Winter 2003

Developing a Methodology to Detect Partial Failures for Dynamic Systems

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A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

ENGINEERING MANAGEMENT

OLD DOMINION UNIVERSITY
December 2003

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ABSTRACT

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The purpose of this research is to develop a decision support system that can assist in detecting partial failures in dynamic systems such as Fire Control System Tracking Radar (TR) onboard Naval Ships. Partial failures do not necessarily shut down the system immediately but cause degradation of operational performance. Previous work has shown that experts in the field of failure detection, test point insertion and Built-In-Test Equipment (BITE) can provide useful input in detecting partial failures. Partial failures affect operational system performance and support costs, which can be significant. Often, however, partial failure detection consists of the estimations and opinions of the experts. This has not been addressed adequately in the literature. It is postulated that the approach developed in this research could be applied to maintain and monitor partial failure. The development of such a testing aid is the thrust of this research effort. Markov chains, k-out-of-n: G: system and critical path tracing techniques, among others are employed. Appropriate survey questionnaires are used for validation of the resulting test model. Application of previous test point insertion techniques are applied as a part of system comparison and assessment.

Co-Director of Advisory Committee: Dr. Andres Sousa-Poza

ACKNOWLEDGEMENTS

I express my deepest appreciation to my dissertation committee – Dr.Resit Unal, Dr. Andres Sousa-Poza, Dr. Charles Keating, and Dr. Bruce A. Conway. My thanks also go to the other faculty, staff, and students in the Engineering Management Department for their support, encouragement, and patience.

Finally, I must acknowledge that I could not have met the challenges of this endeavor without the support and encouragement of my wife. Her sacrifice and love are endless, and are a continuing source of inspiration to me.

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CHAPTER I

INTRODUCTION

1.1. Problem Background

The operation and maintenance of complex and dynamic systems onboard naval ships involves challenging operational problems due to its complex electromechanical units and sophisticated monitoring and control devices. One of the problems during operation is the occurrence of partial failures that do not necessarily shutdown the system immediately. Partial failures may occur for a variety of reasons such as:

- Hardware problems or software problems or both, such as wear and tear of equipment components,
- Fault signals from electronics boards or false operational signals from safety trip systems,
- Sudden perturbation of voltage or current,
- Incomplete or incorrect maintenance of the equipment,
- Wrong action by operator, bad training, and
- Different system environmental conditions, etc.

The journal model of *Journal of Applied physics* was used.

Problems of this type can shutdown a system, and it can take from a few hours to a few days to restore the systems to their full operating condition, depending on the nature of the problem. In restoring the system to operational condition, a major objective is to avoid failure by taking all possible maintenance measures.

On failure of a subsystem, most systems onboard ships that have Built-In-Test Equipment (BITE) switch to a diagnostic mode and internally isolate and identify or predict the failed part(s) using a go or no-go procedure. This procedure itself can produce failures, because some of failure recovery using BITE requires switching the system on and off, and may result in reduction of system performance and reliability. Additionally, it is critical that the BITE has reliability in orders of magnitude greater than the system it is supporting; otherwise, the added complexity may reduce system reliability.

An inaccurate BITE can introduce complications in differentiating between a real false alarm and an accurate alarm. Researchers in this field believe that decreasing the number of connections between any system and its BITE equipment should reduce system weight and the probability of the system faults induced by BITE. However, this action of reducing the connection between the system and its BITE leads to an increase in the time required for diagnosis realization and checkout (Smith, 2001).

1.1.1. Tracking System Boundary, Limitation and Delimitation.

When problems arise, systems like a Fire Control System-Tracking Radar (TR), with automated elements and continuous functions, require a proper identification boundary. The TR system boundary actually depends on which equipment is going to be involved in a specific situation or moment to complete a system operation cycle. Therefore, when a problem arises in the TR, the confines of the problem and its elements need to be identified, and all inputs and outputs must be known at that specific moment.

If one assumes involvement of human factor elements as negligible in these types of systems, it is possible to consider that all complete and partial failures under this condition are treated as hardware problems only. Figure 1 shows the TR system Hierarchy diagram.

1.1.2. Research Hypotheses.

In this research, it is hypothesized that partial failures induced onboard Naval Ships can be detected by inserting observation test points in electronic Naval systems. Furthermore, one can use experts' judgment to determine an appropriate place for test point insertion.

Usually this type of partial failure, when it occurs, does not propagate to the system primary output, or, in other words, cannot be detected by an external test point, and does not shutdown the system. For example, figure 2 demonstrates the effect of three partial failures generated in a system during its normal operation without causing this system to shutdown, or without propagating to the system primary output. These partial failures are denoted as 1, 2, and 3 respectively. Any changes in system performance (calculated in percentage) under influence of these three partial failures over time are shown as two horizontal and dotted lines denoted as 100% for perfect operation and 0% as shutdown.

However, at the time those partial failures occur no action is carried out by the BITE. This means that all of those failures did not propagate to the system primary output. This is an indication that the system test patterns, which were estimated by the experts for the BITE, were not sufficiently high failure coverage. As a result there was no failure detection by BITE or an immediate system shutdown.

The BITE action time area in figure 2 presents the time correction required by BITE to isolate and correct the failure. So, if the question is asked, "What is the difference between the three failures?" the answer is that the first partial failure was induced as soon as the system was switched on without causing any effect on the system operation. In reality, system performance is technically already reduced because of this partial failure. Moreover, BITE could not even recognize the failure until the system enters a shutdown state due to the spreading of the problem. In the second and third failures, both occurred and the system did not reach the 100% performance.

