 for Consumables, weight = 0.1 for Cockpit operations, weight = 0.1 for Cabin services; Ground operations has weight 0.1 into Line services)
115. Consumables handling: Requirements for consumables (e.g., efficiency, supplier control) (weight = 0.1 into Ground operations; weight = 0.1 for Cargo

loading, weight = 0.1 for Cargo screening, weight = 0.2 for Cargo securing/handling, weight = 0.2 for De-icing, weight = 0.1 for Vehicle operation, weight = 0.1 for Cockpit operations, weight = 0.1 for Cabin services; Ground operations has weight 0.1 into Line services)

116. Cockpit operations: Requirements for cockpit operations (e.g., checklists, verbal communication, controls/instruments management, external visual) (weight = 0.1 into Ground operations; weight = 0.1 for Cargo loading, weight = 0.1 for Cargo screening, weight = 0.2 for Cargo securing/handling, weight = 0.2 for De-icing, weight = 0.1 for Vehicle operation, weight = 0.1 for Consumables, weight = 0.1 for Cabin services; Ground operations has weight 0.1 into Line services)

117. Cabin services: Requirements for cabin services (weight = 0.1 into Ground operations; weight = 0.1 for Cargo loading, weight = 0.1 for Cargo screening, weight = 0.2 for Cargo securing/handling, weight = 0.2 for De-icing, weight = 0.1 for Vehicle operation, weight = 0.1 for Consumables, weight = 0.1 for Cockpit operations; Ground operations has weight 0.1 into Line services)

118. Access control: Requirements for access control (e.g., passengers, aircraft, maintenance, delivery channels) (weight = 0.1)

119. Customer services: Requirements for conveyance of information and handling of passengers/families (weight = 0.1) [Management/resources, Information/computing, Human factors, Equipment/maintenance, and Requirements all into Line services with weight = 0.1 each]

Appendix C; Simulations

This appendix documents simulated examples of using roll-up analysis to assess the safety of a system and parts of a system. It also uses the trace-back capability to show how root cause analysis can be performed and salient problems targeted. The first example was generated in mid 2000 in response to questions about how the Markov Tool might be applied (1998 architecture). This example showed how general observations about aggregated information could be traced to specific contributors in a manner that would be very difficult to do efficiently without the methodology. The second example demonstrates how an observed situation can be used to trigger a “follow-the-string” investigation, and how the most important contributors to the situation may well be the least obvious. This result would also be very difficult to reproduce efficiently without the analysis process used in the Markov Tool. The third example is an assessment situation applied to the current architecture. Bob Roginski, one of the Markov Tool programmers, did the computer runs and the production of the output listings.

Simulation Using the 1998 Architecture. Simulated data were entered for a test case, with input data representing a series of aggregations that might be brought to the Markov Tool based on inspectors’ observations. The simulated observations were made starting in January 2000, and ran through early April 2000. The data were generated for a fictitious dynamic situation, with the intent of demonstrating some salient capabilities of the Markov Tool.

The example has inputs from six different assessment dates for 45 inputs (lower and upper bound), including weights for each (810 data entries), simulating a little more than the first three months of CY 2000 for a particular fictitious airline. Also included were six dependence groups (specifying an amount of dependence among each group of inputs). There were two Early-Alert logic constructs added to demonstrate the Early Alert feature. Dependence and Early Alerts can be utilized to any extent desired, if users of the analysis tool wish to do so.

The inputs and the results of the Markov Tool computer model calculations were captured in a computer printout. This output listing included: all inputs and Early Alert logic constructs, 20 module outputs, 36 secondary inputs (module outputs used as subsequent inputs), dependence group outputs, Early Alert outputs, Importance and Sensitivity for each input. All of these had lower and upper bounds at each of the six calendar times. Trends filtering was added as a second pass of output generation to show how it affected the trend plots.

Figure C1 shows the Markov Tool architecture used in this example. This architecture, developed in 1998, decomposed the airline system into four subsystem areas, with 20 modules that were derived from the four subsystems, and with main interconnection influences between the modules. The figure does not show the particular inputs for each of the modules, the weights, the dependence groups, or the Early Alerts, although these have been specified previously (e.g., see Ref. 4).

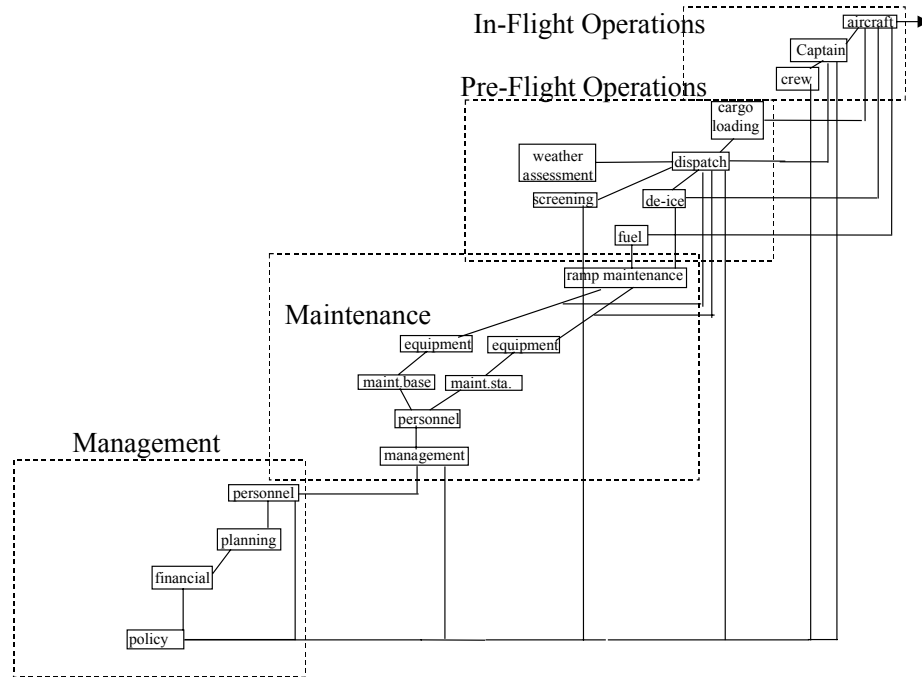


Figure C1. Markov Tool Architecture

The Markov inputs, derived from DOs, are processed to derive Markov outputs and information about the effects of the Markov inputs. This puts linkages in place by which information can be traced back to the DOs.

Finally, decisions are aided based on the information provided by the Markov Tool. Since work in this area is not complete, it is only indicative of how the decision processes might finally evolve.

There are 20 module outputs computed (and explicitly presented in the computer listing) at 6 assessment dates over the reporting period for this test case. However, for simplicity, the trend histories for 8 of the 20 module outputs are presented in Fig. C2. The upper bounds represent the “good” bound for the results; the lower bounds represent the “bad” side.

The “Air Carrier Safety Status” is an overall grade for the airline as a function of time and uncertainty. Other intermediate results contributed to or degraded from this result.

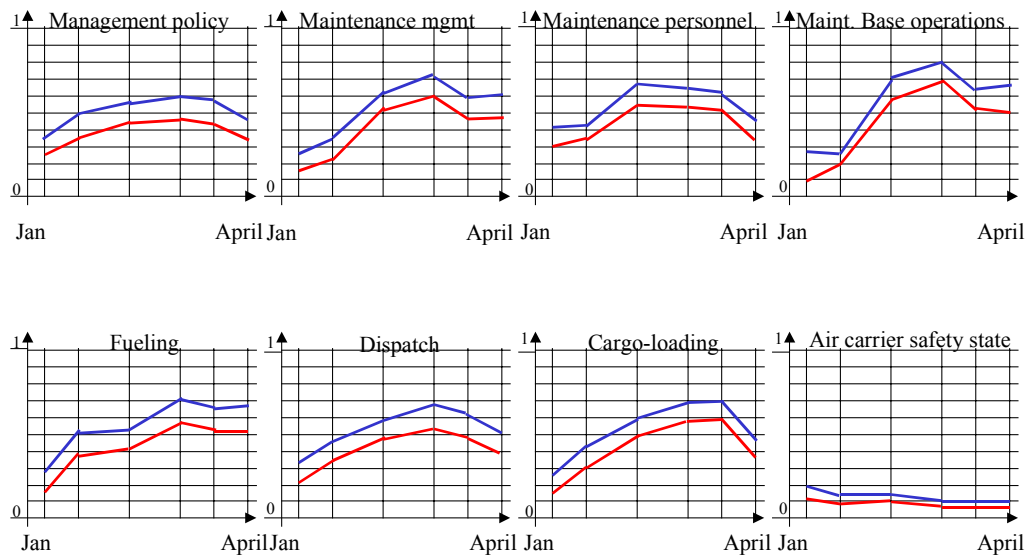


Figure C2. Eight Selected Trends Outputs for the Example

Some questions are appropriate when the output data are examined. Some typical example considerations are listed below. Also included are pointers (derived from Importance and Sensitivity measures) to what path should be followed to answer the questions. Then more detail is offered.

- Why is the overall Air carrier safety score so low, and why is it declining?
[Sensitivity points most strongly at aircraft incidents (most predominant among other factors). This suggests looking closely at the aircraft incidents aggregation process.]
- What contributed to the Maintenance-base early-year improvement, and should this be of concern?
[The Importance measure points mainly to Maintenance base quality (again, there are others of somewhat lesser significance). This suggests looking at the Maintenance base quality aggregation process.]
- What contributed to the Cargo-loading early-year improvement, and is it of concern?
[The Importance measure points mainly to Maintenance base quality (among others). So it is appropriate to look at the Maintenance base quality aggregation process.]
- Why are Management policy and Maintenance management declining?
[The Sensitivity measure points mainly to Management culture (and to others). This suggests looking at the Management culture aggregation process.]

In order to pursue questions such as these, the aggregation process and associated inputs should be examined. In Fig. C3, trend histories for eight of the 45 Markov Tool inputs are shown, as an example selection.

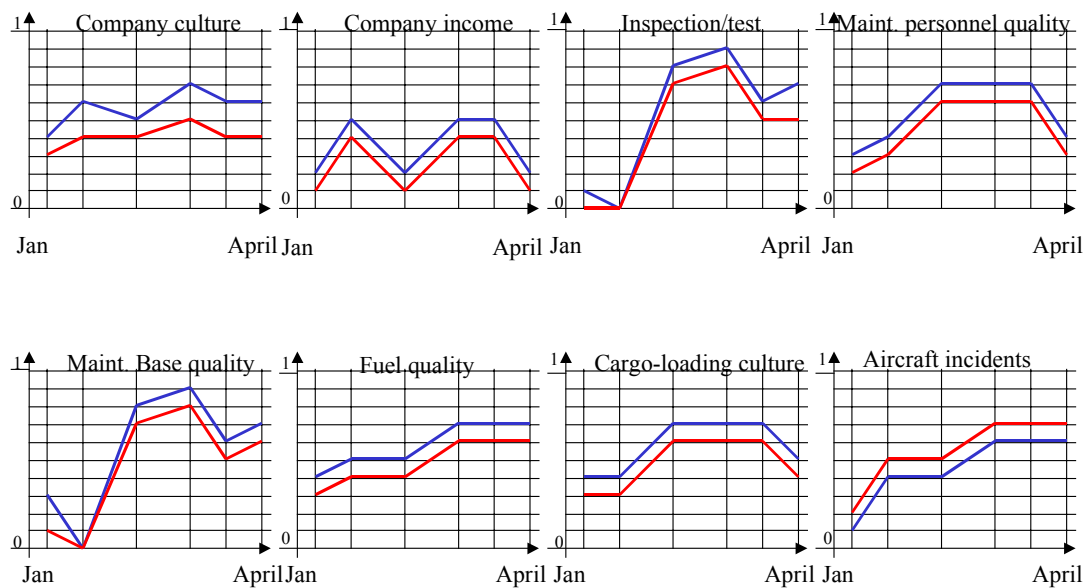


Figure C3. Trends Plots for Eight Example Markov Tool Inputs

Some inputs are “negative,” meaning that fulfillment of the descriptor indicated is “bad” rather than “good.” An example is “Aircraft Incidents” at the lower right. For these, the upper bound indicates “worse,” and the lower bound indicates “better,” rather than the inverse that appears for positive inputs. Reflecting human factors recommendations, this has been changed to a unidirectional methodology in the current architecture.

Examining the trend histories for the inputs leads to a new set of questions. Some examples are shown below:

- What caused the improvements in Inspection/test and Maintenance base quality during the period examined?

[This trend pattern correlates with Maintenance personnel quality improvement, which in turn points to (see input aggregation) the Importance of Morale and Turnover of personnel and Maintenance training— However, the downturn in Maintenance personnel quality noted in April should be a warning flag to watch for possible subsequent ripples into Inspection/test and Maintenance base quality.]

- Why is Fuel quality improving?

[First look at the input aggregation (to be described subsequently). From this, it can be seen that Testing and Fuel handling have high Importance and Sensitivity, and improvement in these correlates with Fuel quality improvement.]

- Why are Aircraft incidents increasing?

[Again, look at the input aggregation. Using Importance and Sensitivity as a guide, note a string of Major component failures, and this correlates with earlier (latent effects) Maintenance problems.]

It is important to remember that each of the 45 Markov inputs (including the 8 illustrated above) can represent an aggregation of observed metrics. For the 8 Markov inputs previously considered, the input aggregation processes will be examined. In each case, the examples illustrate aggregation from observed metrics to Markov inputs. Techniques are described (necessary for an optimum match to each situation) that are utilized to perform the aggregation.

Fig. C4 shows the first of the eight examples—this one using a Markov-model-like latent effects structure and soft aggregation to derive the result based on Management influences and Staff influences. The Markov process allows the incorporation of input dependence groups, three of which are indicated by the loops or ellipses. The circles indicate negative inputs. The weights used in this aggregation are shown; the inputs are ASRATS metrics.

