Fermi National Accelerator Laboratory

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QA Role in Advanced Energy Activities Reductionism, Emergence, and Functionalism; Presuppositions in Designing Internal QA Audits*

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QA ROLE IN ADVANCED ENERGY ACTIVITIES

REDUCTIONISM, EMERGENCE, AND FUNCTIONALISM; PRESUPPOSITIONS IN DESIGNING INTERNAL QA AUDITS

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ABSTRACT

After a brief overview of the mission of Fermilab, this paper explores some of the problems associated with designing internal QA audits. The paper begins with several examples of how audits *should not* be designed, then goes on to analyze two types of presuppositions about organizational *structure* (reductionism and emergence) that can be misleading and skew the data sample if folded too heavily into the checklist. A third type of presupposition (functionalism), is proposed as a viable way of achieving a more well-rounded measure of the performance of an organization, i.e. its effectiveness, not just compliance.

FERMILAB'S ACTIVITIES

Fermilab is a single purpose high-energy physics laboratory which houses and operates the highest-energy particle accelerator anywhere in the world, the superconducting Tevatron. For thousands of years people have wondered what the world was made of and proposed theories to describe its constituents. The first Greek philosopher Thales (6th century B.C.), claimed that the world was made of water, while Anaximenes and Hericlitus said that it was composed of air and fire respectively. Driven by the deep intuitive notion that all things are reducible to fundamental entities, Democritus and Leucippus (5th century B.C.) first postulated the notion of atoms to explain how a changing world like ours was built upon a deeper unchangeable atomic reality. High-energy physicists still believe that the universe is composed of fundamental particles, but they call them quarks and leptons. Unlike the *conceptual* atomic structures that Democritus proposed, quarks and leptons *physically* interact in the detectors at Fermilab. Fermilab's mission is to explore these fundamental building blocks and the forces that interact between

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[1] Fermi National Accelerator Laboratory (Fermilab) is operated by Universities Research Association Inc., for the United States Department of Energy (DOE).

them. At the present time, the intellectual synthesis which describes quarks, leptons and the four forces by which they interact is called the Standard Model. In order to probe anomalies and parameters within and beyond the Standard Model, the superconducting Tevatron produces proton and antiproton beams with energies of nearly a trillion electron volts each (TeV) and collides them together in the center of huge sophisticated apparatus like the Collider Detector at Fermilab (CDF). As trillions of protons and antiprotons collide and annihilate each other, more than 10^{30} particle interactions occur, a few of which produce rare events like the W and Z vector bosons. In addition, Fermilab has just completed a fixed-target physics run in which 800 GeV protons from the Tevatron were directed toward stationary targets, providing a variety of secondary and tertiary particle beams for 16 experiments. Located on 6,800 acres of land, 30 miles west of Chicago, with an annual budget of about $170 million and 2,200 employees, Fermilab is the premier high-energy physics laboratory.

FRAMING THE QUESTIONS

In the paper that I presented at last year's ASQC Energy Division Conference, I described how Fermilab was in the process of developing written QA programs for each Division/Section of the Laboratory.[2] This task has been completed, and now it's time to check how well we've done by performing *internal* audits of the new programs. But how does one go about designing an internal audit program? We will answer this question initially by describing two approaches that have been systematically avoided at Fermilab. The first approach has been caricaturized by Philip Crosby in his book *Quality is Free.*

> Few functions are spoken about more and understood less than auditing. It is often the last refuge of those who didn't really know how to run a prevention-oriented life. Audit is the Bat Masterson of business. When you get into trouble, just call old Bat. He'll find all the bad guys and drag them to justice. And even if he fails to find the real ringleaders, you still look good. After all, you called in the *law* didn't you?[3]

The central problem with the "old Bat" approach (other than sheer dishonesty) is that the audit designer imposes inappropriate presuppositions and agendas onto the organization. The organization is beat before it starts. Whether they have real quality problems or not, the "old Bat" approach will bring some to light. This attitude prohibits any kind of objective and valid audit and (although it may be very valuable in establishing QA careers), it doesn't tell you much about the organization being audited.[4] The second approach to audit design that we have avoided involves starting with a pre-packaged "Prefab" design then imposing it on

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[2] Mark Bodnarczuk, *Towards an "Orthodox" Quality Assurance Program: Canonizing the Traditions at Fermilab*, Presented at the 14th Annual ASQC National Energy Division Conference, Session T, September 1987.