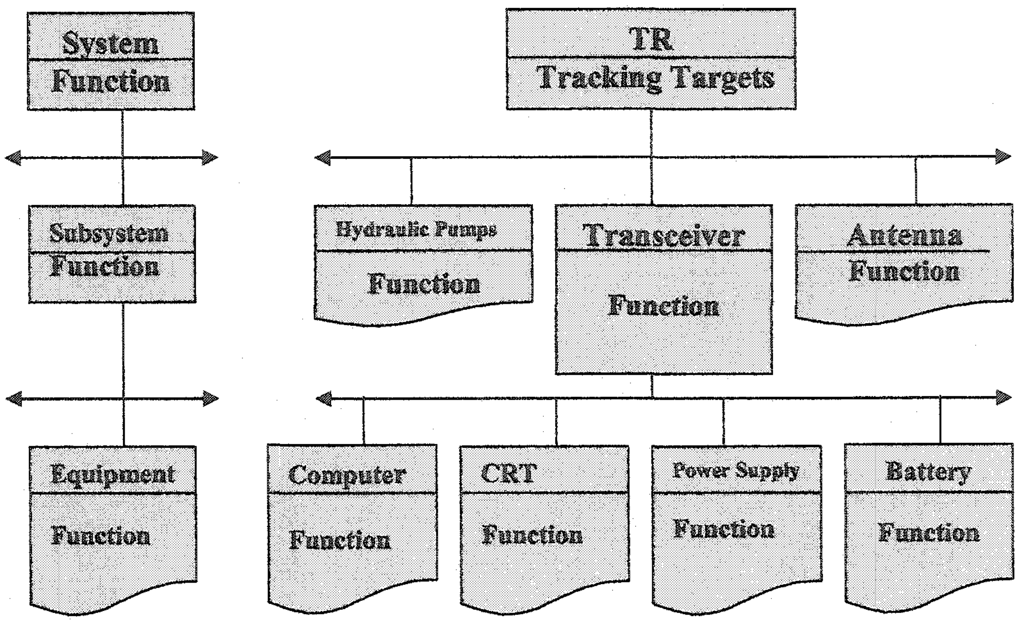

Figure 1. Tracking Radar System Hierarchy Diagram

The BITE action in failures two and three are the same as for the first failure. The problem, therefore, is how can one detect this type of failure without interrupting system operation. This research hypothesizes that a proper system organization of observation point insertions can detect and monitor partial failures, and can be utilized to minimize these types of failures. In addition to minimizing partial failure by using proper observation point insertions, an improvement of the system's availability can be achieved. This, in turn, can lead to improvements in maintenance, performance and cost.

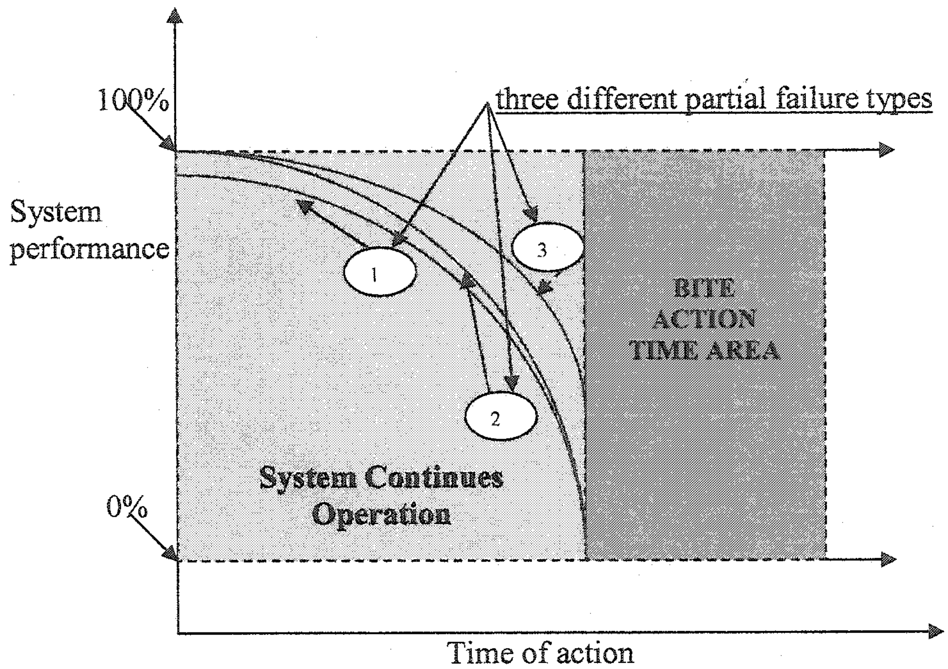

Figure 2. The Effect of Partial Failures Generated in a System During Normal Operation

1.1.3. System Evaluation

This research develops a decision aid that can assist in the detection of a partial failure from a maintenance perspective before it propagates through the system. This is accomplished by developing, selecting and monitoring observation points on the system being studied, using a methodology that combines three techniques:

1. The Multi-State k-out-of-n: G: System,
2. The Markovian Technique,
3. The Critical Path Trace Technique.

This research effort requires two sources of information. Available data is the first resource, and expert opinion the second. Available data includes field data and scheduled maintenance data. Use of expert judgment is necessary when good, or well-organized, historical data is not available. An expert judgment data acquisition approach is utilized in this research, in parallel with the three above mentioned techniques to develop a decision support system that can assist in detection and monitoring of partial failures in fire control system of a TR. Expert elicitation is accomplished using questionnaires, which were also used to validate the research results.

1.1.4. Important Definitions and Assumptions

In this research, *"subsystem"* refers to a piece of equipment or portion of a system, which can be viewed as an independent entity for evaluation in the detection of partial failures. *"System"* refers to an orderly arrangement of components that interact among themselves, with external components, and other systems to perform an intended function. "*Dynamic System*" refers to any operational system under continuous use, with continuous state changes. The state changes are dependent on orders received from hardware or software commands. "C*hallenged system*" refers to component elements of multidisciplinary systems that do not involve human factors. The "*test point*" is said to provide a solution for failure if this specific test point enables the required and specific failure to be detected.

1.2. Research Objective

The primary objective of this research is to test the hypothesized points, which are known to detect partial failures. These hypotheses consist of two points.

1. Observation test points to detect partial failures in electronic Naval systems, which are not detected by BITE, are inserted. and,
2. by using use experts' judgment to determine appropriate place for test point insertion.

A decision aid support system based on maintenance decisions can be developed that can support and manage maintenance with BITE(s) to monitor and predict dynamic system partial failures before they significantly damage the system or its subsystems.

The specific technical objective is to identify and test a feasible approach using the combined methodologies of the multi-state k-out-of-n: G: system, the Markov technique, and observation point insertion using a critical path tracing technique to increase the system reliability and maintainability as a decision aid. This provides the capability to select the appropriate procedure to maintain these types of dynamic systems.

CHAPTER II

LITERATURE REVIEW

The aim of this literature review is to scan earlier studies related to undetected partial failures in dynamic systems that do not cause immediate system failure but yet reduce system performance and availability. There is a significant body of research and publications in the area related to complete systems failures and their effects. Little research, however, has been carried out on partial failures, their effect on reliability, availability and on how to detect them.