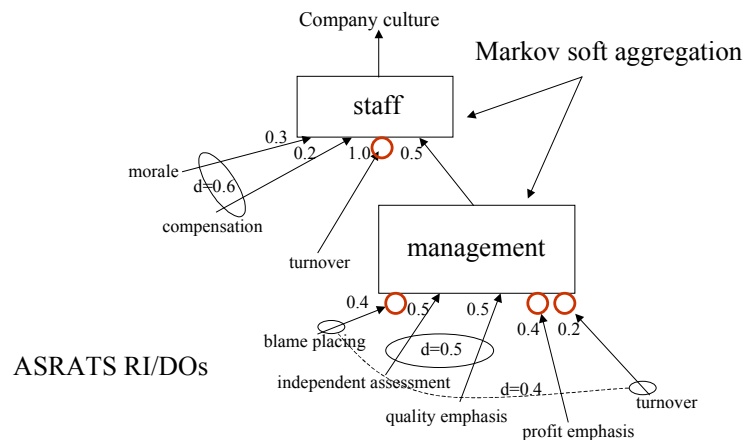


Figure C4. Aggregation of Company Culture Metrics

Company income is the second example (Fig. C5), shown as a straight linear sum, which is intended to be subsequently compared to an expected range that is derived for any airline of interest. An example calculation is illustrated in the upper right part of the figure.

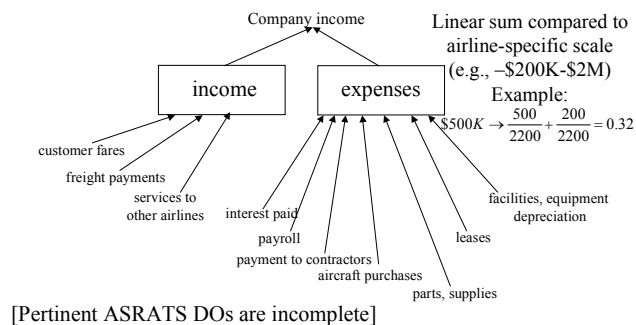


Figure C5. Aggregation of Company Income Metrics

The third example, shown in Fig. C6, represents a hybrid combination (an average in this case) of DOs from RIs and DOs from PMs, where the RI/DOs and PM/DOs are handled differently. For the RI/DOs, a ratio of occurrences to a norm is computed and multiplied by a qualitative measure of seriousness, as shown at the upper left. For the PM/DOs, a Markov soft aggregation is derived. All inputs come from Maintenance DOs. An example of a hybrid combination of the two types of aggregates is a weighted sum.

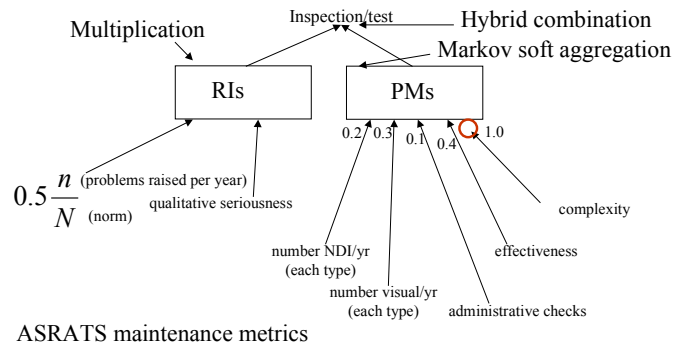


Figure C6. Example Aggregation of Inspection/Test Metrics

In the fourth example (Fig. C7), another combination of PM/DOs and RI/DOs is used. Each portion is computed using Markov soft aggregation of metrics already derived in the maintenance set of DOs. The hybrid combination is a weighted sum, with the weights shown.

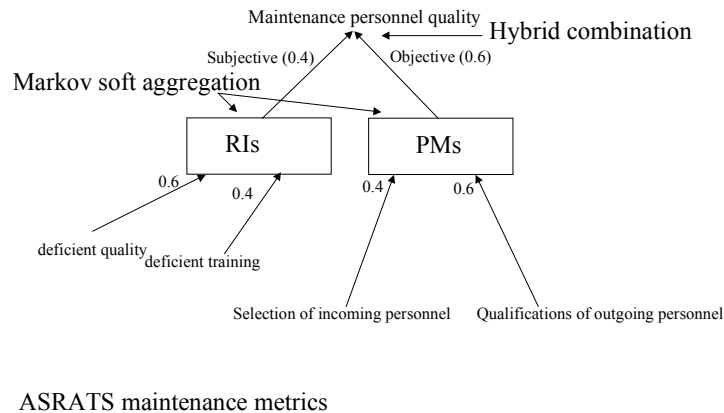


Figure C7. Example Aggregation of Maintenance Personnel Quality

The next example, shown in Fig. C8, uses Markov soft aggregation built around three contributing modules, arranged in a latent effects structure. The weights for primary

inputs and secondary inputs (from module outputs) are shown. There is one negative input (turnover).

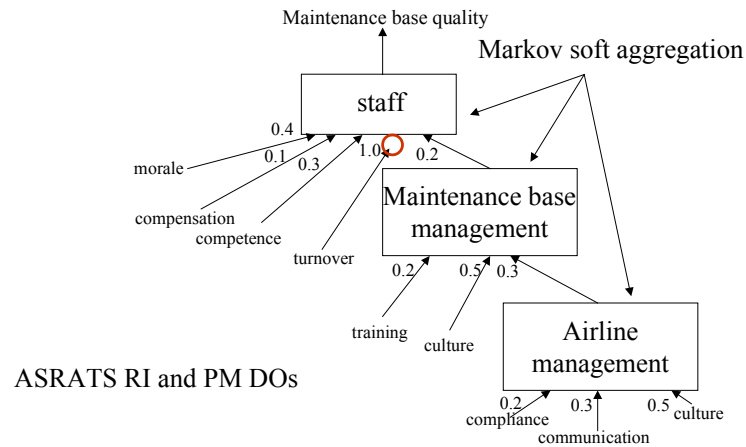


Figure C8. Example Aggregation of Maintenance Base Quality Metrics

For the sixth example, a Markov soft aggregation of two contributing latent effects modules is shown (Fig. C9), including weights.

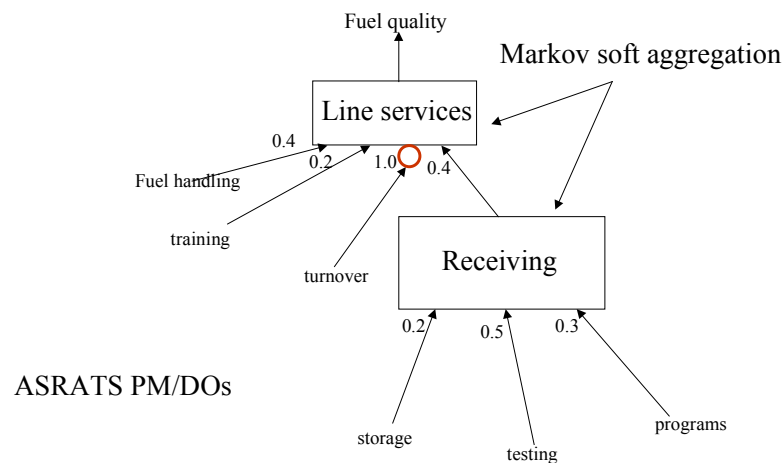


Figure C9. Example Aggregation of Fuel Quality Metrics

The next example, shown in Fig. C10, is for “Cargo Loading Culture,” which has the same structure as the “Company culture” input, previously illustrated. Hence, the same soft aggregation of latent effect module contributions is shown.

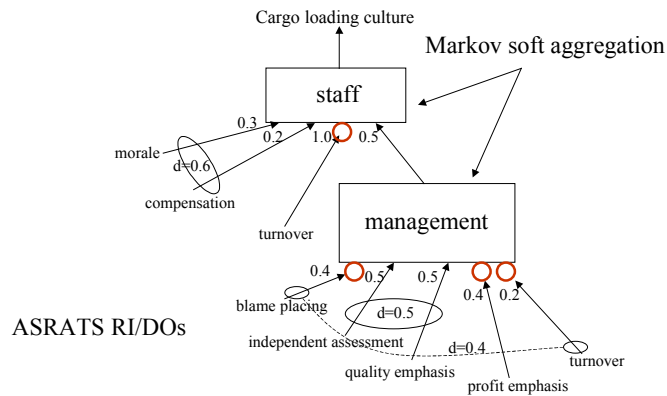


Figure C10. Example Aggregation of Cargo-Loading Culture Metrics

The final example of aggregation is for accumulating metrics relating to incidents, and so the example uses a linear weighted sum of various types of incidents.

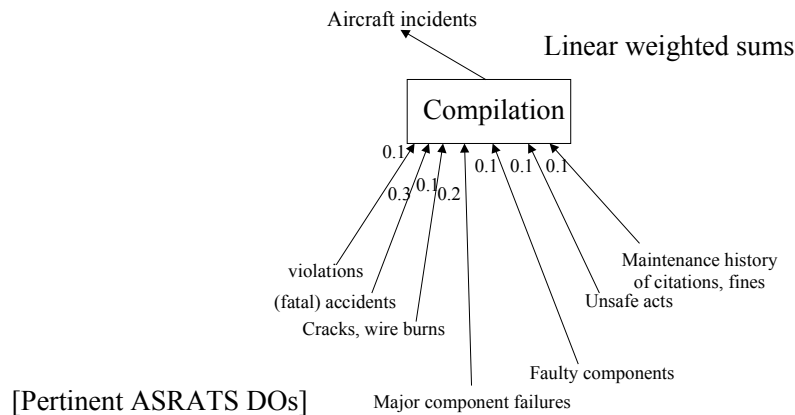


Figure C11. Example Aggregation of Aircraft Incident Metrics

In setting up the test example, two Early Alert logic equations were entered. These Early Alerts are intended to flag specific concerns identified by the system assessors prior to (or during) an assessment period. The logic is expressed in words above the trend charts shown in Fig. C12. The alerts are constructed so that the upper part of the graph (especially above 0.5) flags a concern, and so that there is a sigmoid-like transition from no concern to concern. The effect of filtering is also shown (the dashed lines) in order to demonstrate how filtered results smooth some of the “noise” out of the trend plots. If these results controlled warning lights (a potential choice for the final Markov Tool implementation), the filtering would suppress the tendency of the lights to go on and off due to uncertainty rather than due to change in situation.

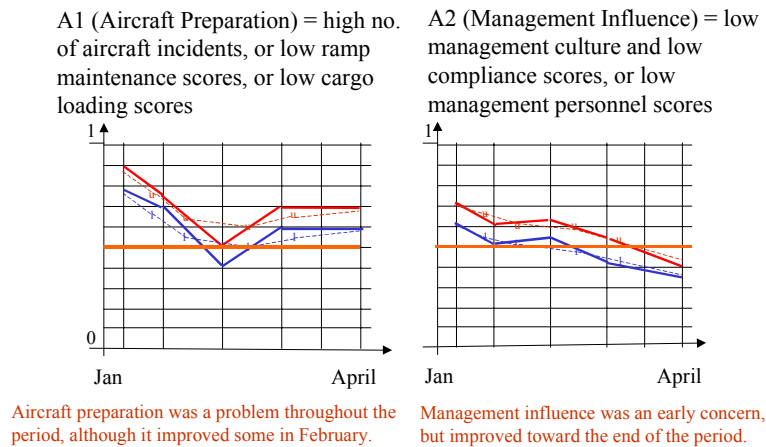


Figure C12. Display of Results of Two Early Alert Logic Constructs

Four types of decision analysis were postulated for the example, and these are shown in Fig. C13.

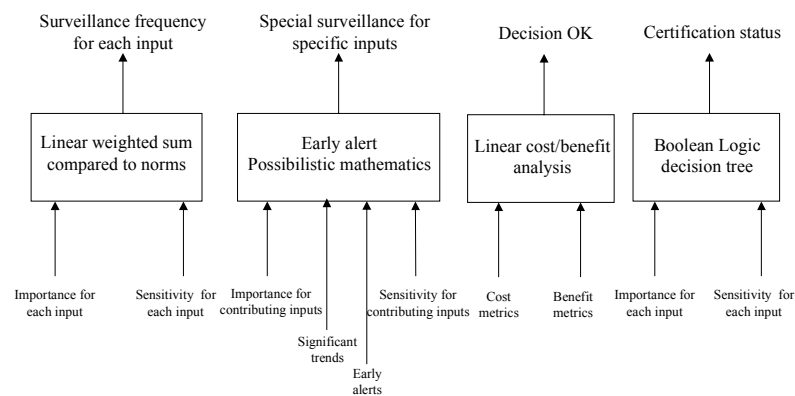


Figure C13. Four Example Types of Decisions and Decision Aids

The left-most process uses Importance and Sensitivity to determine inspection frequency. As inputs take on more Importance/Sensitivity, they are examined more frequently, on the theory that scrutiny of an activity might encourage care in conducting the activity. Most of these Importance and Sensitivity parameters are below 0.01 (the value has now been scaled higher, consistent with human factors considerations), so a relation is postulated that will cause an increase in frequency as values climb above the expected region.

The second decision type is to establish special (e.g., “one-time”) focused scrutiny, where such a need is indicated. The strategy used here is to combine Early Alerts, trends, and Importance and Sensitivity to respond to exceeding a sigmoid threshold.

The third type of decision is a cost/benefit analysis to compare the cost of increased or targeted scrutiny with the expected benefit (statistically derived). This approach recognizes funding and resource limitations that are prevalent in the surveillance community.

The fourth type of decision is a certification indicator that can be derived from the overall safety score, along with logical combinations of the Importance/Sensitivity measures for the most significant inputs. This might be used to help determine whether or not an airline is allowed to fly unrestricted, or how severe possible restrictions must be.

Examples follow for each of the four types of decisions indicated in Fig. C14.

Example Decisions

Surveillance frequency:

All through trends history, “incidents” create the most pointers (first in importance and second in sensitivity). The main aggregation pointer for incidents is to “major component failures.” Assume the reporting norm for this is monthly. Surveillance indicators could be:

$$\frac{\text{Importance}}{0.01} + \frac{\text{Sensitivity}}{0.01} > 2 \Rightarrow \text{weekly} \qquad \frac{\text{Importance}}{0.01} + \frac{\text{Sensitivity}}{0.01} > 10 \Rightarrow \text{daily}$$

At beginning of period, surveillance becomes weekly; at mid-period, it becomes daily

Special surveillance:

A sustained downward trend (over a couple of months) in an output may be a flag to find a source problem. But there must be sufficient importance and/or sensitivity (combined possibilistically). The end-period downward maintenance personnel trend metrics point to maintenance personnel quality, but the importance/sensitivity does not score high.