[3] Philip B. Crosby, *Quality is Free*, (New York: McGraw-Hill Book Company, 1979) p 79.

[4] Arguing against the "old Bat" mentality are QA professionals like George Roberts who claim that there must be auditee participation in the audit, with the objective of developing a "problem-solving partnership", *Quality Assurance in Research and Development*, (New York: Marcel Dekker Inc., 1983) p 123. Another example appeared in a recent article in *Quality Progress*, describing a new role for the QA Department as "...retaining its organizational power, but redirecting that power to *guidance* rather than *enforcement*" [Italics mine], see Henry J. Kohoutek and John Hamish Sellers, "From Criticism to Partnership: A Quality Department Builds a New Role" in *Quality Progress*, vol. XXI, no. 5, May 1988, pp 17-21.

the organization whether it fits or not. Henry Mintzberg calls the "Prefab" approach *pigeonholing* and claims that it is standard operating procedure in what he labels the "Professional Bureaucracy".

> Pigeonholing simplifies matters enormously. People are categorized and placed into pigeonholes because it would take enormous resources to treat every case as unique and requiring thorough analysis. [For example] the management consultant carries his own bag of standard acronymical tricks--MBO, MIS, LRP, PERT, OD. The client with project work gets PERT; the one with managerial conflicts, OD.[5]

The central problem with the "Prefab" approach is that it mashes the "Prefab" grid over the organization whether it fits or not. The "Prefab" approach may give the appearance of initial simplicity because all organizations are handled in the same way, but its ultimate outcome can be a distortion of what the organization is really like. Because Fermilab's approach to developing written QA programs has been inductive, allowing the QA program to grow out of the line people rather than imposing some predesigned QA structure on them, we are striving to adopt the same type of approach in our audit designs. "One size" does not always fit all.[6]

So we come back to our original question in a slightly expanded form; How does one go about designing an internal QA audit that avoids the problems associated with the "old Bat" and the "Prefab" approaches? This is the subject of the remainder of the paper. The heart of any audit is the *checklist*. It is the *checklist* that most deeply determines the starting point, course, and outcome of any audit (if you don't believe this ask the lead auditor of your next external audit for a copy one month before he arrives!). But how does one go about choosing the things that should and should not be included in the checklist?

It is the contention of this paper that one's presuppositions about organizational structure must be carefully analyzed or they could be misleading in the data selection, skewing the checklist choices. The next two chapters describe reductionistic, emergent, and functionalist presuppositions and ask what effect they have if folded into the design of an audit.

STRUCTURAL ANALYSIS

It is fashionable today to talk about "bottoms-up" and "tops-down" approaches to management. In this sense, the "bottoms-up" approach simply means that top management takes seriously the input of line people and has developed a mechanism for communicating this input to top management. As a communications and management tool, this approach (often associated with the Japanese) has had some success in American businesses.[7] The "tops-down" approach on the other hand normally means that top management lets the line people know that they take something like QA seriously and support it fully.

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[5] James B. Quinn, Henry Mintzberg, Robert M. James, *The Strategy Process; Concepts, Contexts, and Cases*, (Englewood Cliffs, NJ: Prentice Hall, 1988) p 640-641.

[6] Juran claims that although there are standard checklists in the QA literature, each company should prepare its own checklist to meet its own unique situation. J. M. Juran (Editor-in-Chief), *Quality Control Handbook*, 3rd ed., (New York: McGraw-Hill Book Company, 1979) p 21-9.

[7] Contrary to some U.S. perceptions of Japan, some Japanese economic theorists claim that the real difference between Japan and the U.S. is the level of education and utilization of human resources. Kenichi Ohmae claims that "The population of the United and States is now twice that of Japan, but both have roughly equal numbers of engineers. The United States has a higher illiteracy rate and more citizens on welfare." Kenichi Ohmae, *Beyond National Borders; Reflections on Japan and the World*, (Homewood, Ill: Dow Jones-Irwin, 1987) p 5.