Most of the research reviewed assumes that any operational system has only two states: failure and operation. Only a few researchers addressed a system under the assumption of more than two states i.e.: partial failures, partial work (Lewis, 1994; Ebeling, 1996; T. A. Cruse, S. Mahadrevan, 1994).

In addition to earlier studies, this literature review gathers current research and frames the current research topic within the context of this overall body of knowledge. The literature review will summarize research on partial failures and recovered an approach to detect partial failure based on literature search results.

This literature review includes the following sections: 1) Failure Definitions and Related Topics, 2) k-out-of-n: G/F: Systems, 3) Architecture and Stress Influence, 4) Test Point Arrangements, 5) Previous Work in Test Point Insertion, 6) Built in Test Equipment, and 7) Specialist Judgment Elicitation.

2.1. Failure Definitions and Related Topics

There are many research papers on failure related topics, i.e., failure rate, failure repair, failure frequency, etc.; however, there appear to be only a few specific research papers and texts available on failure classification, definitions, and types. Rausand (2001) classified the failures as shown in figure 3. He positioned partial failure under extended failures, and then he divided the partial failures into two categories; sudden failure and gradual failure. The category depends on the system reaction and performance to the failure.

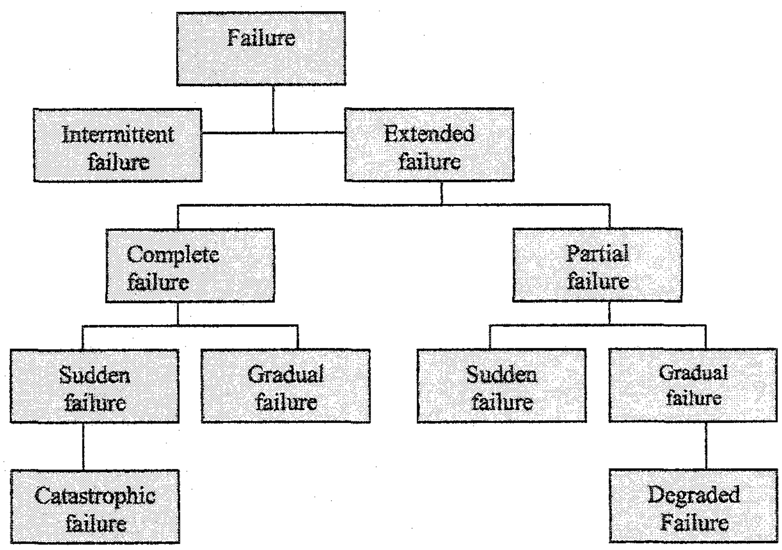

Figure 3. Rausand (2000) Failure Classification

Corner and Angstadt (2001) studied the failure modes and identified complete failure as 100% loss of one or more function, while partial failures as degraded or partial loss of one or more function. They concluded that it is difficult to identify the complete list of fundamental failure modes, and to determine whether a failure mode is fail-danger, or fail-safe. Generally, it is a function of the process (initiation based on an increasing or decreasing signal) and its design (on-off versus modulating signal, de-energized versus energized to initiate, ect.). Table-1 displays the general component failure modes that were determined following the functional analysis of component input/output loops (Corner and Angstadt, 2001).

Complete Failure	Partial Failure
• Control Output >100%	• Control Output High
• Control Output Frozen	• Control Output Low
• Control Output <0%	• Control Output Slow to Respond
• Process Variable Indication>100%	• Control Output Too Fast
• Process Variable Indication Frozen	• Control Output Erratic
• Process Variable Indication <0%	• Auto Controller in Manual Mode
• Control Output Indication >100%	• Process Variable Indication High
• Control Output Indication Frozen	• Process Variable Indication Low
• Control Output Indication <0%	• Process Variable Indication Erratic
• False Discrete Indication	• Control Output Indication High
• Alarm Fail to Function	• Control Output Indication Low
• Alarm Spuriously Function	• Control Output Indication Erratic
• Interlock Fail to Function	• Alarm Function Delayed
• Interlock Spuriously Function	• Interlock Functions Early
	• Interlock Function Delayed
	• Interlock voting channel fail to function
	• Interlock voting channel spuriously function

Table 1. General Component Failure Modes

Yellman (1999) addresses failure and its general terms, which can legitimately apply to an unsatisfactory output of an item from any cause, to an unsatisfactory output caused by an internal condition, or to an unsatisfactory memory state. Yellman (1999) emphasized that distinctions among these types of failures should be made by preceding the word failure with an appropriate adjective and not by creating definitions for failure itself, which are impractical and unnecessarily narrow. A paper by R. Rees (1997) addresses what a failure is, and what the different issues are in relation to the failure. Rees' work clarifies one of the main issues in this research: the requirement to understand the meaning of defect, malfunction, failure, and fault terms that merely include and exclude failure by type, cause, and degree of use. For example, Rees stated that failure is a "matter of function only." He also found that neither hardware nor software should ever be described as "failed," but rather as being or having been "in a condition that can be associated with functional failure." One can agree with Rees that failure should not necessarily mean that "something is broken," but one also can argue that failure does not necessarily mean that something has actually functioned unsatisfactorily. So, what exactly is a function? Most engineers define function as a purpose of an item (Smith.2001). If one were to attempt to determine how much failure impacts the system function, output reliability performance would also have to be one of the focal points of this research.

Generally, few technicians can distinguish between meanings of the word "failure." Yellman (1999), for example, stated, "...The failure dichotomy lies in clearly distinguishing between two types of events. 1.) Functional failure: unsatisfactory performance (e.g., an item delivering unsatisfactory output) occurring during a process such as operation or testing. 2.) Material failure: An undesired physical condition (e.g., an internal part of an item being damaged or broken), which is also permanent (i.e., it will persist until it is repaired). Such a condition could exist during operation or testing." Additionally, Rees (1997) and Shedletsky and McClusky (1975) differ from Yellman's (1999) statement by adding the condition that "... at the time there is no demand on an item to function at all."