The downward cargo loading trend metrics point to culture, which scores more than 0.001 in both importance and sensitivity. This in turn has metrics pointing to “turnover” and “morale,” which then qualify for special (unscheduled) scrutiny.

Decision OK:

Cost of turnover/morale investigation = \$1K (wages) + \$1K (travel)

Potential benefit = change fatal accident probability from 10^{-5} /year to 10^{-6} /year, potentially saving \$3.6K during year (200 passengers at \$2M/passenger \times accident probability) \Rightarrow investigation OK

Certification status:

A restriction might be placed on the airline if aircraft safety state falls below 0.5, or if incidents score above 0.5, or if compliance scores below 0.5.

Consideration might be given to de-certifying a carrier if safety state falls below 0.1, or if incidents above 0.5 *and* compliance below 0.5.

This airline might have immediately gone under restriction, and its certificate might have been pulled in February.

Figure C14. Illustration of Four Types of Decisions

Finally, an example of following information learned through an analysis back through to a conclusion about potential causes is illustrated. This process is summarized in Fig. C15, which shows an example scenario of “pulling the thread” to work through the available and pertinent information.

Maintenance personnel also correlates with the Maintenance base parameters. It gives a second pointer to Maintenance personnel quality and a pointer to the corresponding Early Alert.

Maintenance personnel quality also correlates and gives a main pointer to Selection of incoming personnel. This also suggests looking at the Early Alert shown at the upper right. The Early Alert gives a low-assessment report on Management influence early, but it improves as the period observed progresses.

The decision analysis indicated uses the above information to ratchet up the inspection frequency on Major component failures and indicates a special targeted surveillance of Personnel selection practices. A cost/benefit analysis endorses this in the early part of the period. It isn't justified in the latter portion due to lack of Importance/Sensitivity metrics, but a watch on the situation is advisable.

Incident Investigation Simulation. A scenario considered is that maintenance personnel have been working an unusual amount of overtime and it has been brought to the attention of management or inspection personnel. In order to investigate this situation, a limited subset of the Markov Latent Effects structure is necessary. An appropriate subset is shown in Fig. C16. The intent of the simulation is to test the Markov Latent Effects approach capability to indicate root causes and to provide trace-back investigative pointers to those causes.

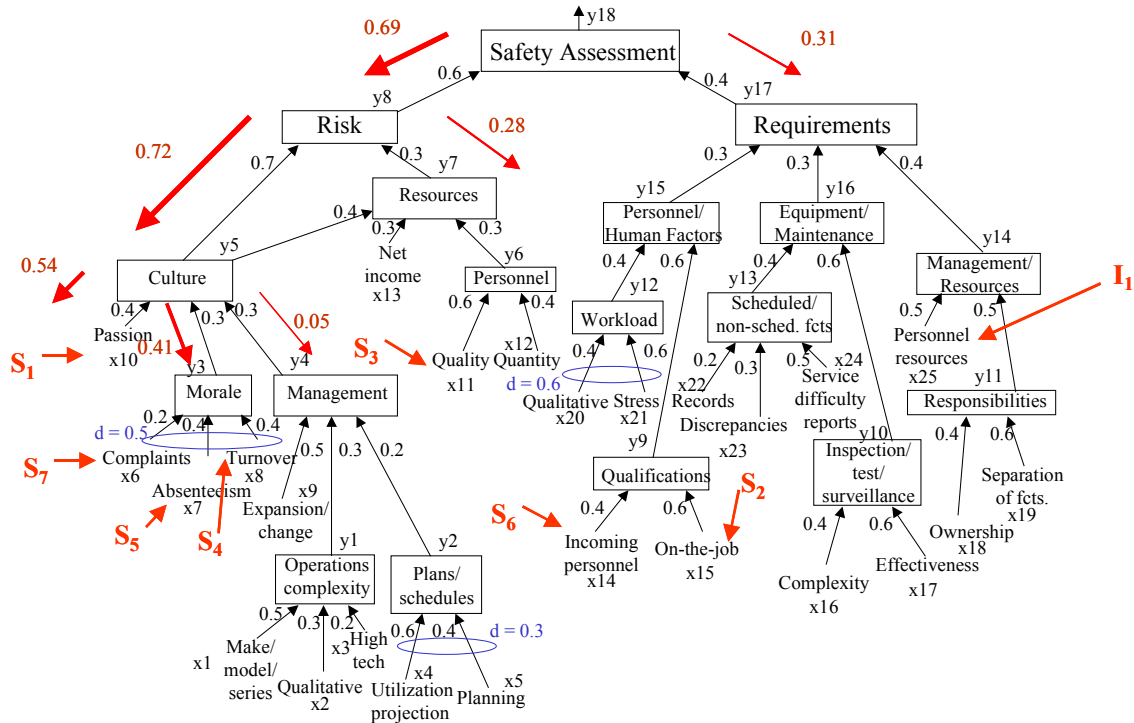


Figure C16. Problem Investigation Scenario

The modules shown in boxes represent factors that might have bearing on the situation. The unboxed inputs (primary inputs) represent measurable data (DOs). The connections between modules (secondary inputs) represent influences of one factor on another. The numbers shown are “weights” for each input. The sum of the weights into each module is one. Dependence groups are illustrated by ellipses and include the amount of dependence. Input assessment values and weights combine to contribute to the overall assessment. Uncertainty (e.g., by possibilistic functions) is also included.

There are 18 outputs generated from 25 inputs in the subset. For the assessment exercise, values were sought for all 25 inputs. The general picture obtained would have been very difficult to assess from these inputs even for this simple scenario without the analysis. For example, the score for the qualitative assessment of Workload indicated a problem, since that is what triggered the investigation. However, Personnel resources were found to be ample, which was unexpected. Many other areas showed potential problems; many showed lack of problems. The analytical soft aggregation was performed, and then Importance (contributing to safety) and Sensitivity (margin for safety improvement) measures were obtained for every input. The findings were significant, as outlined below.

1. The identified problem (excessive overtime) might have been thought to be best associated with the inputs on qualitative assessment of workload (which the surveillance activity had scored at a problematic level) and lack of personnel resources. However, the aggregation assessment found the Workload input number 13 out of 25 in Sensitivity rank (not a major contributor to a safety problem). The Personnel resources might have also been thought to be a candidate for a problem area, but this ranked number 11 in Sensitivity. The results mean it is necessary to look somewhere else for the explanation. This is the objective of the soft aggregation weighted assessment analysis.
2. The number one input in Sensitivity rank was the “Low passion” input to Culture (scored by inspection as poor). The next two in Sensitivity rank were “On-the-job personnel qualifications” and “Quality” of working personnel. The next two pointers were to Personnel turnover and Absenteeism. So the aggregate of information leads in what may be a totally unexpected direction. The indication is that the excessive overtime probably isn’t due to a workload problem, but may very well point out a need to work on the attributes of existing personnel.
3. The Importance metrics show the major contributors to the safety posture the maintenance activity has. Number one in rank is “Personnel resources,” which would be a surprise to anyone who thought this was the main contributor to the problem.

One of the significant benefits of Sensitivity and Importance metrics is guidance on deductive paths leading to an explanation of why particular safety scores are achieved. These transcend Sensitivity and Importance for primary inputs to include secondary inputs (which are crucial to include for path tracing). Starting at the top of Fig. C16, Secondary Importance and Secondary Sensitivity metrics assist in determining the most significant paths down the tree. In this case, we are looking for potential solutions to a perceived problem (as opposed to best practices), so Sensitivity metrics are more

beneficial. Although this only provides guidance among what may be closely competing branches, this process is greatly preferable to exhaustive search or intuitive exploration. Here are results from the computed values:

1. Treating y_8 (output of Risk path) and y_{17} (output of Requirements path) as inputs to the final module, the Secondary Sensitivity of y_8 is 0.69 and the Secondary Sensitivity of y_{17} is 0.31. This indicates that it would be more productive to explore the Risk path first.
2. Since y_8 is derived from y_5 and y_7 , these Secondary Sensitivities are calculated as 0.72 and 0.28, respectively. This suggests examination of the Culture path.
3. Since y_5 is derived from x_{10} , y_3 , and y_4 , these Secondary Sensitivities are calculated as 0.54, 0.41, and 0.05, respectively. This suggests examination of the Passion input as a prime concern, and the Morale input as a significant concern.

Any investigation can be improved through utilization of human skills and experience. However, the systematic derivation of trace-back pointers outlined in this example demonstrates that computed guidance can be valuable in helping assure nothing is missed, in documenting an efficient approach, and in generally making the process more defensible.

Simulation Exercise on New Architecture. A simulation exercise was also run on the current architecture, with the aims of testing the Markov Tool's ability to identify a generic problem and to give guidance on efficiently correcting the problem. Trapezoidal uncertainty (or lesser uncertainty) functions were entered for all 119 inputs. This was done at four separate assessment dates, ranging over the first three months of CY 2001. Four of the input histories are plotted in Fig. C17 as examples.

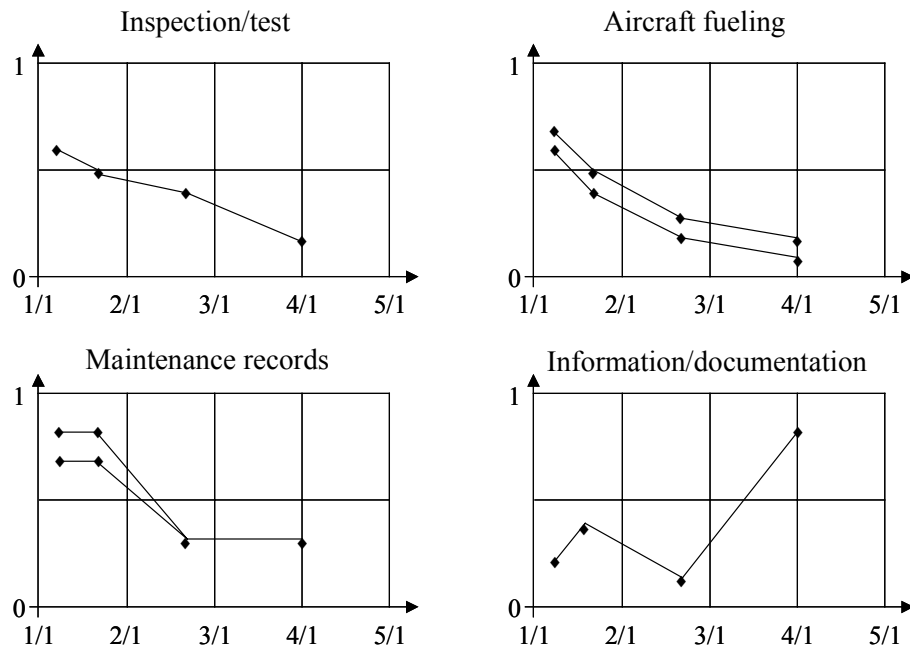


Figure C17. Four Example Input Histories

The inputs shown illustrate that some inputs were improving; some were degrading, although a general scenario was being portrayed. Uncertainty ranged from point values to trapezoids, but only a maximum of interval uncertainty is shown on the plots.

Users are also given word guidance on the meaning of scores. This is shown in Fig. C18.

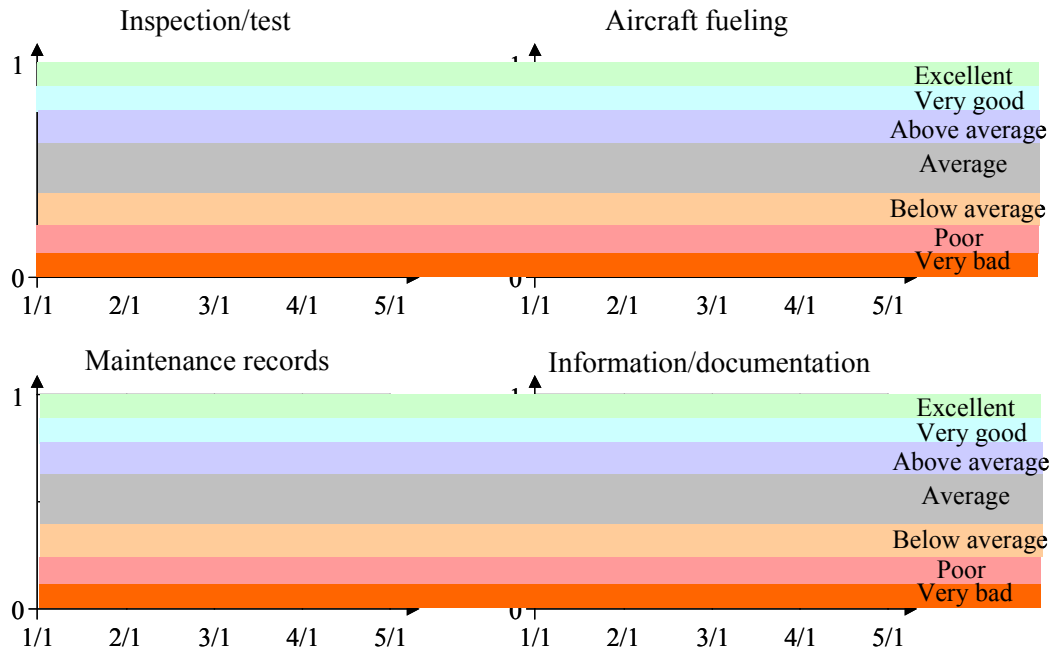


Figure C18. Word Guidance on Meaning of Entered Values

Figure C19 illustrates some examples of the output histories.