But I want to discuss another way of thinking about "tops-down" and "bottoms-up" that has little to do with the way it is used in the previous paragraph. In order to understand and fully describe the nature of any *physical* thing from a galaxy to a one-celled animal, one must have some understanding of the components of the object, how those components interact, and what their function and purpose is. Understanding people and the nature of organizations composed of people is in some sense analogous, although organizational structure tends to be much harder to quantify. Yet organizations (like physical things) have components which interact and can be functionally described as goal seeking organizational "organisms." Properly describing and analyzing the components, interaction, and function of an organization is what audits should be about. One of the problems we are concerned with in this paper is focusing too heavily on the components and/or interaction, but neglecting to adequately consider the function and goals of an organization.

The first type of structural presupposition, reductionism, is also referred to as a "bottoms-up" (B->U) analysis, but it is very different than the B->U management style discussed above. It deals with the *components* of an organization and can initially be described with a hyperbole. A truly B->U account of economic theory would claim that knowing all the particle states in all the brains of all the people who work on Wall Street would somehow systematically explain and allow us to predict "economic laws". A slightly more believable B->U example would claim that if you could know all the particle states in *my* brain, you would be able to systematically explain and predict what my mental states are and probably exert control over them. Moving a little closer to our point, a B->U account of a person's job performance involves reducing the tasks assigned to him/her into distinct modules of performances that can be measured, timed and/or optimized. Fredrick W. Taylor's theory of "Scientific Management" and time and motion studies earlier in this century are testimony to how problematic this approach can be. Taylor would follow employees around with a stop watch, timing and listing each minuscule task that they did. This assumes that a person's overall performance is simply the sum of the tasks they perform, a position which this paper rejects.[8] The problems encountered in reducing an individual's job performance to individualized discreet packets become exponentially more complicated when multiplied by over 2,000 employees at a basic research laboratory like Fermilab.

But *intuitions* about reductionism are very strong because it is a huge driving force behind much of our science (the universe is reducible to quarks, leptons, and four forces), and it has been intuitively appealing for so long (it goes back to the 5th Century B.C.). Reductionism is built so deeply into our cultural view of the world that it is natural for us to try to apply it to everything (after all, the entire universe is reducible isn't it?). But this type of intuition can be misleading when applied to organizational "organisms."

If one were to hold a B->U presupposition about Fermilab's organization (consciously or unconsciously) how might that manifest itself in designing an audit and the selection of checklist items? Out of n^m possible data points (modularized job performances, discreet procedures etc.) that could be included in the checklist, some particular subset is chosen. The issue is how one really knows that the 20 or 200 data points selected are really a valid indicator of the success of

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8 Taylor's book *The Principles of Scientific Management* was published commercially in 1911, also see *The Encyclopaedia Britannica*, 15th ed., vol 11, (Chicago: Encyclopaedia Britannica Inc., 1986) p 588-589. Taylor's model has had some value in manufacturing and repetitive production environments.

the organization in meeting its stated goals.[9] These questions will be discussed in much more detail in the next section, but one comment as a precursor. Starting from a B->U view of an organization which supposes that one can take individual tasks and somehow "sum them up" to equal an "organization," the checklist selections will tend to be made independent of combinatorial considerations and the functional relation of those activities to overall goals.

Our second presupposition, the "tops-down" (T->D) approach, is also very different than the management style mentioned above. Viewing the organizational "organism" through this grid focuses on the *interaction* of the components at various levels. Back to our original hyperboles. The T->D account of economic theory would say "Of course economic laws can not be systematically explained or predicted even if you could know all the particle states in all the brains of all the people on Wall Street because once any system reaches a certain level of complexity, new properties and laws *emerge* that can not be totally explained by lower level properties. The properties of mental states can not therefore be explained simply by knowing the particle states in my brain. Getting back to our point, evaluating a person's job performance is more than simply summing up the total number of task modules that they perform. There are new emergent properties that appear when organizations reach a certain level of complexity and these properties foster downwards (not B->U) causation. The major new property that emerges is the "management level." One may analyze an employee's performance down to the last detail and not be able to isolate or identify a performance problem as a component of her performance. It may be an interactional problem, i.e., it took her twice as long to complete the task because it required action by another level of management which assigned her a low priority and over which she had no organizational control. The frequency of this type of problem grows as a function of the size and complexity of the organization, with the new *emergent* levels of management taking on a life of their own independent of the sum of the components.