Failure as error latency is a final issue to be discussed in this section. The definition of error latency of a fault is the number of random input vectors applied to a circuit until the fault is detected at one of its primary outputs. The meaning of circuit in this research can be extended to cover a larger combination, or sequence of circuits, which can be treated as whole component(s), or even system(s). Shedletsky and McCluskey (1975) present error latency as a random variable assuming values from the set of positive integers, and say its value depends on the circuit and the fault in question. Their assumption, which was used to enhance our model, considers also that any fault is nothing but a complete test set of affected and unaffected subsets. The affected subset is the collection of all input vectors that detect the fault, and the unaffected subset of the remaining input vectors are the ones that do not detect the faults.

2.2. k-out-of-n: G: Systems Technique in Relation to Failure

Several researchers studied the reliability model based on different failure modes (failure modes were defined and determined in relation to system component configuration and relationship). In analyzing a complex system, a particular failure mode may be applied to the entire system. However, an alternative approach is to determine an appropriate reliability for each component of the system. This is requiring applying the rules of probability according to the configuration of the components within the system individually, and then to take the sum, which depends on the components' configuration in the system (Ebeling, 1996). The two primary configurations are series and parallel. When the system is connected in series, for example, the only way the system can function is when all components are in operation. In a parallel configuration, or the redundancy case, at least one component must function for the system to function. However, many research papers and texts have studied the use of the k-out-of-n: G system approach to calculate the reliability and availability, but only with the assumption that the system has only two states, binary zero as a failure state, and binary one as a success state (Lio, 1998; Angus, 1988; Scheuer, 1988). A k-out-of-n: G system means that an n component system works if and only if at least k components work or do not fail. This can be explained more easily by looking to series and parallel systems as special cases of the k-out-of-n: G systems, i.e., a series system is n-out-of-n: G; and a parallel system is 1-out-of-n: G.

Scheuer (1988) studied the reliability of k-of-n: systems where component failure induces higher failure rate in the survivors. He assumed that the components are independent and identical components (i.i.d) with constant failure rates. Shao and Lamberson (1991) modeled the reliability and availability of an n-unit shared load repairable k-out-of-n: G system with imperfect switching, in which i.i.d components with constant failure rates were considered. Hasset (1995) investigated the reliability and availability of repairable 1-out-of-2: G systems composed of 2 s-identical components with varying failure rates. Liu (1998) developed a model to calculate the reliability of a sharing k-out-of-n: G system, which is composed of independent non-identical components (non-iid) and arbitrary failure time distribution. This assumption, in Lio's opinion, is more general and realistic than the model with i.i.d components with exponential failure time distributions.

However, before the dynamic system reaches its failure state (shut down), it must give some type of symptom(s), either immediate and fast output results or graded and slow output results. These output results depend on three factors: the components' status state and system configuration, and the components' resistance to handle the failure stress. These results are a series of partial failures of different stress magnitudes induced before the system is forced to stop due to complete failure. Causes of failure are due to external or internal factors or both, i.e., aging, corrosion, bad maintenance or operation, high voltage or current, or environment.

In reality, to represent any system status state one must have more flexible tools such as a multi-state system model that can represent all states individually in relation to components states. Huang and Zuo (2000) demonstrated this flexibility in dealing with a multi-state system model, where they present the system relationship with its components in such a way that the system can not be in any state required level unless a minimum of k of its components (operating ones) are on the same state level.

2.3. Architecture and Stress Influence

In many research papers of k-out-of-n: G: systems, stress was named as a major failure factor. The nature of the stresses that trigger the failure mechanism can be electrical, mechanical, thermal, chemical, or radioactive (Smith, 2001). The types of stresses, which represent diverse physical phenomena, are point stresses, diffused stresses, and treating stresses (Ebeling. 1996). Stress distribution among system components should be in equilibrium in relation to the components' configuration and their distributions. One of the key factors in equipment engineering design is the design safety factor margin, sometimes called the safety factor. The safety factor is defined as the ratio of the resistance of the system to the stress placed on the system (Ross. 1970; Lewis, 1994; Ebeling, 1996; Haldar and S. Mahadervan, 2000; Smith, 2001). Most previous research that applied stress on their models to study system reliability and availability did so without considering the failure action process. During the application of the stress on equipment, they missed the observation of system failure behavior. System behavior under the influence of failure can behave differently depending on the process along which failure progresses, which may be a direct or indirect indication, as has been explained in an earlier section.

Zahalca and Chardi (1996) studied system configurations from the perspective of their sensitivity to the stress influence. Their demonstration shows that, with an increased number of components in a series configuration, lower stress sensitivity can be developed on the system components. Furthermore, for any system with five or fewer components in parallel configuration, induction shows greater sensitivity to the stress than a series configuration does.

Zahalca and Chardi (1996) assumed that the stress process is a homogenous Poisson process. Their results show that in any system subject to a common homogeneous Poisson stress process, the failure rate is constant or increasing and converges rapidly to a constant. This demonstration confirms that the most reliable configuration is most sensitive to stress. On the other hand, it can be conjectured that the reliability and the stress sensitivity increases in the same order, so, the more reliable a configuration is, the more stress-sensitive it will be.

2.4. Test Point Arrangements.

Many military standards and texts specify test points (Smith, 2001) in relation to system performance verification and diagnosis. MIL-STD1765 gives wide explanation on test points, which are characterized into three factors: safeties, sensitivity, and protection. With this characterization, the test points are defined for both electrical and mechanical systems under the requirements of their performance verification and diagnostic.

MIL-STD-1765 defines the test points under two categories: standard functional and maintenance. **Functional test points** are those points which are available in external connectors by virtue of normal input/output (I/O) signal transfer. The **maintenance test points** are those points which are available in external maintenance connectors to supplement functional test points, as required, to accomplish performance verification and diagnostic testing. However, this does not exclude maintenance test points being available in functional connectors. Now, for example, when there is a failure of any equipment in a system, the failure will be isolated by the BITE (if the system has one). Then the BITE shifts to next step, which is a go or no-go test that will tell if the diagnostic reading is available in the connectors that are external to each individual component. This operation between BITE and test point arrangement in monitoring the dynamic system is going to be improved.