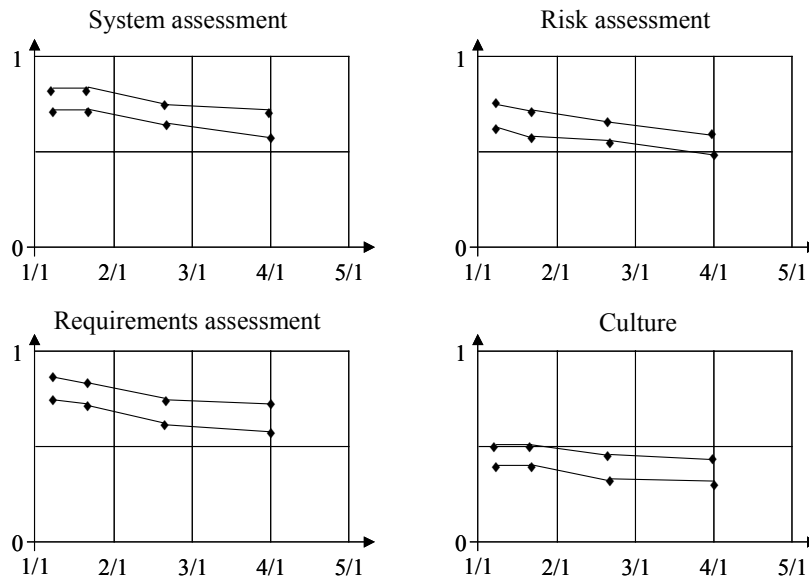


Figure C19. Example Output Histories

Two examples of Early Alerts are shown in Fig. C20. Since these are warnings of danger rather than attributes, the sense of the ordinate is inverse to that of inputs and outputs. Also shown are the individual contributors most responsible for the Early Alert status.

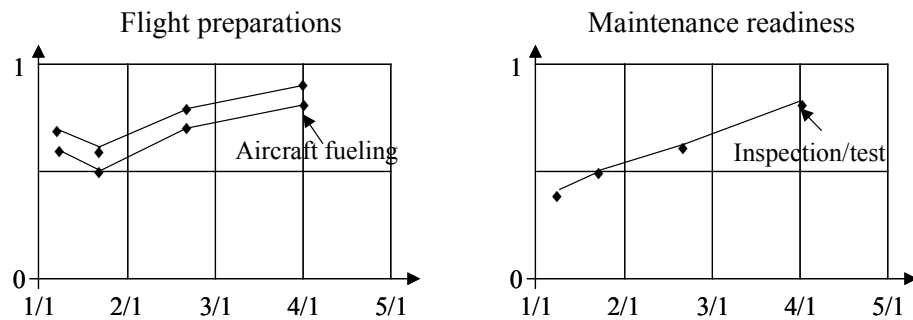


Figure C20. Example Early Alerts

The outputs showed that the overall system assessment was somewhat above average initially, but was degrading slightly with time. The information provided by the Importance and Sensitivity rankings showed that a few of the inputs offered special potential for improvement in system safety. The Early Alerts also flagged two of these same inputs (Aircraft fueling and Inspection/test).

For these reasons, corrective action was limited to the flagged inputs and all others were left alone. The corrective action was in the form of additional surveillance and controls. Because of limited resources, this type of solution must be limited to areas of high payoff potential. That identification capability is one of the major attributes of the Markov approach.

Near the end of the fourth month, inputs were re-evaluated for the critical inputs; all others were left as originally measured. Examples of the results are shown in Fig. C21, where the top two inputs were improved and the bottom two were not.

This is followed by output derivation based on the limited corrective actions. The results are shown in Fig. C22, where the System assessment can be observed to have improved substantially, as did the Risk assessment portion of the system. The two outputs at the bottom of Fig. C22 did not change, because the corrective action did not affect the contributing inputs. Finally, in Fig. C23, the Early Alert status can be seen to have improved substantially.

All of these results could have also been obtained with a massive effort across the entire system. But the point of the exercise is to show that significant changes could be brought about at low cost by knowing exactly where to apply effort.

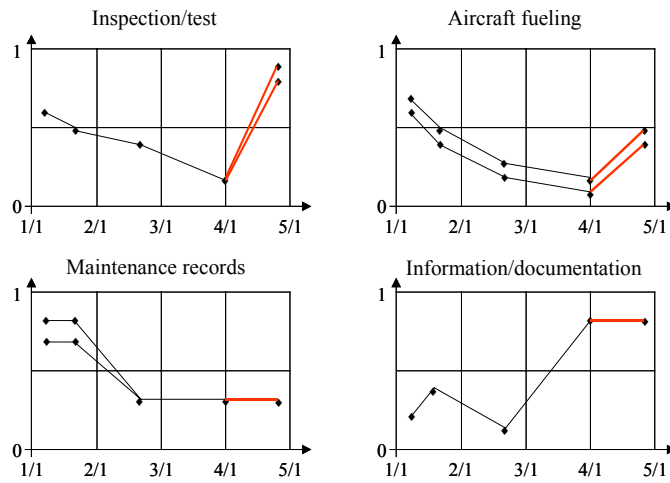


Figure C21. Example Input Histories Following Corrective Action

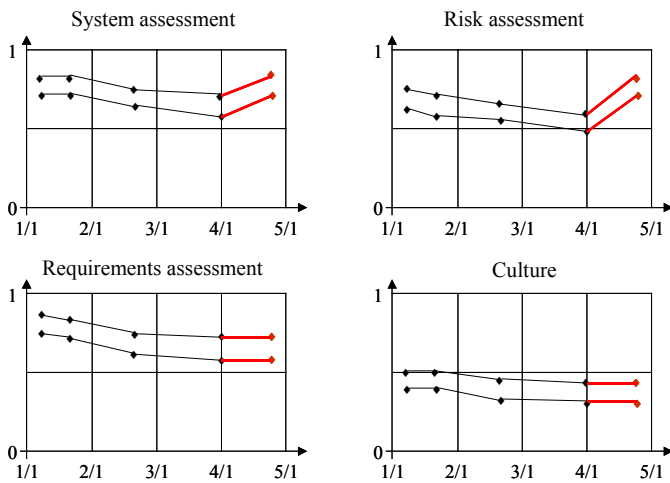


Figure C22. Example Output Histories Following Corrective Action

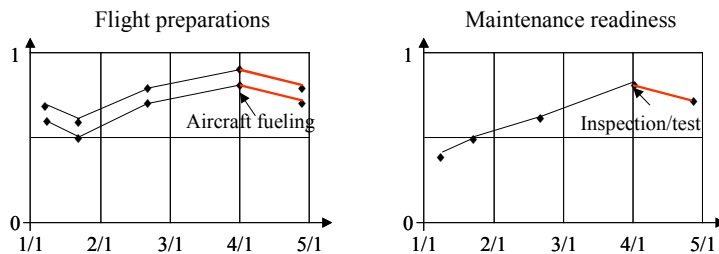


Fig. C23. Example Early Alerts Following Corrective Action

Appendix D: Mathematical Equations

Module and Sub-Module Equations (Including Dependence):

$$v_1 = \frac{1}{1 + e^{-5.5(0.9x_6 + 0.1x_9 - 0.5)}}$$

$$v_2 = \frac{1}{1 + e^{-5.5(0.8x_7 + 0.2x_9 - 0.5)}}$$

$$v_3 = \frac{1}{1 + e^{-5.5(0.9x_8 + 0.1x_9 - 0.5)}}$$

$$v_4 = \frac{1}{1 + e^{-5.5(0.6x_{10} + 0.4x_{11} - 0.5)}}$$

$$y_1 = \frac{1}{1 + e^{-5.5(0.1(\sum_{i=1}^5 x_i + \sum_{i=1}^4 v_i + x_{11}) - 0.5)}}$$

$$y_2 = \frac{1}{1 + e^{-5.5(0.2x_{12} + 0.1y_1 + 0.1\sum_{i=13}^{19} x_i - 0.5)}}$$

$$v_5 = \frac{1}{1 + e^{-5.5(0.1x_{23} + 0.4x_{24} + 0.3x_{25} + 0.2x_{26} - 0.5)}}$$

$$D_1 = 0.5(0.1)(x_{28} + x_{29}) + (0.5)[\min(x_{28}, x_{29})](0.2)$$

$$y_3 = \frac{1}{1 + e^{-5.5(0.2(x_{20} + v_5 + x_{27}) + 0.1(x_{21} + x_{22}) + D_1 - 0.5)}}$$

$$D_2 = 0.5(0.2y_2 + 0.1y_1) + 0.5[\min(y_1, y_2)](0.3)$$

$$y_4 = \frac{1}{1 + e^{-5.5(0.2(x_{31} + x_{33}) + 0.1(x_{30} + x_{32} + x_{34}) + D_2 - 0.5)}}$$

$$y_5 = \frac{1}{1 + e^{-5.5(0.2(x_{36} + x_{39} + y_3) + 0.1(x_{35} + x_{37} + x_{38} + y_4) - 0.5)}}$$

$$v_6 = \frac{1}{1 + e^{-5.5(0.1x_{47} + 0.4x_{44} + 0.3x_{46} + 0.2x_{45} - 0.5)}}$$

$$y_6 = \frac{1}{1 + e^{-5.5(0.2(x_{40} + v_6 + x_{41} + y_1) + 0.1(x_{42} + x_{43}) - 0.5)}}$$

$$v_7 = \frac{1}{1 + e^{-5.5((0.2)(x_{51} + x_{52} + x_{53} + x_{54} + x_{55}) - 0.5)}}$$

$$v_8 = \frac{1}{1 + e^{-5.5(0.4x_{60} + 0.2x_{61} + 0.4x_{62} - 0.5)}}$$

$$y_7 = \frac{1}{1 + e^{-5.5(0.1(x_{48} + x_{49} + v_7 + x_{56} + x_{57} + x_{59} + v_8 + y_4) + 0.05(x_{50} + x_{58} + y_5 + y_6) - 0.5)}}$$

$$D_3 = 0.8(0.2)(x_{63} + x_{64}) + 0.2[\min(x_{63}, x_{64})](0.4)$$

$$y_8 = \frac{1}{1 + e^{-5.5(0.2(x_{66} + x_{67}) + 0.1(x_{65} + x_{68}) + D_3 - 0.5)}}$$

$$y_9 = \frac{1}{1 + e^{-5.5(0.2(x_{69} + x_{71} + x_{75}) + 0.1(x_{70} + x_{72} + x_{73} + x_{74}) - 0.5)}}$$

$$D_4 = 0.8(0.2x_{81} + 0.1x_{80}) + 0.2[\min(x_{81}, x_{80})](0.3)$$

$$y_{10} = \frac{1}{1 + e^{-5.5(0.2(x_{76} + x_{78} + x_{79}) + 0.1x_{77} + D_4 - 0.5)}}$$

$$v_9 = \frac{1}{1 + e^{-5.5((0.2)(x_{83} + x_{84} + x_{85} + x_{86} + x_{87}) - 0.5)}}$$

$$y_{11} = \frac{1}{1 + e^{-5.5(0.1(x_{82} + v_9 + x_{88} + x_{89} + x_{91} + x_{93} + x_{94} + x_{95}) + 0.05(x_{90} + x_{92} + y_{10} + y_8) - 0.5)}}$$

$$y_{12} = \frac{1}{1 + e^{-5.5(0.2(x_{96}) + 0.1(x_{97} + x_{98} + x_{99} + x_{100} + x_{101} + x_{102} + x_{103} + x_{104}) - 0.5)}}$$

$$v_{10} = \frac{1}{1 + e^{-5.5((0.2)(x_{106} + x_{107} + x_{108}) + 0.3x_{105} + 0.1x_{109} - 0.5)}}$$

$$v_{11} = \frac{1}{1 + e^{-5.5((0.2)(x_{112} + x_{113}) + 0.1(x_{110} + x_{111} + x_{114} + x_{115} + x_{116} + x_{117}) - 0.5)}}$$

$$y_{13} = \frac{1}{1 + e^{-5.5(0.2v_{10} + 0.1(v_{11} + x_{118} + x_{119} + y_{78} + y_9 + y_{10} + y_{11} + y_{12}) - 0.5)}}$$

$$y_{14} = \frac{1}{1 + e^{-5.5(0.6y_7 + 0.4y_{13} - 0.5)}}$$

Input Variable Names:

- x_1 = operation maturity
- x_2 = stability vs change
- x_3 = lack of citations & fines
- x_4 = operations simplicity
- x_5 = relations—unions & regulators
- x_6 = control outsourcing & leasing
- x_7 = trends analysis capabilities
- x_8 = planning & scheduling
- x_9 = training quality
- x_{10} = policy quality
- x_{11} = safety organization
- x_{12} = independent assessment
- x_{13} = quality assurance control
- x_{14} = communication style
- x_{15} = lack of blame-placing tendencies
- x_{16} = passion—responsibility—effort
- x_{17} = going beyond regulations
- x_{18} = self-disclosures
- x_{19} = employee morale
- x_{20} = lack of flight accidents & incidents & occurrences
- x_{21} = lessons-learned program
- x_{22} = analysis history
- x_{23} = personnel actions history
- x_{24} = components condition history
- x_{25} = structural conditions history
- x_{26} = wiring conditions history
- x_{27} = major subsystems conditions history

x_{28} = lack of employee fatalities
 x_{29} = lack of employee injuries
 x_{30} = company net income status
 x_{31} = company personnel resources
 x_{32} = company facilities
 x_{33} = company tools availability
 x_{34} = company expendable supplies availability
 x_{35} = information analysis success
 x_{36} = information & documentation accuracy
 x_{37} = information completeness
 x_{38} = information non-ambiguity
 x_{39} = information timeliness
 x_{40} = computing data quality
 x_{41} = computing security
 x_{42} = computing hardware performance
 x_{43} = programming quality
 x_{44} = software backup
 x_{45} = computing hardware backup
 x_{46} = computer communications backup
 x_{47} = computer support personnel backup
 x_{48} = inspections & test quality
 x_{49} = maintenance parts quality
 x_{50} = maintenance equipment age
 x_{51} = dispatch analysis quality
 x_{52} = dispatch flight controls
 x_{53} = dispatch & pilot concurrence
 x_{54} = dispatch fuel margins
 x_{55} = dispatch & ATC relations
 x_{56} = operations human factors
 x_{57} = discrepancy handling quality
 x_{58} = maintenance equipment usability
 x_{59} = margins over authorized defects
 x_{60} = international simplicity
 x_{61} = geographic simplicity
 x_{62} = climatic simplicity
 x_{63} = authorities defined
 x_{64} = responsibilities defined
 x_{65} = adequate personnel resources
 x_{66} = adequate facilities
 x_{67} = sufficient tools
 x_{68} = sufficient expendable supplies
 x_{69} = real-time status & reporting
 x_{70} = complete reports & records
 x_{71} = defined communications channels
 x_{72} = electronic communication links
 x_{73} = software quality

x_{74} = computing hardware quality
 x_{75} = computing backup
 x_{76} = training quality requirements
 x_{77} = workload requirements
 x_{78} = personnel qualifications
 x_{79} = personnel communications
 x_{80} = management & labor relations
 x_{81} = relations with regulators
 x_{82} = condition of maintenance equipment
 x_{83} = maintenance records
 x_{84} = lack maintenance discrepancies
 x_{85} = lack of service difficulty reports
 x_{86} = maintenance training
 x_{87} = maintenance administrative checks
 x_{88} = maintenance surveillance
 x_{89} = parts & supplies availability
 x_{90} = maintenance communications links
 x_{91} = equipment configuration control
 x_{92} = aircraft liquid replenishment
 x_{93} = aircraft weight and balance
 x_{94} = maintenance efficiency
 x_{95} = aircraft fueling
 x_{96} = safety program requirements
 x_{97} = safety policies
 x_{98} = personnel training requirements
 x_{99} = resource requirements
 x_{100} = processes and functions
 x_{101} = trainer qualifications requirements
 x_{102} = trainee qualifications requirements
 x_{103} = lack of non-compliance findings
 x_{104} = programs and procedures
 x_{105} = fuel controls
 x_{106} = maintenance releases
 x_{107} = pre-flight packages
 x_{108} = dispatch releases
 x_{109} = flight monitor backup
 x_{110} = cargo loading
 x_{111} = cargo screening
 x_{112} = cargo securing and handling
 x_{113} = de-icing
 x_{114} = ground vehicle operations
 x_{115} = consumables handling
 x_{116} = cockpit operations
 x_{117} = cabin services
 x_{118} = access control
 x_{119} = customer services