Because the T->D presupposition views the emerging levels as increasing in sophistication and complexity, it is the top levels that direct what goes on at the bottom in a downwards direction. Given this type of presupposition (consciously or unconsciously) the audit designer will be more focussed on the interrelationship of activities at a given level and the interaction between what amount to relatively autonomous levels. There are times when these "relatively autonomous" levels of management seem impenetrable to changes coming from either the top down or the bottom up. With all our attempts to be like the Japanese, the T->D approach is deeply ingrained in American culture and especially in the "Professional Bureaucracy." Like reductionism, folding too many T->D emergent based data selections into the audit design skews the *checklist* by focusing too strongly on the interaction of levels. As if choosing a subset of data points out of n^m points is not complicated enough, the addition of emergent interactional properties which are not present in the reductionistic analysis introduces a new and expanded set of data points to choose from (n^m + emergent properties). Reductionism concerns itself too much with details and emergence focuses too heavily on interactions. What is needed is a way to select a subset of n^m + emergent properties to get a proper distribution of "emergent" interactions that link the "reductionistic" details. This is the subject of the next section.

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[9] Roberts give some ideas about this when he says "Internal auditing may require an intensive evaluation of all aspects of one specific project using the QA plan and project technical plan as a basis for tailoring the checklist." The QA plan must be used as a *basis* for tailoring the checklist, but how does one choose exactly *which* data points are actually picked to be included in the checklist. See Roberts, p 123.

FUNCTIONAL ANALYSIS

The final presupposition we will discuss is functionalism. The functional analysis is based on the process of quantifying the stated *goals* of an organization and proceeds from very different presuppositions than either the T->D or B->U approaches. A functional analysis isolates, quantifies, and ranks the overall goals of an organization beginning with the most general/abstract and moving towards the smaller more concrete ones.[10] The whole idea is to approach audit design from the perspective of whether the laboratory is *functioning* as is ought to be. Like the written QA programs Fermilab has developed, this type of audit design is tailored to the goals of specific organizations. There are a few steps to doing a functional analysis.

The first is to isolate the stated goals of the organization. Each of Fermilab's QA Programs contains an introductory QA Program overview statement from the Head of that Division, briefly stating what are the goals of the organization. In addition, the lead auditor meets with the QA Officer of that Division in order to obtain additional information for the actual analysis. The stated goals are written down in sentences using active verbs which describe (if possible) measurable performances. These goals are then discussed with the individual Department Heads and Division Head and corrections made. One must specify measurable criteria that can be either confirmed or falsified because this part of the functional analysis is designed to take the fuzzy, abstract, non-quantitative goals and (as far as possible) quantify them. Examples of quantified goals are normally included in experimental proposals, i.e., the experiment will be built in X months, with Y dollars, and accumulate Z data events on tape, given T running time. The stated goals of the organization should be listed and agreed upon by the lead auditor, the QA Officer, the Department and Division Heads.

The second step is ranking the goals in their order of importance by asking the rhetorical question: Can I meet this goal without doing this performance first? Using Fermilab as an example we begin by stating the most abstract general goal of the Laboratory, i.e., to isolate the fundamental constituents of the universe and the forces that interact between them. This is about as abstract a goal as you can get. One then asks the rhetorical question "Can I isolate these constituents if I don't have a cutting-edge physics program?" No. "Can I have a cutting edge physics program if I don't have a Physics Advisory Committee (PAC) that chooses the type of experimental program that will probe pertinent parameters both within and beyond the Standard Model as we know it today?" No. So the most general goal of Fermilab is to carry out or *execute* the physics program specified by the PAC. By *execute* the physics program we mean that the experiments that are approved and scheduled to be installed, commissioned, and run do this within the time and cost constraints. We will call the goal of executing the physics program our Terminal Objective (T.O.). All other goals that must be done in order to accomplish the Terminal Objective we will call Subordinate Objectives (S.O.)[11].