2.5. Previous Work on Test Point Insertion

Krishnamurthy (1987) showed that the optimal test point placement for a dynamic system by re-convergent fan out is a complete failure recovery. Briers and Toton (1986) were the first to propose a systematic method for test point placement to increase pseudo-random pattern testability. They use simulation statistics to identify correlations between signals, and then insert test points to break the correlation. The number of test points inserted by this method is large. Youssef (1993) used the critical path testability measures to guide the placement of test points. Youssef (1993) identifies sectors of hard-to-detect faults and inserts test points at the origin. Cheng (1995) enhanced the procedure proposed by previous researchers by using a cost function, which is based on the critical path testability measures, in linear time, the gradient of the function with respect to each possible test point. The gradients are used to approximate the global testability impact for inserting a particular test point. Based on these approximations, a test point is inserted and the critical path of testability measures is recomputed. This process is iterated until the testability is satisfactory. Massoud, Armita, and Navabi (2000) proposed a method in which a failure was induced in the circuit and a test applied to detect the failure. This is the opposite of the fault simulation proposed by (Cheng, 1995), in which a fault is inserted in the circuit and various tests are applied until one is found to detect the fault.

2.6. Built in Test Equipment

The duty of the BITE is to detect, identify, and isolate failure from the system during the failure diagnosis. There are two types of BITE: concurrent and nonconcurrent. The concurrent BITE is an off-line test of either structural or functional integrity. The nonconcurrent one is defined as an on-line test using either information redundancy or hardware redundancy or both. Using BITE can eliminate the cost of test pattern generation and fault simulation, shortening the time duration of the test, simplifying the external test equipment, and simplifying the adoption of the engineering changes (Paul H. Bardell, W. H. McAnney, and J. Savir, 1987).

Generally, there is no one best BITE structure. BITE is a collection of possibilities, the choice of which depends upon the application. The factors to consider include fault coverage required, the system overhead, which is tolerable, the system performance and the performance impact of the BITE technique, and the socket or test time, which is allowed. Some of the BITE structures modeling techniques are Scan-path, the random test socket, simultaneous self-test… etc. For more detail about type of BITE structures and their functions, see Paul H. Bardell, W. H. McAnney, and J. Savir (1987).

2.7. Expert Judgment Elicitation

2.7.1. Overview

This research utilizes expert judgment methodology in using observation points to monitor and detect partial failures. The field of expert judgment elicitation is generally accompanied with decision sciences that include how uncertainty in decision-making can be eliminated or minimized. Most literature considers that the main premise of the study of decision science is that ultimately humans are responsible for making and implementing decisions, either directly or through the use of surrogate algorithms and simulations (Hogarth, 1982, and Burge, 2001). There are many methods and models for analyzing decisions and designing strategies for implementing them. Each seeks to augment or supplement human abilities in some manner.

Salo(2002) defines decision-making for a partial system failure as "...an event with unknown outcome." Therefore, it is sensible at the time of modeling and analysis in engineering to start with the employment of safety factors using deterministic analysis, followed by probabilistic analysis with reliability-based safety factors (Ayyub, 2001).

In eliciting the expert's judgment for decision-making, it is required to select appropriate and direct methods of elicitation that involve direct questioning of the domain expert on how they do their work and how they can give information to improve it. Hugarth (1982) stated,

> "[...] Questioning is a form of communication between people in which a questioner tries to elicit information from a respondent. Questioners seek a particular kind of information and try to convey that desire through the questioning process. For adequate communication to take place, the respondent must understand the meaning of questions. At the same time, the questioner must understand the meaning of the response and judge whether it is a satisfactory answer to the question. Speaking the same language is a necessary but not sufficient condition for this communication process to take place."

The above statement shows that there are three main points to be considered in developing questionnaires eliciting expert judgment and opinion: understanding the meaning of the question, understanding the response and judgment, and speaking the same language. Belson (1968) suggested a technique for the pre-tested phase whereby responders are asked to repeat their understanding of the meaning of the question in their own words. This technique is analogous to back translating, when questions are translated into another language. On the basis of his use of this technique, Belson (1968) concludes pessimistically that even with well-developed, simplified questionnaires, many respondents do not understand the question as the researcher intended.

Expert judgments are the expressions of informed opinion, based on knowledge and experience, given in response to a technical problem. Thus, expert judgment can and legitimately should change over time as the expert receives new information, which can be then utilized to predict future events (Morey, 2000).

2.7.2. Definition and Meaning of Specialist/or an Expert

Conway (2003) stated that, "expert performance is vital to any analysis using expertise. If internal and external environment requirements exist for assessing the accuracy of expert judgment, the evaluation is straightforward. However, environment requirement standards rarely exist in domains requiring expertise, which is why experts exist in the first place". The first requirement is, therefore, to determine who is an expert. Many researchers have defined the meaning of expert. For example Conway (2003) defines experts by expanding Morey's (2000) expression as "individuals who have background in the subject area and are recognized as such by their peers as qualified to address the technical problems". Also, Ayyub (2001) emphasizes that an expert is someone who has had much training and has knowledge in some special field. These are rather generalized definitions and often insufficient in determining appropriate individuals to elicit for expert opinion. (Chytka et. al, 2003) address this, stating, "a pinpoint definition is required to fully comprehend the degree and type of knowledge necessary to qualify an individual as an expert. Currently, one of the widely utilized methods is peer identification, which seems to be capable of expressing expert identification. Professionals are asked whom they would consider to be an expert. When there is some agreement on the identity of such individuals, then they are labeled to have expertise. " Chytka et. al (2003) follows the same expression of expert judgment as Shanteau (2000).

Expertise is not just possessing knowledge or having qualifications; it is a highly specialized set of skills that have been honed in a particular situation for a specific purpose (Morgan and Henrion 2001; Shanteau, 2000; Jackson 1999). As such, being an expert is quite distinct from having an education. Experts need to know more than just the mere facts or principles of a domain in order to solve problems. Experts need to know which kinds of information are relevant to which kinds of judgments, how reliable different information sources are, and how to make hard problems easier by dividing them into smaller, more manageable units. Eliciting this type of knowledge, which is normally based on personal experience rather than formal training, is difficult (Jackson 1999).

2.7.3. Studies in Expert Elicitation

Knowledge elicitation studies and methods are classified in many ways to obtain the information required to solve problems. One of the common ways relies on how directly solicitors obtain information from the domain expert (Burge, 2001). Directly obtained information involves questioning a domain expert on how they do their work. Burge (2001) classifies these methods by the ways they interact with the domain expert.

Others, like Hudlicka (1997), classify knowledge elicitation by what type of information is obtained.