Secondary Input/Module Output Names:

y_1 = management approach
 y_2 = culture
 y_3 = history
 y_4 = resource provisions
 y_5 = information & documentation
 y_6 = computing
 y_7 = operations
 y_8 = management & resources
 y_9 = information & computing
 y_{10} = human factors
 y_{11} = equipment & maintenance
 y_{12} = requirements
 y_{13} = line services
 y_{14} = safety assessment

v_1 = outsourcing & leasing
 v_2 = trends analysis
 v_3 = planning & scheduling capability
 v_4 = policy capability
 v_5 = conditions history
 v_6 = computing backup
 v_7 = dispatch
 v_8 = environment
 v_9 = maintenance functions
 v_{10} = operational control
 v_{11} = ground operations

Dependence groups (function of specified set of dependent variables with amount of dependence specified):

$D_1 = 0.5(x_{28}, x_{29})$
 $D_2 = 0.5(y_1, y_2)$
 $D_3 = 0.2(x_{63}, x_{64})$
 $D_4 = 0.2(x_{80}, x_{81})$

Appendix D. Evaluations

The intent of evaluation is to find out how peers judge the scientifically soundness of the work and to find out from potential users whether or not the tool being developed is useful and usable. As the Markov Tool was being developed, several modes of evaluation were being conducted. The initial development was under the umbrella of the CS⁴ (Certification and Surveillance System Safety Support) activity sponsored by FAA/AAR-424. As the modeling work developed, it was subjected to peer review by the team members. There were also periodic review meetings sponsored by FAA at which FAA and industry personnel participated. A human factors examination was made. Write-ups, such as SAND reports, conference papers, conference publications and journal publications were subjected to company, and national and/or international peer review.

Some of the many questions raised during the evaluations are addressed here. It is important that the issues involved be illuminated so that there are no misunderstandings about what the Markov approach is aimed at and how it is planned to achieve its objectives.

1. *We need analysis tools, but what does the Markov Tool offer?* The main advantages of the Markov Tool are that it is quantitative over a continuum (no “yes/no” inputs), it logically aggregates concerns that might be accumulated over time (latent effects), it accounts for dependence among the inputs, it produces information about how important and sensitive each of the inputs is to the final “grade,” and it can be readily customized to a particular application.
2. *What is the strategic foundation for the Markov Tool?* The overarching strategy (Fig. 6) is really the basic foundation, because the tool works best within that context. The immediate foundation is the way the inputs are derived from data metrics (the Markov aggregation process), as well as the way in which the outputs are used (hybrid analysis and decision-aid analysis). The philosophical foundation is the recognition of latent effects, such as described in the Reason model.
3. *Why was a new architecture necessary?* The 1998 architecture was developed with the knowledge of the necessity of a latent effects structure, but without the benefit of the ASRATS work. We learned much during the ASRATS project about how a two-tiered (risk and performance) structure could benefit safety. The original Markov architecture was not intended to be final.
4. *Is the data collection for the Markov Tool different than that for ASRATS? Who does it?* No, there is no difference. But input aggregation is required for the Markov Tool, and this could have any degree of sophistication desired. Aggregation could be done by a team using the Markov aggregation results, possibly supplemented by appropriate work process guidance in order to recognize relationships that affect data-gathering.
5. *How were the number of inputs and extent of architectural detail determined?* This was a judicious compromise between the benefits of higher definition in higher level of detail and the price in terms of complexity and loss of a top-down system view. For a standalone tool, the decision was made to keep the number of inputs at around 100 (there are 119).

6. *Inspectors aren't analysts. How can they use such a tool?* It may be advantageous for inspectors to become more analytically oriented if they are to be efficient in the future of higher technology systems and more demand for efficiency. Making defensible decisions is also an issue.
7. *Is the tool intended to compare airlines or other competing systems?* This isn't the intent, but it could be used this way. The intent is for each application to customize the tool. If this is done, it works against comparative assessments.
8. *Why isn't the system decomposition based directly on IDEF0?* It is related to IDEF0, in that the system function must be understood in order to actually go out and take measurements. Also, the Performance part of the Markov architecture was linked to IDEF0, although risk considerations also drove it. However, a different architecture (Markov/Reason) was found to be more valuable in identifying global concerns, such as the effects of safety culture, the effects of unambiguous and effective communication, the effects of open communication, the need for an overall safety function, the need for independent assessment, the effects of a highly competitive environment, etc. This information is not kept forever separate from the functional model, or from a future understanding of organizational structure, both of which help determine how these concerns are addressed for a particular situation.
9. *Why aren't processes addressed?* The processes that a particular organization might choose to address a safety risk or concern is of interest, and some of these have already been addressed, but the Markov methodology is generic.
10. *What is the purpose of having three levels, with no rollup?* The Markov tool hierarchy of three levels apparently created some "cognitive dissonance." So it was re-structured to utilize one level. More levels could be added, but the fit with the ASRATS methodology would be weakened.
11. *How are subjective variations in inputs combated?* It is important to have assurance that variations due to the subjectivity involved in selecting parameters such as inputs, weights, and dependence are carefully controlled, and to utilize empirical evidence for the choices.
12. *What is the purpose of the uncertainty capability?* There can be input uncertainty, for example, if (a user organization choice) the user is allowed to select from a zero to one scale to say, "I really can't decide (even looking at the guidance criteria) between a point-two and a point-three." This uncertainty could be captured as 0.2-0.3. The uncertainty feature also allows for sending two inspectors out with the same guidance criteria and getting back a point-two from one inspector and a point-three from the other. The user organization could do anything they want with these types of data, including averaging to take out all uncertainty. But the tool allows the more realistic capture of uncertainty, if so desired.
13. *Should the model parameters be fixed?* The architecture, weights, and dependence should be fixed for a particular application of the tool in order to obtain trends analysis. Infrequent changes could be made (e.g., due to lessons learned) with the recognition that trends would be disrupted. This is a user-organization choice and has nothing to do with the methodology offered.
14. *Are inputs objective or subjective?* One would prefer that all inputs be defined observations, not subjective judgment. That's a good piece of guidance to keep in mind, but the goal can only be approached through the use of the guidance criteria.

However, for “quick looks” and similar applications, the tool allows for subjective inputs.

15. *How can we validate the assumptions inherent in the model?* The Markov evaluation, although not considered complete, addresses this issue. But they aren’t really assumptions—we have background literature and/or experience that helps justify the approach and its details.
16. *What do I do with an output, say of 0.5?* The actual output is meaningful, but not as meaningful as trends associated with the output. It’s analogous to a teacher grading students—You need to know how the grade (Markov output) was derived and how other similar students (airlines) might perform in a similar grading situation. If different teams, different weights, etc., were used for different airlines, comparative data would not be useful for specific comparison (e.g., a 4 compared to a 6). But in any situation you would know that a 0 was very bad and a 1.0 was very good. And when everything else is constant, a declining grade is important information about safety getting worse.
17. *What actions do inspectors take?* The real decisions are foreseen to be made at the team level, although the inspectors could take action. Beyond the obvious results (when something is going bad, look at it in more depth or cause changes in it), the decision-aid tool capabilities could assist in determining actions. Lots of expertise is still required to do this job right. The Markov Tool gives a focused starting point for inspection expertise to take over, utilizing a systemic approach.
18. *Shouldn’t aggregation of the Risk decomposition and the Requirements decomposition be joined at a lower level?* There hasn’t been any scientific evidence found supporting one way over the other, but it makes logical sense to keep them separate since evaluation might be sought of some risk or functional subsystem, for example, of compliance with requirements.

Appendix E. Software Implementations

In early 2001, Tom Witkowski proposed converting the Markov Tool to a web-based version. Following a decision to do so, all work ceased on the Windows-based version, which was being worked on at Gram, Inc., by Tony Zimmerman and two assistants. It is now archived, but its features assisted the new work. With LDRD support, we also continued Bob Roginski's Markov programming, which is a Fortran/DOS version. This enabled crosschecking results and efficiently separating the mathematical processing from the user interfacing. The decision was also made to use 0-to-1 inputs and outputs, and to allow either fixed inputs or uncertain inputs, carrying upper and lower bounds (at various levels of presumption) into the calculations.

Various security features were added to the Markov Tool, so that users can use a common structure, but will continue to be isolated from each other. An illustration of the security logic is shown in Fig. F1. The login requires a username, which is the user's e-mail address. A password is also required. The connecting computer IP (Internet Protocol) address and a random number also become part of the user's session ID. This prevents any potential capture of session information observed from the user's computer being applied to another computer. The random number allows session identification and isolation. The configuration of the Web page displayed for inputs is tailored to the user's authorizations, thereby controlling input privileges.

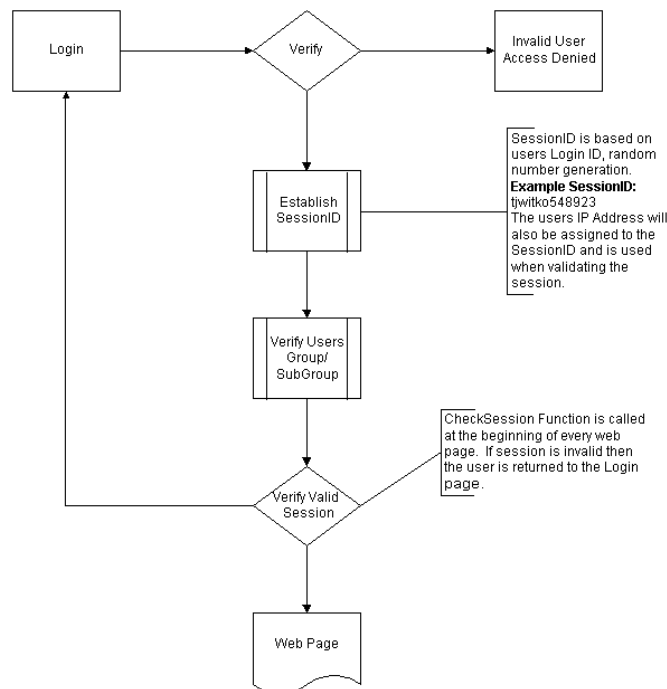


Figure F1. Security Strategy

An image of the login screen is shown in Fig. F2.



Figure 2. Login Screen Image

Once identified, the user sees a screen that introduces the Markov architecture, as shown in Fig. F3.

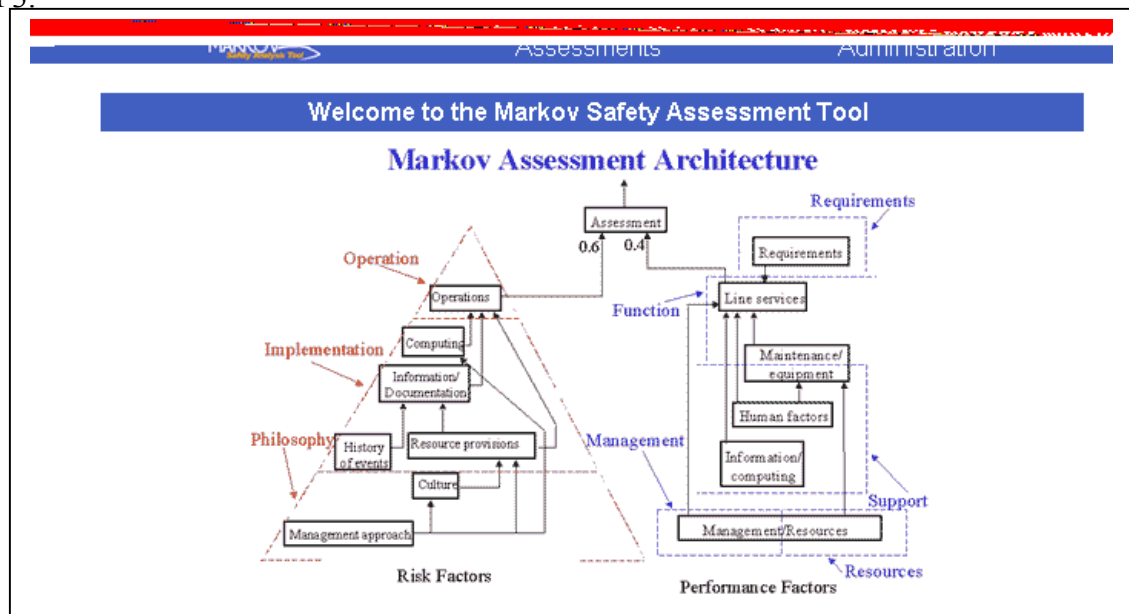


Figure F3. Screen Display of Markov Architecture

Appended below the architecture is a summary description of the Markov Tool and its intended application. An image of this information is displayed in Fig. F4.