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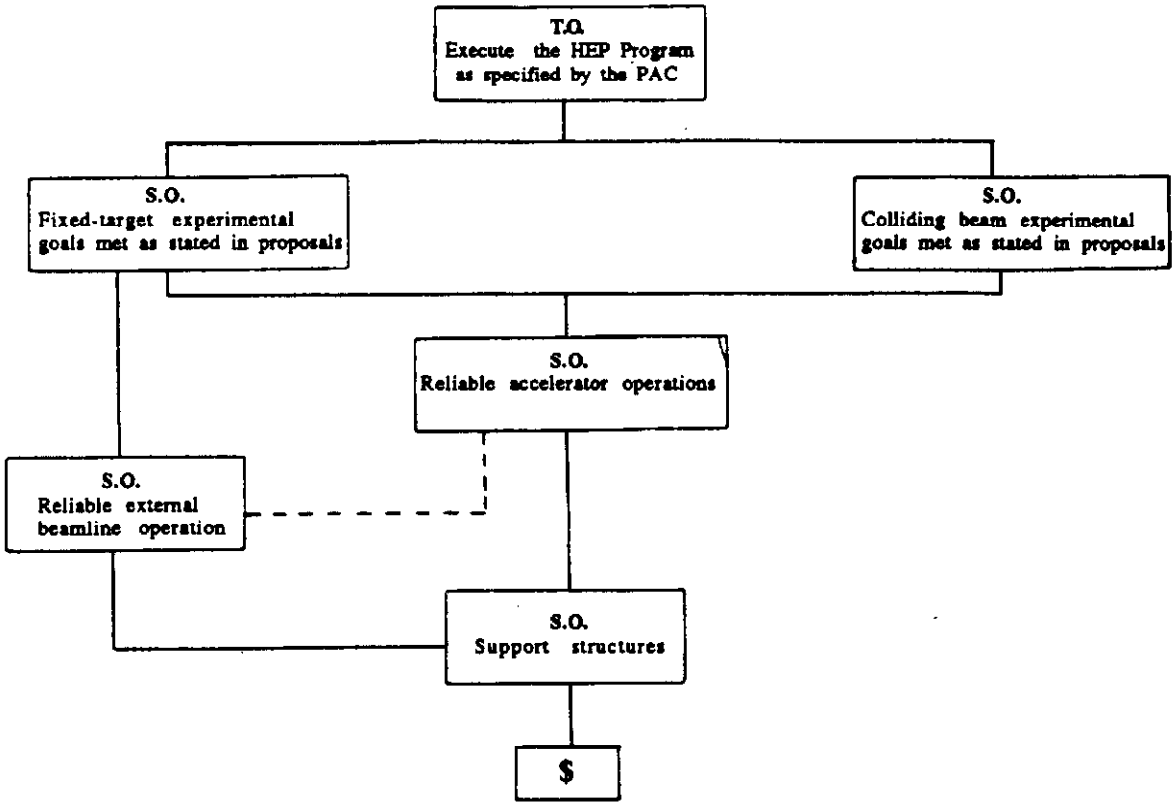
[10] This is not out of keeping with the spirit and philosophy of DOE-CH policy as stated in Orders CH-5000.1 (Functional Appraisal Policy and Procedures), CH-5000.a (Functional Appraisal System), and CH-5000.2 (Performance Appraisal of Major Laboratories).

[11] This type of analysis was originally developed for doing instructional design (CRI) by Robert F. Mager and Peter Pipe, but I have applied a modified version of their principles in doing what I call the Functional Analysis, see Robert F. Mager, *Preparing Instructional Objectives*, 2nd ed., (Belmont, CA: Fearon-Pitman Publishers Inc., 1962).