2.7.4. Knowledge Elicitation Methods

As stated previously, knowledge elicitation methods have been classified in many ways (Burge, 2001). One common way is by how directly information is obtained from the domain expert. Direct methods involve directly questioning a domain expert on how they do their work (Hogarth, 1982). Burge (2001) found that in order for these methods to be successful, the domain expert has to be reasonably articulate and willing to share information. The information has to be easily expressed by the expert, which is often difficult when tasks performed by the expert have become 'automatic' or internalized. Indirect methods are used in order to obtain information that cannot be easily expressed directly (Hudlicka, 1997).

2.7. Literature Review Summary

Table 2 below summarizes the main points in the literature review. Ted W. Yellman (1999) emphasized that distinguishing among failure terms should be done by preceding the word failure with an appropriate adjective and not by creating definitions for failure itself, which are impractical and unnecessarily narrow. In other words, during partial failure, satisfactory and unsatisfactory system output indicates different meaning. This is because system output depends on the combination of system functions and performance cycles in the case of the occurrence of partial failure. Yellman's (1999) conclusion can enhance current research where more than two states are assumed i.e. a partial failure state. Rausand (2000) classifies failure in relation to complete failures and partial failures. This classification is used in current research to distinguish between complete and partial failure, and to simplify this distinction. Table 2 expresses the meaning between complete and partial failures. and Zuo (2000), who studied systems and their components (subsystems), stated, "both the system and its components can have more than two states, e.g., completely working, partially working, partially failed, completely failed." Algorithms for reliability evaluation of such systems are presented. Huang's and Zuo's (2000) work is potentially useful in developing a test methodology. Stress can be involved in inducing and spreading the partial failures from the defective component to neighboring components. Cruse and Mahadreven (1994) studied the influence of stress, and they concluded that the noncritical failures in a defective component cause a distributed stress on non-defective components. In current research, an observation test point can provide a possibility for monitoring partial failures, which are indicated by Cruse and Mahadreven (1994) as noncritical failures.

Zahalca and Chardi (1996) conclude that system sensitivity increases with the number of components in a series configuration, which is less sensitive than parallel configuration. This study also confirms that the most reliable configuration is most sensitive to stress. In current research, system confirmation with respect to test point insertion can be utilized by looking to the components with parallel configurations more carefully than series configurations. This is a key motivator for the present study. Ebeling (1996) enhanced the assumption of partial failure states when he stated that "[…] a component having a constant failure rate has slightly better than one-third chance of surviving to its mean time to failure," which means that the system can pass through more than one partial state before reaching complete failure.

An early study on using critical path tracing to detect failures was presented by Premachandran and Aramvici (1991). They proposed and developed a modification algorithm of the critical path tracing method to make it exact for combinational circuits. Based on critical path tracing, Shadfar, Paymandoust and Navabi (2000) used fault simulation to detect faults. Their method applied a fault test to a circuit, and detected faults were reported. This is different from the other methods in which a fault is inserted in the circuit and various tests are applied until one is found to detect the fault. In this research, our intention is to minimize the number of observation test points to only parallel system (circuit) configurations. Touda and McCluskey (1996) introduced test pattern procedures. They proposed detection of complete failure coverage using critical path tracing by using test patterns.

A further approach to the determination of partial failure involves the use of experts, who are relied upon to provide knowledge related to the failure process and outcomes. Morey (2000) defined experts based on knowledge and experience. As is known, there is no boundary for knowledge. As a result, no single methodology exists. Therefore, building knowledge about any system requires the use of questionnaires. Additionally, based on the literature review, qualitative assessments are easier to elicit than probabilities. Hugarth (1982) gives a more specific expert definition and the criteria needed to be developed to select subject matter experts. Ahti (2002) defines uncertainty for decision-making as an event with an unknown outcome.

Author(s)	Major Points/Finding	Current Research/ Research Implications
Yellman (1999)	"Satisfactory" and "Unsatisfactory" system output in relation to failures.	Enhance current research
Rausand (2001)	Classified the failure in relation to complete failures and partial failures	Use as a baseline to differentiate between the complete and partial failures
Huang, Zuo (2000)	The system and it is components can have more than one states	Potentially useful in developing Test Methodology
Cruse and Mahadrevan (1994)	"Stress influence" Noncritical failures in a defective component cause a distributed stress on non-defective components	Stress clear feedback can be used to minimize the stress on non-defective components
Zahalca and Chardi (1996)	"System Sensitivity" increases with the number of components in a series configuration, which is less sensitive than parallel configuration	A key motivator for present study
Ebeling (1996)	Mean Time To Failure in Constant Failure rate system has better than one-third chance of components surviving	Enhance the assumption of partial failure states.
Menon and Aramovici (1991)	"From Pessimistic to optimistic results" An early study on using critical path tracing to detect failures	A key motivator for present study
Shadfar, Paymandoust, and Navabi (2000)	Detected faults using fault simulation based on critical path tracing.	Critical path tracing techniques used in parallel configuration to detect and monitor partial failures that cause system degrading.
Touba and McCluskey (1996)	A complete failure coverage using critical path tracing using test patterns.	Selected test patterns to cover maximum partial failure
Meyer (2000)	Elicitation of experts based on knowledge and experience.	Building knowledge about any system require use of questionnaires
Hugarth (1982)	Gives more specific expert definition	A key motivator for present study.
Salo (2002)	Defines decision-making for a partial failures state as a unknown system outcome	Enhance the assumption of partial failure states.

Table 2. Literature Review Summary

2.9. Research Problem

Based on the literature summary, this research will address partial failures in operating systems such as fire control tracking radar onboard naval ships. When these types of partial failures occur in such systems, they lead to challenging operational problems. Consequently, minimizing or eliminating these types of failures can improve system performance and reduce maintenance cost.

2.10. Research Purpose

The purpose of this research is to develop a methodology to detect partial failure in fire control system tracking radar. Early detection of partial failures can improve performance and reduce repair costs. Two main steps are to be used to detect partial failures. The first is by inserting observation test points to detect partial failures in electronic naval systems not detected by BITE. The second is by relying on the experts' judgment to determine the appropriate place for test point insertion. The expert judgment generated result will be used to validate the first approach which is based on the three techniques. The expected findings of the research for the system under study can improve system performance, aid in decision-making, and reduce overall repair time.