This analysis tool is based on a top-down system assessment model of a generic Part 121 air transportation operation, which is used to calculate bottom-up aggregation safety scores using inputs that can be measured by inspection. The scores are calculated for the entire system and for its subsystems. In addition to calculation of safety scores, trends history of these scores is provided for tracking multiple situations. There are also early alerts, where action need not wait on trends history accumulation.

A secondary capability of the tool is based on "trace-back" metrics to help investigate which parts of the system have the most potential for cost-effective safety improvement, and which parts are the most successful in contributing to safety. These are termed "importance" (success) measures, "sensitivity" (potential for improvement) measures, and productive investigation path indications (secondary importance and sensitivity), all of which can support investigations.

Figure F4. Displayed Description of Markov Tool

A user with proper authorization will be able to view and/or add assessments. The assessment selection window is shown in Fig. F5. "Assessment Group" partitioning is to allow application of the Markov Tool to different subsystems for an authorized organization.

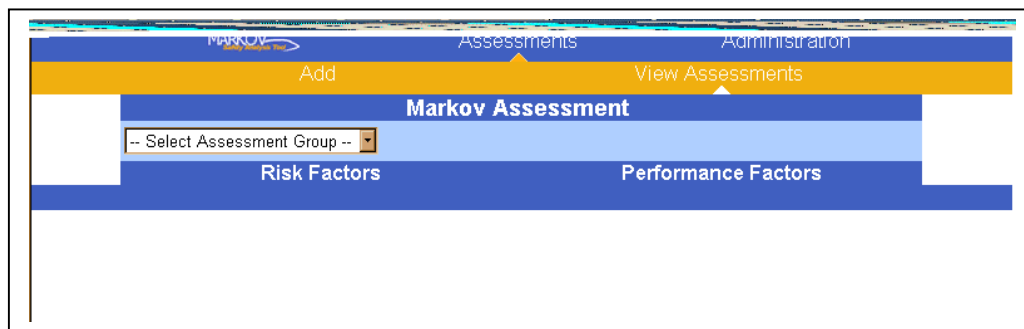


Figure F5. Assessment Group Window

Figure F6 shows access to a particular assessment made at a particular date within the Assessment Group. The date is associated with the beginning of the assessment entries and is appended to the group name.



Figure F6. Window for One Factor of Assessment Group at a Particular Date

When a Factor is displayed, inputs pertinent to that module are shown. An example is displayed in Fig. F7, where the “Computing Data Quality” input for the “Computing” module in the Risk Factor section is being entered. Both the slider near the top of the entry portion and the numbers in the boxes below display the entered values. These can be entered by clicking and dragging the sliders or by numeric entry in the boxes. Software checks assure that the upper bound is at least as large as the lower bound.

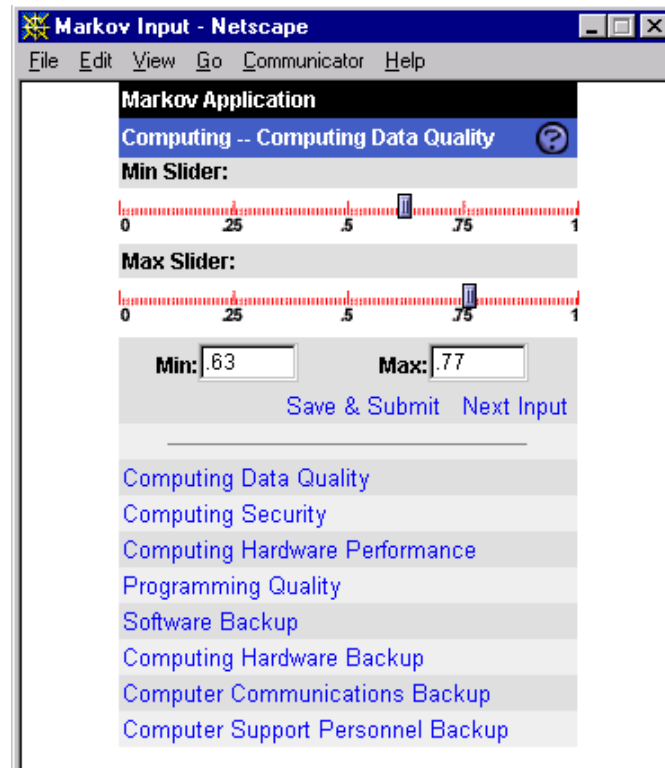


Figure F7. Screen Shot of Input Entry

The complete list of Web-based software tools is:

Windows 2000 – Operating System for the web server

Internet Information Server 5.0 – Web server, which handles and distributes web requests.

VBScript – Server Side programming language used to access the database and to perform calculations. VBScript is a subset of the Visual Basic language.

Active Server Pages – This is an object model used by Internet Information Server. Active Server Pages will have the “.asp” extension, unlike “normal” HTML pages which have the “.htm” or “.html” extension.

Microsoft Access – Program used to create and manage the Markov Database.(Development Environment Only—We will probably use SQL Server in final version)

Microsoft SQL Server 7.0 – When Markov is ready to be placed in a production environment then we will need to migrate the database to SQL Server.

Software Artisans ExcelWriter – Used to generate dynamic graphs for Trends plotting.

HTML – Markup language used by web browsers to display information to the client.

Javascript/DHTML – Scripting languages used to produce the sliders application.

The FORTRAN software can be best understood by seeing a listing from one of the simulation programs. The listing shows all inputs entered (with up-to-trapezoidal uncertainty) for five evaluation dates. It shows all output calculations, including Early Alerts, and intermediate calculations, such as dependence groups and Sub-Factors.

Execution No. 1: Simulated Run Date: 01/04/2001

The following is a listing of COSMET Input File FAA-DAY1.DAT

```
$*****
$   File Name: FAA-DAY1.DAT (1 of 5)       Simulated Run Date: 01/04/2001   *
$                                           *
$   Prepared by:  Bob Roginski           Last Modified:  04/30/2001         *
$*****

DEBUGINFO                = Yes                $ Add Debugging Info. to QA File
SOLVECUTSETEQUATION      = No
$$$ CAPTURE               = FAA-CAP2.DAT  $ Capture Results in this file

$*****
$ The following modules define the Risk Management Approach  *
$*****

MODULE:   X9-OUTPUT                $ Training
  INPUT:   X9                      1.0
           0.8
  END-INPUT
END-MODULE

MODULE:   V1                      $ Control of Outsourcing / Leasing
  INPUT:   X6                      0.8
           0.2    0.3
  END-INPUT
  INPUT:   X9-OUTPUT              0.2
END-MODULE
```

```

MODULE:  V2                                $ Trends Analysis
  INPUT:  X7                                0.8
          0.65    0.7    0.8    0.85
  END-INPUT
  INPUT:  X9-OUTPUT                        0.2
END-MODULE

MODULE:  V3                                $ Planning / Scheduling
  INPUT:  X8                                0.9
          0.65    0.7    0.8    0.85
  END-INPUT
  INPUT:  X9-OUTPUT                        0.1
END-MODULE

MODULE:  X11-OUTPUT                        $ Safety Organization
  INPUT:  X11                                1.0
          0.65    0.7    0.8    0.85
  END-INPUT
END-MODULE

MODULE:  V4                                $ Safety Policy
  INPUT:  X10                                0.6
          0.65    0.7    0.8    0.85
  END-INPUT
  INPUT:  X11-OUTPUT                        0.4
END-MODULE

MODULE:  Y1                                $ Management Approach
  INPUT:  X1                                0.1
          0.65    0.7    0.8    0.85
  END-INPUT
  INPUT:  X2                                0.1
          0.65    0.7    0.8    0.85
  END-INPUT
  INPUT:  X3                                0.1
          0.5
  END-INPUT
  INPUT:  X4                                0.1
          0.65    0.7    0.8    0.85
  END-INPUT
  INPUT:  X5                                0.1
          0.5
  END-INPUT
  INPUT:  V1                                0.1
  INPUT:  V2                                0.1
  INPUT:  V3                                0.1
  INPUT:  V4                                0.1
  INPUT:  X11-OUTPUT                        0.1
END-MODULE

$*****
$ The following module defines the Risk Culture *
$*****

MODULE:  Y2                                $ Culture
  INPUT:  X12                                0.2
          0.2    0.3
  END-INPUT
  INPUT:  X13                                0.1
          0.5
  END-INPUT
  INPUT:  X14                                0.1
          0.3    0.4
  END-INPUT

```



```

INPUT:      X15      0.1
            0.3      0.4
END-INPUT
INPUT:      X16      0.1
            0.2      0.3
END-INPUT
INPUT:      X17      0.1
            0.65     0.7     0.8     0.85
END-INPUT
INPUT:      X18      0.1
            0.65     0.7     0.8     0.85
END-INPUT
INPUT:      X19      0.1
            0.3
END-INPUT
INPUT:      Y1      0.1
END-MODULE

```

```

$*****
$ The following modules defines the Risk History of Events  *
$*****

```

```

MODULE:  V5      $ Conditions
INPUT:   X23      0.1
        0.65     0.7     0.8     0.85
END-INPUT
INPUT:   X24      0.4
        0.2
END-INPUT
INPUT:   X25      0.3
        0.8
END-INPUT
INPUT:   X26      0.2
        0.65     0.7     0.8     0.85
END-INPUT
END-MODULE

```

```

MODULE:  Y3      $ History
INPUT:   X20      0.2
        0.65     0.7     0.8     0.85
END-INPUT
INPUT:   X21      0.1
        0.65     0.7     0.8     0.85
END-INPUT
INPUT:   X22      0.1
        0.65     0.7     0.8     0.85
END-INPUT
INPUT:   V5      0.2
INPUT:   X27      0.2
        0.65     0.7     0.8     0.85
END-INPUT
DEPENDENCY-GROUP: 0.5
INPUT:   X28      0.1
        0.8
END-INPUT
INPUT:   X29      0.1
        0.8
END-INPUT
END-GROUP
END-MODULE

```

```

$*****
$ The following module defines the Risk Resource Provisions *
$*****

```

```

MODULE:  Y4      $ Resource Provisions

```

```

INPUT:      X30      0.1
            0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X31      0.2
            0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X32      0.1
            0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X33      0.2
            0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X34      0.1
            0.65    0.7    0.8    0.85
END-INPUT
DEPENDENCY-GROUP: 0.5
    INPUT:  Y2      0.2
    INPUT:  Y1      0.1
END-GROUP
END-MODULE

```

```

$*****
$ The following module defines the Risk Information / Documentation *
$*****

```

```

MODULE:  Y5      $ Information / Documentation
INPUT:   X35      0.1
        0.65    0.7    0.8    0.85
END-INPUT
INPUT:   X36      0.2
        0.2
END-INPUT
INPUT:   X37      0.1
        0.65    0.7    0.8    0.85
END-INPUT
INPUT:   X38      0.1
        0.65    0.7    0.8    0.85
END-INPUT
INPUT:   X39      0.2
        0.65    0.7    0.8    0.85
END-INPUT
INPUT:   Y3      0.2
INPUT:   Y4      0.1
END-MODULE

```

```

$*****
$ The following modules define the Risk Computing *
$*****

```

```

MODULE:  V6      $ Backup
INPUT:   X44      0.4
        0.5
END-INPUT
INPUT:   X45      0.2
        0.5
END-INPUT
INPUT:   X46      0.3
        0.5
END-INPUT
INPUT:   X47      0.1
        0.5
END-INPUT
END-MODULE

```

```

MODULE:  Y6      $ Computing
INPUT:   X40      0.2

```

```

        0.5
END-INPUT
INPUT:    X41          0.2
        0.65    0.7    0.8    0.85
END-INPUT
INPUT:    X42          0.1
        0.65    0.7    0.8    0.85
END-INPUT
INPUT:    X43          0.1
        0.65    0.7    0.8    0.85
END-INPUT
INPUT:    V6          0.2
INPUT:    Y1          0.2
END-MODULE

```

```

$*****
$ The following modules define the Risk Operations *
$*****

```

```

MODULE:    V7                                $ Dispatch
INPUT:     X51          0.2
          0.5
END-INPUT
INPUT:     X52          0.2
          0.65    0.7    0.8    0.85
END-INPUT
INPUT:     X53          0.2
          0.65    0.7    0.8    0.85
END-INPUT
INPUT:     X54          0.2
          0.65    0.7    0.8    0.85
END-INPUT
INPUT:     X55          0.2
          0.65    0.7    0.8    0.85
END-INPUT
END-MODULE

```

```

MODULE:    V8                                $ Environment Variations
INPUT:     X60          0.4
          0.3
END-INPUT
INPUT:     X61          0.2
          0.3
END-INPUT
INPUT:     X62          0.4
          0.3
END-INPUT
END-MODULE

```

```

MODULE:    Y7                                $ Operations
INPUT:     X48          0.1
          0.6
END-INPUT
INPUT:     X49          0.1
          0.65    0.7    0.8    0.85
END-INPUT
INPUT:     X50          0.05
          0.65    0.7    0.8    0.85
END-INPUT
INPUT:     X56          0.1
          0.5
END-INPUT
INPUT:     X57          0.1
          0.5
END-INPUT
INPUT:     X58          0.05
          0.65    0.7    0.8    0.85

```

```

END-INPUT
INPUT:      X59          0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      V7          0.1
INPUT:      V8          0.1
INPUT:      Y4          0.1
INPUT:      Y5          0.05
INPUT:      Y6          0.05
END-MODULE

```

```

$*****
$ The following module defines the Performance Management / Resources *
$*****