The figure above shows the Terminal Objective supported by a five-part structure of Subordinate Objectives. The rules for hierarchically ranking them specify that objectives that must be completed *first* directly support the ones above them with a solid line, i.e., the Terminal Objective is at the top of the figure, but it can not be achieved without the completing each of the Subordinate Objectives underneath it. Objectives that can be completed *independent* of one another but are necessary for reaching the Terminal Objective are placed side by side (fixed-target and colliding beams programs). We can demonstrate how the analysis works by using a rhetorical question method. Fermilab can not carry out the colliding beams portion of the HEP program if the accelerators are not working properly, but they can carry out the colliding beams portion of the HEP program if the fixed-target areas are not operating. Moving down the chart, Fermilab can not carry out the reliable operation of the accelerator without support departments and funds from the DOE. The most basic Subordinate Objectives are toward the bottom of the diagram. In the same way that a person can not become competent at critiquing American poetry unless he understands English, Fermilab can not attain any of the objectives in the figure without the appropriate amount of financial support (from DOE) to run the program that is specified by the PAC.

Once the audit designer has this higher-level functional analysis complete, he can turn-up the magnification another notch by making each of the Subordinate Objectives into a Terminal Objective. Each new Terminal Objective is subsequently quantified by first isolating and listing the stated goals of that portion of the organization, then ranking them using the rhetorical question approach. Once ranked, the list of Subordinate Objectives should satisfy the question "If I perform all these Subordinate Objectives will I reach my Terminal Objective?" If the answer is yes, then that part of the analysis is completed. What one winds up with is a structure that is based not on B->U *component* driven

reductionism or T->D *interaction* of emergent management levels, but a structure that is predicated on the functions and stated goals of the laboratory.

Our original problem was finding a way to control the selection of data points that make up the checklist in a way that would yield a realistic picture of the organization being audited. With the functional analysis of the organization in hand, the lead auditor (and audit team members that he designates) have some guidance with which to begin the selection process. The data points that are eventually included in the checklist should rise from the structure built from the analysis. It should be clear by now, that data points can come from the top or the bottom of the chart although those closer to the top represent the highest goals of that particular organization. An all too frequent way of choosing data points for a checklist is the "honey-dip" method where the designer opens to a section of the QA Program (maybe with closed eyes), plops his finger on the page and audits the section his finger hits first. But if the designer does a functional analysis to determine which sections are functionally important, even if he "honey-dips", the probability of picking more salient checklist choices is still greater than without any analysis.

It is important to note that the QA organization has no *line* responsibilities and should not view this exercise as making *line* decisions about how the activities of the organization are being carried out. The functional analysis is simply a way for the QA organization get a handle on goals that are specified by the line organization, with a view to gaining a more objective measurement of the organization.

BUT WHAT DOES IT COST YOU?

The B->U account has some valid points, but what does this type of approach cost you in the end? We already hinted at our conclusions when we stated that starting from a modularized reductionistic view of an organization predisposes one to the notion that one can "sum up" individual discreet procedures etc. to equal an "organization." This data sample will tend to be skewed in the direction of unimportant details that may be unrelated to the "Big Picture" goals of the Laboratory. The checklist selections will tend to be made independent of combinatorial considerations and the functional relation of individual components to larger considerations. One of the generic problems of a B->U account is that as the "so-called" structure is being "reconstructed," important higher-level generalizations may be left out. This can be seriously misleading in the overall evaluation of the final audit findings. What is more interesting is how the intuitive appeal of reductionism as a "scientific" methodology can further mask the problem in piles of unimportant non-salient details. A common phenomenon is that auditors "feel around in the dark" at random hoping to find something that doesn't seem quite right. When they find something (and they always do) this often becomes a "node" upon which to build a "trail" of evidence back up to the top or down to the bottom.[12]

The T->D approach likewise has some valid aspects, primarily in management issues and the interaction between levels of management. Because the T->D model specifies that an organization increases in complexity and sophistication with each ascending level of management, an analysis based on this type of presupposition will focus mainly on the interaction within a particular level or the interaction between the levels on the way down to the entry level positions. As in the example given above, there is no doubt that layers of bureaucratic management can produce a tremendous entropy in task execution and this point needs to be addressed by the audit. But again, focusing too much on these aspects will skew the checklist in the opposite direction of the B->U analysis, i.e., the

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[12] Juran calls this going on a "fishing expedition", p 21-7.

checklist questions tend to miss some of the important details, details that were actually overstated in the reductionistic model.