2.11. Contributions

The literature review yielded important observations on partial and complete system failures. The first observation is that most of the researchers have concluded that all complete failures are induced as a chain of partial failure states. This is true, but when researchers estimate operating systems as a set of only two-status states, they increased uncertainty in detection of complete and partial failures. This is because the probability for all the system status states is not considered. Moreover, as a result of two-status states, estimation by BITE systems may not provide sufficiently high fault coverage. This occurs especially when there is a large system network that contains many partial failures (which can lead to complete system failure), where the BITE detection system can easily ignore these types of failures. By testing and adjusting the arrangement between the system performance, reliability and monitoring test point insertions, one can control and optimize the detection and monitoring of partial failures. An important contribution of this study is to illustrate a new kind of decision-making, which has potential for applications other than on naval ships.

The second observation is that from previous experiments and knowledge, researchers estimate two sets of states that consist of either operating state or non-operating state. This action of state estimation covers system function failures only and not failures that occur in system performance, which includes partial failures. In such cases, a different approach is required because in addition to detecting system function failures, one is required to detect maximum system performance failures. This can be achieved by inserting test points in the appropriate complete failure recovery critical path to monitor and control failure. By doing so, maximum monitoring, and control coverage is obtained for every specified set of test points, which in turn increases the system's performance and availability.

This research also serves to develop a practical tool for tactical and operational decision-making that may be adopted as a standard approach in decision-making processes that involve maintenance investment. At this time, there is no existing model that addresses all the relevant issues to solve this problem. The usefulness of this study's findings is not limited to supporting the BITE for dynamic systems. It can also be used to generate recommendations for fundamental applications at organizations that support ship/shipyard maintenance in predicting (i.e., as field observers) small production problems, which do not shut down the system but can create operational problems later through partial failures.

CHAPTER III

RESEARCH OBJECTIVE

3.1. Primary Objective

The primary objective of this research is to test if a model can be developed to determine the insertion of observation test points to detect partial failures in electronic naval systems not detected by BITE. The model is based on k-of-n: G system, Markovian Chain technique, and critical path tracing. For validation, expert judgment is used to determine whether the predicted insertion points are appropriate. This model should improve decision-making on maintenance that will support and manage BITE(s) to monitor and predict dynamic system partial failures before they significantly damage the system or its subsystems.

3.2. Model Description Using The Three Techniques

In operation, dynamic systems change their states continuously in relation to functional required at a specific moment. This means that each stated movement of the system requires a specific number of system components to function as required correctly so that the system can change its current state to the next state. In this research, system states are going to be defined as the final system state that results from the summation of all system components that are required to function at that specific moment. Therefore, system states individually can be treated as a final summation output result of the combined multi-components' final states at a given specific point in time. Figure 4 demonstrates the above discussion. In this case, each system's final state depends on several factors. Some of those factors are the components' location in relation to the system structure at that specific time, and the stress that is shared by each component.

The components' final state has a great impact on the system state's result because each system state level requires the same number of components to be at or above a certain state (Huang and Zuo, 2000). However, maintaining any system's state may require at least a specific number of components to operate clearly. The required number of components depends on the system-state (activity) being considered. In conclusion, the relationship between the system's state and the components' state is bi-directional.

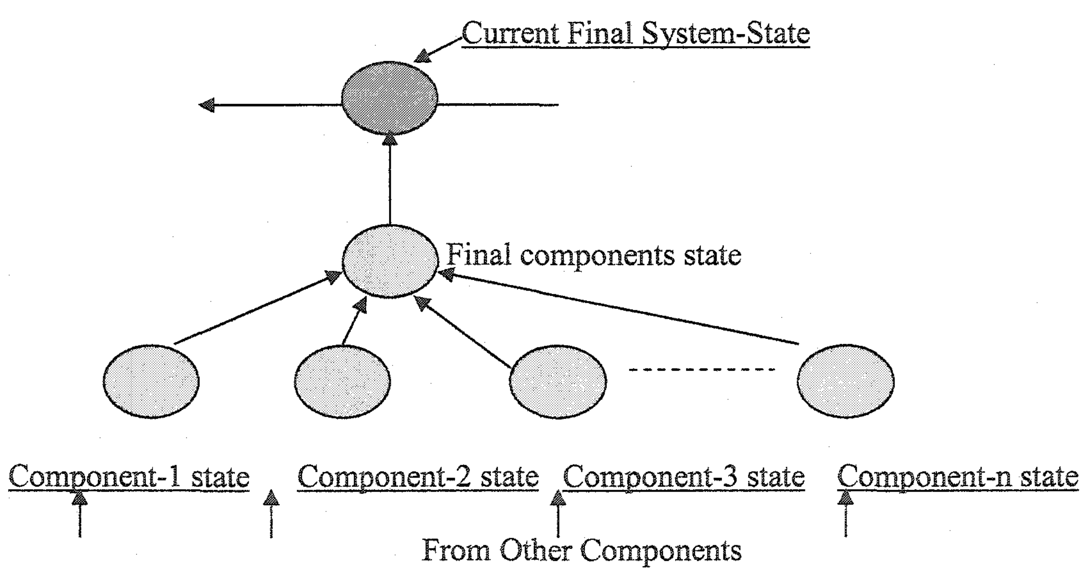

Figure 4. Final System State Resulting From a Summation of All System Components

Based on the above description, the model may deal with the components of the operating system that are as dynamic in behavior as the multi-state *k*-out-of-n: G: system-states. Also, at the time of system failure or partial failure represented, Markov chain techniques can be utilized with the assumption that there are more than two states (depending on the system components' structure and location). The system can consist of several types of component configurations: series-series, series-parallel, parallel-series, parallel-parallel, or combination thereof. Figure 5 a, b, c, and d demonstrate different system configurations operational states.