```

```

MODULE:      Y8                      $ Management / Resources
DEPENDENCY-GROUP: 0.2
  INPUT:      X63          0.2
           0.65    0.7    0.8    0.85
  END-INPUT
  INPUT:      X64          0.2
           0.65    0.7    0.8    0.85
  END-INPUT
END-GROUP
INPUT:      X65          0.1
           0.7
END-INPUT
INPUT:      X66          0.2
           0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X67          0.2
           0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X68          0.1
           0.65    0.7    0.8    0.85
END-INPUT
END-MODULE

```

```

$*****
$ The following module defines the Performance Information / Computing *
$*****

```

```

MODULE:      Y9                      $ Information / Computing
INPUT:      X69          0.2
           0.3
END-INPUT
INPUT:      X70          0.1
           0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X71          0.2
           0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X72          0.1
           0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X73          0.1
           0.6
END-INPUT
INPUT:      X74          0.1
           0.65    0.7    0.8    0.85
END-INPUT
INPUT:      X75          0.2
           0.5
END-INPUT
END-MODULE

```

```

$*****
$ The following module defines the Performance Human Factors  *
$*****

```

```

MODULE:    Y10                                $ Human Factors
  INPUT:    X76                                0.2
            0.6
  END-INPUT
  INPUT:    X77                                0.1
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X78                                0.2
            0.6
  END-INPUT
  INPUT:    X79                                0.2
            0.65  0.7  0.8  0.85
  END-INPUT
  DEPENDENCY-GROUP: 0.2
    INPUT:  X80                                0.1
            0.6
    END-INPUT
    INPUT:  X81                                0.2
            0.6
    END-INPUT
  END-GROUP
END-MODULE

```

```

$*****
$ The following modules define the Performance Equipment / Maintenance *
$*****

```

```

MODULE:    V9                                $ Functions
  INPUT:    X83                                0.2
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X84                                0.2
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X85                                0.2
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X86                                0.2
            0.6
  END-INPUT
  INPUT:    X87                                0.2
            0.6
  END-INPUT
END-MODULE

```

```

MODULE:    Y11                                $ Equipment / Maintenance
  INPUT:    X82                                0.1
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X88                                0.1
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X89                                0.1
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X90                                0.05
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X91                                0.1
            0.65  0.7  0.8  0.85
  END-INPUT
  INPUT:    X92                                0.05
            0.65  0.7  0.8  0.85

```

```

END-INPUT
INPUT:      X93          0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X94          0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X95          0.1
           0.6      0.7

END-INPUT
INPUT:      V9          0.1
INPUT:      Y10         0.05
INPUT:      Y8          0.05
END-MODULE

```

```

$*****
$ The following module defines the Performance Requirements *
$*****

```

```

MODULE:      Y12                      $ Requirements
INPUT:      X96          0.2
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X97          0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X98          0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X99          0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X100         0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X101         0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X102         0.1
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X103         0.1
           0.6

END-INPUT
INPUT:      X104         0.1
           0.65    0.7    0.8    0.85

END-INPUT
END-MODULE

```

```

$*****
$ The following modules define the Performance Line Services *
$*****

```

```

MODULE:      V10                      $ Operational Control
INPUT:      X105         0.3
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X106         0.2
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X107         0.2
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X108         0.2
           0.65    0.7    0.8    0.85

END-INPUT
INPUT:      X109         0.1

```

```

        0.65    0.7    0.8    0.85
END-INPUT
END-MODULE

```

```

MODULE:    V11                                $ Ground Operations
  INPUT:    X110                                0.1
            0.3    0.4
END-INPUT
  INPUT:    X111                                0.1
            0.65    0.7    0.8    0.85
END-INPUT
  INPUT:    X112                                0.2
            0.3    0.4
END-INPUT
  INPUT:    X113                                0.2
            0.65    0.7    0.8    0.85
END-INPUT
  INPUT:    X114                                0.1
            0.65    0.7    0.8    0.85
END-INPUT
  INPUT:    X115                                0.1
            0.65    0.7    0.8    0.85
END-INPUT
  INPUT:    X116                                0.1
            0.65    0.7    0.8    0.85
END-INPUT
  INPUT:    X117                                0.1
            0.65    0.7    0.8    0.85
END-INPUT
END-MODULE

```

```

MODULE:    Y13                                $ Line Services
  INPUT:    X118                                0.1
            0.65    0.7    0.8    0.85
END-INPUT
  INPUT:    X119                                0.1
            0.65    0.7    0.8    0.85
END-INPUT
  INPUT:    V10                                0.2
  INPUT:    V11                                0.1
  INPUT:    Y8                                  0.1
  INPUT:    Y9                                  0.1
  INPUT:    Y10                                 0.1
  INPUT:    Y11                                 0.1
  INPUT:    Y12                                 0.1
END-MODULE

```

```

$*****
$ The following module defines the Overall Safety Assessment *
$*****

```

```

MODULE:    Y14                                $ Assessment
  INPUT:    Y7                                  0.6
  INPUT:    Y13                                 0.4
END-MODULE

```

```

$*****
$ The following are the Early Alert Definitions *
$*****

```

```

EARLY-ALERT:
  E1 = X95 | X110 | X112 | X113 | X93
END-ALERT

```

```

EARLY-ALERT:
  E2 = X48 | X86 | X87
END-ALERT

```

```

EARLY-ALERT:
  E3 = X9 & ( X76 | X78 | X86 )
END-ALERT

```

```

EARLY-ALERT:
  E4 = X81 & ( X3 | X103 )
END-ALERT

```

```

EARLY-ALERT:
  E5 = Y2 & ( X14 | X16 | X17 | X19 )
END-ALERT

```

```

EARLY-ALERT:
  E6 = X6 | X7 | X12 | X21 | X24
END-ALERT

```

The following table contains the module output values for 01/04/2001.

Table No. 63 (Module Table Part II)
NMODLS = 27 MAXMOD = 100

No.	MODNAM	NORMOD	OUTMOD	OUTMOD	OUTMOD	OUTMOD
1.	X9-OUTPUT	1	0.838891	0.838891	0.838891	0.838891
2.	V1	2	0.279444	0.279444	0.375845	0.375845
3.	V2	4	0.737455	0.777781	0.844589	0.871331
4.	V3	4	0.716850	0.764298	0.841761	0.872015
5.	X11-OUTPUT	4	0.695297	0.750260	0.838891	0.872695
6.	V4	4	0.715989	0.770400	0.850122	0.878140
7.	Y1	4	0.646175	0.688518	0.765516	0.791008
8.	Y2	4	0.359024	0.377232	0.481517	0.498764
9.	V5	4	0.520613	0.541157	0.581759	0.601687
10.	Y3	4	0.700079	0.737937	0.803756	0.831578
11.	Y4	4	0.604406	0.657694	0.768987	0.806250
12.	Y5	4	0.589043	0.638408	0.726527	0.762362
13.	V6	1	0.500000	0.500000	0.500000	0.500000
14.	Y6	4	0.620293	0.656418	0.721531	0.748402
15.	V7	4	0.659260	0.706822	0.789182	0.823465
16.	V8	1	0.249740	0.249740	0.249740	0.249740
17.	Y7	4	0.590840	0.629231	0.699005	0.727438
18.	Y8	4	0.701091	0.750260	0.831318	0.863244
19.	Y9	4	0.561561	0.595078	0.659260	0.689439
20.	Y10	4	0.653056	0.671505	0.706822	0.723622
21.	V9	4	0.671505	0.706822	0.770299	0.798187
22.	Y11	4	0.695131	0.741684	0.826590	0.856053
23.	Y12	4	0.689439	0.739814	0.823465	0.856620
24.	V10	4	0.695297	0.750260	0.838891	0.872695
25.	V11	4	0.561561	0.608259	0.729088	0.765397
26.	Y13	4	0.701372	0.750993	0.827766	0.853194
27.	Y14	4	0.677606	0.726840	0.798638	0.821650

The next table contains the intermediate Dependency Group calculations for 01/04/2001.

Table No. 66 (Dependency Group Table)
NMGRPS = 4 MXDGRP = 300

No.	DEPAMT	NORGRP	GRPOUT	GRPOUT	GRPOUT	GRPOUT
1.	0.500000	1	0.160000	0.160000	0.160000	0.160000
2.	0.500000	4	0.122065	0.128734	0.158655	0.164241
3.	0.200000	4	0.260000	0.280000	0.320000	0.340000
4.	0.200000	1	0.180000	0.180000	0.180000	0.180000

The next table shows the primary Importance and Sensitivity values calculated for all primary inputs in all modules for 01/04/2001.

Table No. 67 (Markov Importance & Sensitivity Table)
NPINPS = 119 MAXINP = 1000

No.	INPNAM	PRIPTR	MKVIMP	IMPIDX	MKVSEN	SENIDX
1.	X9	1	7.073572E-04	57	8.341984E-05	59
2.	X6	2	3.253953E-04	62	9.288987E-04	60
3.	X7	4	1.251491E-03	56	1.921960E-04	56
4.	X8	6	1.330092E-03	59	2.136361E-04	53
5.	X11	8	2.116256E-03	60	3.031649E-04	55
6.	X10	9	9.933913E-04	118	1.578471E-04	57
7.	X1	11	1.403523E-03	119	4.071617E-04	62
8.	X2	12	1.403523E-03	58	4.071617E-04	54
9.	X3	13	9.067793E-04	61	7.828349E-04	58
10.	X4	14	1.403523E-03	105	4.071617E-04	61
11.	X5	15	9.067793E-04	31	7.828349E-04	118
12.	X12	21	1.432207E-03	33	4.000784E-03	119
13.	X13	22	1.432207E-03	49	1.419096E-03	48
14.	X14	23	1.004733E-03	50	1.833531E-03	36
15.	X15	24	1.004733E-03	51	1.833531E-03	69
16.	X16	25	7.182119E-04	52	2.105579E-03	112
17.	X17	26	2.134680E-03	106	7.149069E-04	75
18.	X18	27	2.134680E-03	107	7.149069E-04	105
19.	X19	28	8.615872E-04	108	1.970013E-03	12
20.	X23	30	1.758260E-04	48	5.477362E-05	31
21.	X24	31	1.879271E-04	63	4.721037E-04	33
22.	X25	32	5.604705E-04	64	1.269618E-04	44
23.	X26	33	3.573193E-04	79	1.069138E-04	49
24.	X20	34	1.548166E-03	53	3.783297E-04	50
25.	X21	35	6.998382E-04	55	1.978285E-04	51
26.	X22	36	6.998382E-04	71	1.978285E-04	52
27.	X27	38	1.548166E-03	113	3.783297E-04	76
28.	X28	39	1.193044E-03	39	8.124274E-05	78
29.	X29	40	1.193044E-03	45	8.124274E-05	106
30.	X30	41	7.049620E-03	30	2.054244E-03	107
31.	X31	42	1.517876E-02	32	3.953532E-03	108
32.	X32	43	7.049620E-03	34	2.054244E-03	110
33.	X33	44	1.517876E-02	81	3.953532E-03	81
34.	X34	45	7.049620E-03	66	2.054244E-03	71
35.	X35	48	3.452155E-03	67	1.037997E-03	16
36.	X36	49	1.784363E-03	96	5.492914E-03	30
37.	X37	50	3.452155E-03	76	1.037997E-03	32
38.	X38	51	3.452155E-03	78	1.037997E-03	34
39.	X39	52	7.238904E-03	109	2.011305E-03	79
40.	X44	55	2.235457E-03	75	1.990507E-03	39
41.	X45	56	1.170335E-03	44	1.099498E-03	113
42.	X46	57	1.725685E-03	54	1.575971E-03	40
43.	X47	58	5.876223E-04	80	5.692091E-04	45
44.	X40	59	4.659557E-03	70	3.708420E-03	19
45.	X41	60	7.204007E-03	72	1.988576E-03	14

46.	X42	61	3.426313E-03	74	1.026969E-03	15
47.	X43	62	3.426313E-03	77	1.026969E-03	73
48.	X51	65	8.561369E-03	111	6.273904E-03	42
49.	X52	66	1.358532E-02	114	3.420553E-03	66
50.	X53	67	1.358532E-02	115	3.420553E-03	67
51.	X54	68	1.358532E-02	116	3.420553E-03	96
52.	X55	69	1.358532E-02	117	3.420553E-03	109
53.	X60	70	7.570572E-03	35	2.400152E-02	13
54.	X61	71	4.127552E-03	37	1.173504E-02	80
55.	X62	72	7.570572E-03	38	2.400152E-02	63
56.	X48	73	4.832792E-02	46	2.654519E-02	64
57.	X49	74	6.192306E-02	47	1.712059E-02	103
58.	X50	75	2.903123E-02	112	8.783238E-03	70
59.	X56	76	3.958411E-02	69	3.248357E-02	72
60.	X57	77	3.958411E-02	73	3.248357E-02	74
61.	X58	78	2.903123E-02	68	8.783238E-03	41
62.	X59	79	6.192306E-02	97	1.712059E-02	95
63.	X63	85	7.951745E-03	98	1.236709E-03	77
64.	X64	86	7.951745E-03	99	1.236709E-03	111
65.	X65	87	2.633484E-03	100	9.450708E-04	114
66.	X66	88	6.372832E-03	101	1.517020E-03	115
67.	X67	89	6.372832E-03	102	1.517020E-03	116
68.	X68	90	2.844941E-03	104	7.949319E-04	117
69.	X69	91	2.867666E-03	87	5.359661E-03	35
70.	X70	92	3.620743E-03	88	1.106912E-03	37
71.	X71	93	7.484744E-03	89	2.152441E-03	38
72.	X72	94	3.620743E-03	91	1.106912E-03	46
73.	X73	95	2.867666E-03	93	1.741904E-03	47
74.	X74	96	3.620743E-03	94	1.106912E-03	65
75.	X75	97	4.896848E-03	65	4.044222E-03	2
76.	X76	98	5.940892E-03	95	3.106873E-03	68
77.	X77	99	3.564560E-03	40	1.052371E-03	97
78.	X78	100	5.940892E-03	103	3.106873E-03	98
79.	X79	101	7.588877E-03	17	2.031006E-03	99
80.	X80	102	4.028097E-03	18	1.333889E-03	100
81.	X81	103	6.595516E-03	5	2.546435E-03	101
82.	X83	104	6.219549E-04	36	1.592163E-04	102
83.	X84	105	6.219549E-04	42	1.592163E-04	104
84.	X85	106	6.219549E-04	110	1.592163E-04	9
85.	X86	107	4.830889E-04	24	2.423985E-04	11
86.	X87	108	4.830889E-04	27	2.423985E-04	87
87.	X82	109	2.770135E-03	12	7.775890E-04	88
88.	X88	110	2.770135E-03	13	7.775890E-04	89
89.	X89	111	2.770135E-03	7	7.775890E-04	91
90.	X90	112	1.302301E-03	8	3.977003E-04	93
91.	X91	113	2.770135E-03	10	7.775890E-04	94
92.	X92	114	1.302301E-03	4	3.977003E-04	17
93.	X93	115	2.770135E-03	90	7.775890E-04	18
94.	X94	116	2.770135E-03	92	7.775890E-04	43
95.	X95	117	2.362605E-03	3	1.068892E-03	21
96.	X96	121	6.222717E-03	28	1.500985E-03	7
97.	X97	122	2.794290E-03	29	7.855703E-04	8
98.	X98	123	2.794290E-03	41	7.855703E-04	10
99.	X99	124	2.794290E-03	14	7.855703E-04	90
100.	X100	125	2.794290E-03	15	7.855703E-04	92
101.	X101	126	2.794290E-03	6	7.855703E-04	24
102.	X102	127	2.794290E-03	9	7.855703E-04	27
103.	X103	128	2.182644E-03	11	1.223057E-03	5
104.	X104	129	2.794290E-03	19	7.855703E-04	85
105.	X105	130	2.084759E-02	16	4.028349E-03	86
106.	X106	131	1.243448E-02	1	2.827632E-03	4
107.	X107	132	1.243448E-02	25	2.827632E-03	25
108.	X108	133	1.243448E-02	26	2.827632E-03	26
109.	X109	134	5.441961E-03	82	1.488228E-03	3
110.	X110	135	1.561826E-03	83	2.559584E-03	82
111.	X111	136	3.480380E-03	84	1.039166E-03	83
112.	X112	137	3.233773E-03	43	4.648405E-03	84
113.	X113	138	7.338252E-03	22	2.010360E-03	6
114.	X114	139	3.480380E-03	85	1.039166E-03	22
115.	X115	140	3.480380E-03	86	1.039166E-03	23
116.	X116	141	3.480380E-03	23	1.039166E-03	1