The auditor wants "details" and "inter-management interaction" to be a part of the audit analysis and design, but which are the *salient* points? Analyzing an organization functionally can algorithmically help the audit designer to determine this. With the functional analysis you will miss some of the *details* that were in the B->U account, and you will miss some of the *interaction* between levels of management in the T->D account, but this sifting of the data is exactly what should happen. The real goal is to get the proper mixture and distribution of component details and interaction between management levels, allowing the process to be specified by the stated goals of that organization. The designer consequently has a quantitative algorithmic way to determine at least the broad parameters of his checklist. It also provides a rational method by which to justify the contents of the checklist should they be questioned.

CONCLUSIONS

All organizations consist of components which interact, producing a goal seeking organizational "organism." Focusing too heavily on just the components and/or the interaction of those components does not produce an accurate functionally centered view of the state of the organization. It is common today to hear talk about auditing for *effectiveness* rather than strictly for *compliance*, but it is not at all common to hear how exactly one goes about doing this. The notion of effectiveness is alluded to by Juran who says, "A well-conducted audit is not limited to the study of documents, important though these are. The real need is to *understand the deeds* which have been performed. In consequence, the auditor should also examine at first hand those matters which cannot be reflected solely by documents, e.g.: the state of knowledge, motivation, and morale of the personnel; the atmosphere of creativity and improvement; the level of mutual confidence and collaboration."[13] Still, confusion prevails about exactly what effectiveness is. But if a definition of organizational effectiveness is captured by *anything*, it is captured by the success (or failure) to meet stated goals. And if a *measurement* of organizational effectiveness is captured by *anything*, it seems plausible that it should be captured by a functionally based goal centered audit design.

Maybe we can learn something here from the way science works. First, there has always been a place for "thought experiments" in trying to understand robust problems that will not yield to scientific explanation. "The function of the thought experiment is to assist in the elimination of prior confusion by forcing the scientist to recognize contradictions that had been inherent in his way of thinking from the start. Unlike the discovery of new knowledge, the elimination of existing confusion does not seem to demand additional empirical data."[14] In a sense, our reflections on reductionism, emergence, and functionalism are a "thought experiment" aimed at eliminating some of the confusion in designing QA audits. But science also proceeds by isolating specific problems that need to be solved (How do we audit for effectiveness?), then postulating a theoretical solution to that problem, attempting to confirm or falsify it.[15] In this sense, our theories tell us *which* empirical data are salient, guiding the direction of research. "Scientific hypotheses and theories are not *derived* from observed facts, but *invented* in order to account for them. They constitute guesses at the connection that might obtain between the

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13 Juran, p 21-11.

14 Thomas S. Kuhn, "A Function for Thought Experiments" in Ian Hacking ed. *Scientific Revolutions*, (Oxford: Oxford University Press, 1985) p 7 ff.

15 Karl Popper, *The Logic of Scientific Discovery*, (New York: Harper & Row Publishers, 1968), p 40 ff.

phenomena under study, at uniformities and patterns that might underlie their occurrence. 'Happy guesses' of this kind require great ingenuity, especially if they involve a radical departure from current modes of scientific thinking, as did, for example, the theory of relativity and quantum theory."[16] At this stage, the functional analysis presented in this paper is a theory in Hempel's sense of the word, but we have not stopped here. At Fermilab, we have and continue to test the functional analysis and have achieved success in moving closer to designing and carrying out audits that measure the functional goals of the laboratory. But in order for theories to be confirmed to a high degree of precision, they must be performed independently, by different experimenters, often under varied conditions. It is hoped that this paper will stimulate others to think seriously about the functional approach and other "how possible" audit scenarios, i.e., how is it even possible to measure the effectiveness of a pure research "organism" like Fermilab through examining the components, interaction, and function of its constituents.

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16 Carl G. Hempel, *Philosophy of Natural Science*, (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1966, p 15.