117.	X117	142	3.480380E-03	2	1.039166E-03	28
118.	X118	143	3.099610E-02	21	8.372826E-03	29
119.	X119	144	3.099610E-02	20	8.372826E-03	20

Next we have the secondary Importance and Sensitivity values calculated for all inputs of all defined modules for 01/04/2001.

Table No. 67A (Module Importance & Sensitivity Table)					
NTINPS = 153 MAXINP = 1000					
----- Module 1 = X9-OUTPUT -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X9	0.778804	1	0.101022	1
----- Module 2 = V1 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X6	0.187235	1	0.603284	1
2.	X9-OUTPUT	0.164696	2	4.005930E-02	2
----- Module 3 = V2 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X7	0.674910	1	0.115609	1
2.	X9-OUTPUT	0.179344	2	2.541146E-02	2
----- Module 4 = V3 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X8	0.713877	1	0.128762	1
2.	X9-OUTPUT	8.232547E-02	2	1.348388E-02	2
----- Module 5 = X11-OUTPUT -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X11	0.738100	1	0.141727	1
----- Module 6 = V4 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X10	0.544600	1	9.464841E-02	1
2.	X11-OUTPUT	0.383045	2	5.796974E-02	2
----- Module 7 = Y1 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X1	8.844904E-02	9	2.623223E-02	6
2.	X2	8.844904E-02	7	2.623223E-02	3
3.	X3	5.747941E-02	8	5.068184E-02	5
4.	X4	8.844904E-02	10	2.623223E-02	1
5.	X5	5.747941E-02	1	5.068184E-02	2
6.	V1	3.673688E-02	2	6.664579E-02	4
7.	V2	9.651726E-02	4	1.973811E-02	10
8.	V3	9.555591E-02	3	2.051465E-02	8
9.	V4	9.667634E-02	5	1.960953E-02	7
10.	X11-OUTPUT	9.456650E-02	6	2.131308E-02	9
----- Module 8 = Y2 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X12	6.566709E-02	6	0.202597	1
2.	X13	6.566709E-02	7	6.826654E-02	5
3.	X14	4.637689E-02	9	8.888390E-02	8
4.	X15	4.637689E-02	1	8.888390E-02	3
5.	X16	3.330379E-02	2	0.102599	4
6.	X17	9.683817E-02	3	3.395960E-02	2
7.	X18	9.683817E-02	4	3.395960E-02	9
8.	X19	3.986027E-02	8	9.574632E-02	6
9.	Y1	9.439017E-02	5	3.669945E-02	7
----- Module 9 = V5 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X23	0.102718	3	3.351740E-02	2
2.	X24	0.109538	4	0.320021	3
3.	X25	0.306633	2	7.893088E-02	4
4.	X26	0.202053	1	6.617109E-02	1
----- Module 10 = Y3 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X20	0.174402	1	4.469239E-02	4
2.	X21	8.038559E-02	5	2.325362E-02	1

3.	X22	8.038559E-02	6	2.325362E-02	5
4.	V5	0.125742	7	7.364527E-02	3
5.	X27	0.174402	4	4.469239E-02	2
6.	X28	0.135460	2	9.519570E-03	6
7.	X29	0.135460	3	9.519570E-03	7
----- Module 11 = Y4 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X30	9.057167E-02	2	2.706973E-02	6
2.	X31	0.190938	4	5.238641E-02	2
3.	X32	9.057167E-02	6	2.706973E-02	4
4.	X33	0.190938	7	5.238641E-02	1
5.	X34	9.057167E-02	1	2.706973E-02	3
6.	Y2	0.132924	3	9.946118E-02	5
7.	Y1	0.124398	5	1.483230E-02	7
----- Module 12 = Y5 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X35	9.491761E-02	6	2.889300E-02	2
2.	X36	4.928339E-02	5	0.154844	5
3.	X37	9.491761E-02	1	2.889300E-02	6
4.	X38	9.491761E-02	3	2.889300E-02	7
5.	X39	0.197049	4	5.613817E-02	1
6.	Y3	0.203242	7	5.135177E-02	3
7.	Y4	9.049297E-02	2	3.262116E-02	4
----- Module 13 = V6 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X44	0.250260	1	0.250260	1
2.	X45	0.134136	3	0.134136	3
3.	X46	0.195297	2	0.195297	2
4.	X47	6.831998E-02	4	6.831998E-02	4
----- Module 14 = Y6 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X40	0.127702	2	0.104005	1
2.	X41	0.196117	6	5.550022E-02	5
3.	X42	9.421363E-02	5	2.858516E-02	6
4.	X43	9.421363E-02	1	2.858516E-02	2
5.	V6	0.127702	3	0.104005	4
6.	Y1	0.190609	4	5.965090E-02	3
----- Module 15 = V7 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X51	0.116125	2	8.863094E-02	1
2.	X52	0.181940	3	4.792667E-02	2
3.	X53	0.181940	4	4.792667E-02	3
4.	X54	0.181940	5	4.792667E-02	4
5.	X55	0.181940	1	4.792667E-02	5
----- Module 16 = V8 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X60	0.102950	1	0.358519	1
2.	X61	5.664121E-02	3	0.168501	3
3.	X62	0.102950	2	0.358519	2
----- Module 17 = Y7 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X48	7.692750E-02	8	4.703415E-02	9
2.	X49	9.703489E-02	2	2.985969E-02	4
3.	X50	4.733463E-02	7	1.511563E-02	5
4.	X56	6.368163E-02	10	5.815601E-02	1
5.	X57	6.368163E-02	1	5.815601E-02	10
6.	X58	4.733463E-02	4	1.511563E-02	2
7.	X59	9.703489E-02	5	2.985969E-02	7
8.	V7	9.706998E-02	3	2.982941E-02	8
9.	V8	3.121883E-02	6	8.478990E-02	11
10.	Y4	9.254724E-02	12	3.372366E-02	12
11.	Y5	4.312124E-02	11	1.899046E-02	3
12.	Y6	4.348886E-02	9	1.865272E-02	6
----- Module 18 = Y8 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	X63	0.205285	1	3.370631E-02	4
2.	X64	0.205285	2	3.370631E-02	5
3.	X65	7.009854E-02	4	2.571080E-02	1
4.	X66	0.165988	5	4.141901E-02	2
5.	X67	0.165988	6	4.141901E-02	3
6.	X68	7.563203E-02	3	2.160601E-02	6

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----- Module 19 = Y9 -----
No.  INPNAM      MODIMP      IMPNDX      MODSEN      SENNDX
1.   X69          7.975523E-02      3      0.156838      1
2.   X70          0.100260      7      3.152822E-02      7
3.   X71          0.202786      2      6.170729E-02      3
4.   X72          0.100260      4      3.152822E-02      5
5.   X73          7.975523E-02      6      4.981013E-02      2
6.   X74          0.100260      1      3.152822E-02      4
7.   X75          0.134607      5      0.117340      6
----- Module 20 = Y10 -----
No.  INPNAM      MODIMP      IMPNDX      MODSEN      SENNDX
1.   X76          0.155119      4      8.568910E-02      1
2.   X77          9.436098E-02      6      2.864912E-02      3
3.   X78          0.155119      1      8.568910E-02      6
4.   X79          0.196314      3      5.563260E-02      4
5.   X80          0.106342      5      3.637712E-02      5
6.   X81          0.171572      2      6.998012E-02      2
----- Module 21 = V9 -----
No.  INPNAM      MODIMP      IMPNDX      MODSEN      SENNDX
1.   X83          0.185034      1      4.936810E-02      4
2.   X84          0.185034      2      4.936810E-02      5
3.   X85          0.185034      3      4.936810E-02      1
4.   X86          0.144735      4      7.551301E-02      2
5.   X87          0.144735      5      7.551301E-02      3
----- Module 22 = Y11 -----
No.  INPNAM      MODIMP      IMPNDX      MODSEN      SENNDX
1.   X82          7.708664E-02      1      2.210331E-02      9
2.   X88          7.708664E-02      2      2.210331E-02      10
3.   X89          7.708664E-02      3      2.210331E-02      8
4.   X90          3.655567E-02      5      1.127856E-02      1
5.   X91          7.708664E-02      7      2.210331E-02      2
6.   X92          3.655567E-02      8      1.127856E-02      3
7.   X93          7.708664E-02      10     2.210331E-02      5
8.   X94          7.708664E-02      9      2.210331E-02      7
9.   X95          6.590332E-02      12     3.043819E-02      11
10.  V9           7.593535E-02      4      2.296551E-02      4
11.  Y10          3.345371E-02      6      1.394234E-02      6
12.  Y8           3.881126E-02      11     9.338928E-03      12
----- Module 23 = Y12 -----
No.  INPNAM      MODIMP      IMPNDX      MODSEN      SENNDX
1.   X96          0.169778      1      4.285688E-02      1
2.   X97          7.774782E-02      2      2.233128E-02      8
3.   X98          7.774782E-02      3      2.233128E-02      9
4.   X99          7.774782E-02      4      2.233128E-02      2
5.   X100         7.774782E-02      5      2.233128E-02      3
6.   X101         7.774782E-02      6      2.233128E-02      4
7.   X102         7.774782E-02      7      2.233128E-02      5
8.   X103         6.094797E-02      9      3.486137E-02      6
9.   X104         7.774782E-02      8      2.233128E-02      7
----- Module 24 = V10 -----
No.  INPNAM      MODIMP      IMPNDX      MODSEN      SENNDX
1.   X105         0.263866      1      5.843372E-02      1
2.   X106         0.164051      2      4.070427E-02      2
3.   X107         0.164051      3      4.070427E-02      3
4.   X108         0.164051      4      4.070427E-02      4
5.   X109         7.456471E-02      5      2.124463E-02      5
----- Module 25 = V11 -----
No.  INPNAM      MODIMP      IMPNDX      MODSEN      SENNDX
1.   X110         4.377287E-02      4      7.356702E-02      3
2.   X111         9.645149E-02      2      2.958628E-02      1
3.   X112         8.974566E-02      5      0.135396      4
4.   X113         0.198977      6      5.758289E-02      2
5.   X114         9.645149E-02      7      2.958628E-02      5
6.   X115         9.645149E-02      8      2.958628E-02      6
7.   X116         9.645149E-02      3      2.958628E-02      7
8.   X117         9.645149E-02      1      2.958628E-02      8
----- Module 26 = Y13 -----
No.  INPNAM      MODIMP      IMPNDX      MODSEN      SENNDX
1.   X118         7.561468E-02      3      2.160011E-02      3
2.   X119         7.561468E-02      5      2.160011E-02      6
3.   V10          0.178424      8      3.398146E-02      4

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4.	V11	6.695959E-02	9	2.801040E-02	7
5.	Y8	8.050704E-02	1	1.795301E-02	1
6.	Y9	6.220576E-02	2	3.150872E-02	2
7.	Y10	6.892241E-02	7	2.656131E-02	9
8.	Y11	7.980495E-02	4	1.847745E-02	8
9.	Y12	7.947889E-02	6	1.872089E-02	5
----- Module 27 = Y14 -----					
No.	INPNAM	MODIMP	IMPNDX	MODSEN	SENNDX
1.	Y7	0.499232	1	0.141118	1
2.	Y13	0.402136	2	7.111794E-02	2

Finally, we have the Early Alert Results for 01/04/2001.

Table No. 68 (Early Alert Table Part II)
NALRTS = 6 MXALRT = 15

No.	EANAME	NOREAL	EALOUT	EALOUT	EALOUT	EALOUT
1.	E1	2	0.600000	0.600000	0.700000	0.700000
2.	E2	1	0.400000	0.400000	0.400000	0.400000
3.	E3	1	0.200000	0.200000	0.200000	0.200000
4.	E4	1	0.400000	0.400000	0.400000	0.400000
5.	E5	4	0.501236	0.518483	0.622768	0.640976
6.	E6	1	0.800000	0.800000	0.800000	0.800000