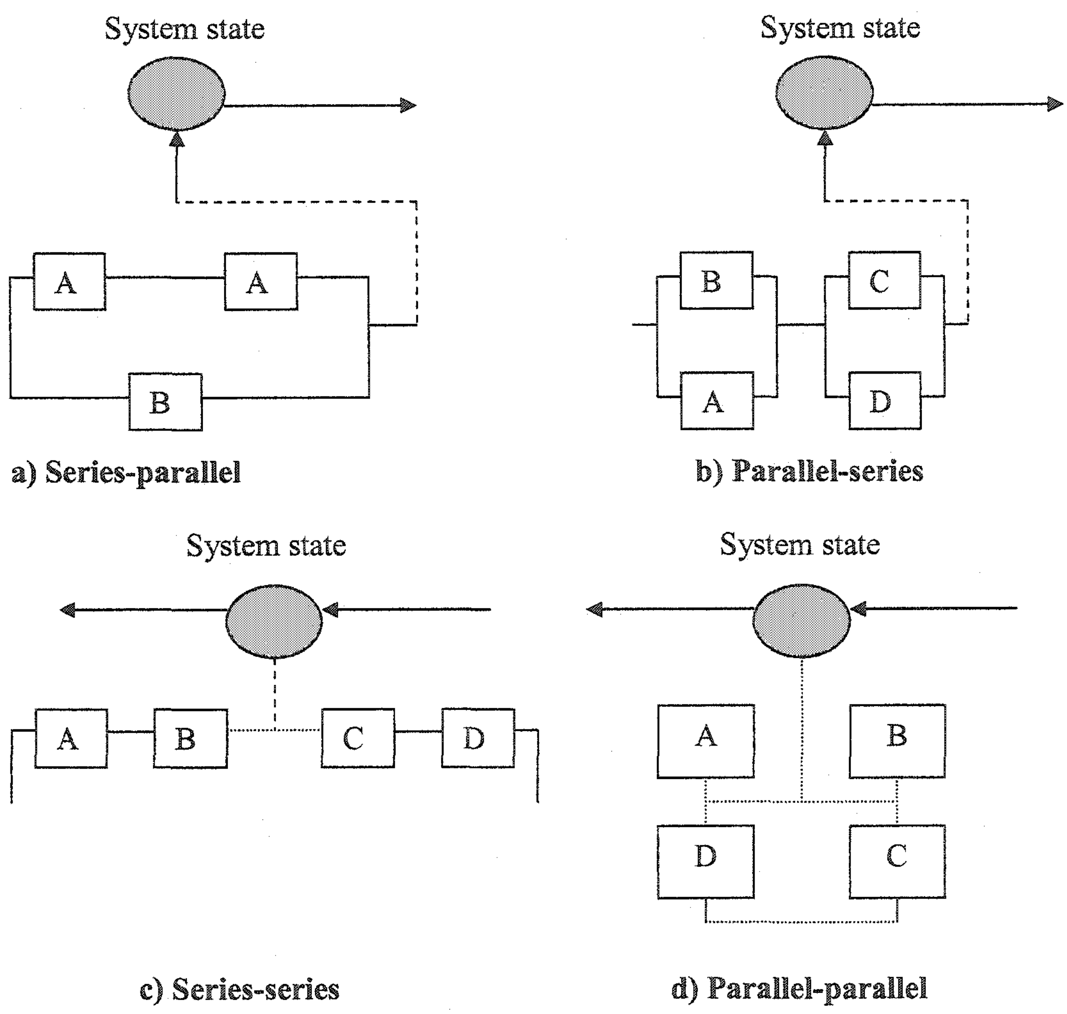

Figure 5. Different System Configurations Operational States

Cruse and Mahandevan (1994) differentiate between critical and noncritical failures (or failure and/or partial failure) in that critical failures result in immediate, total failure of the system, whereas non-critical failures degrade the system performance, resulting in changes in external load within the failure context on the components by creating a chain of failure events.

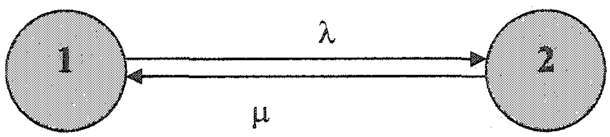

Figure 6. Two States Markov Model

Therefore, non-critical failures do not directly result in system failure; instead, the degradation caused by their occurrence affect the probability of occurrence of the critical failure. Also, Cruse and Mahandevan considered that "…. the distinction between critical and noncritical failure modes in their methodology is maintained in the construction of the failure tree, by identifying several levels. At level I, the probability of each individual failure mode is estimated for an intact system, i.e., no damage has occurred. At level II and above, the probabilities of occurrence of the critical failure modes are estimated after accounting for the non-critical mode. This is done through reanalysis of the system after incorporating the effect of noncritical failure, such as load redistribution and /or changing the finite element mesh to show local cracking." In reality, they proposed a model, which can treat each system state as combination levels of components and subcomponents.

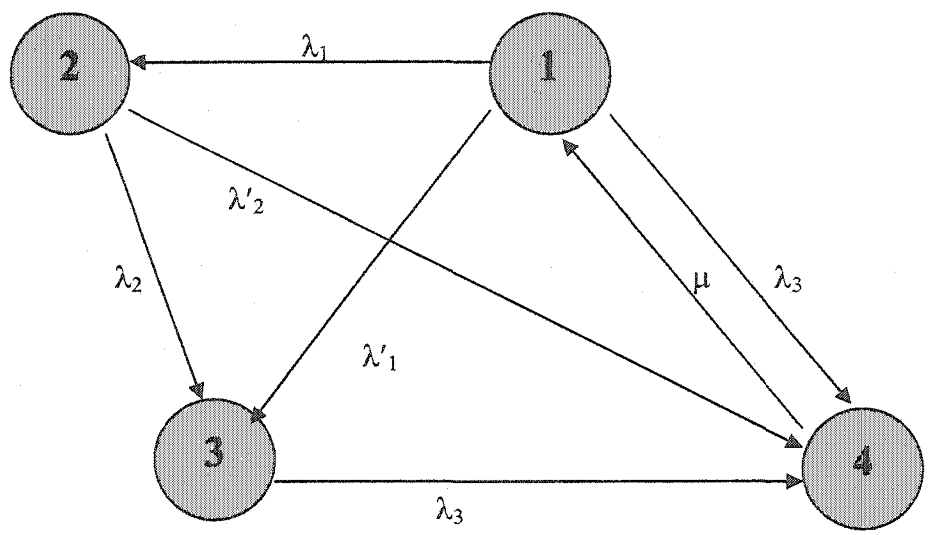

Figure 7. Multi States Markov Proposed Model

3.3. Mathematical Model Description

A system is considered 100% reliable if all its components are operational and can be represented by a two-state Markov model as given in Figure 6, i.e., operation or failure. If the system is not 100% reliable, then the components cannot be represented as in Figure 6. A more detailed model becomes necessary. A multi-state Markov model may be required to include all detailed states of components. For simplicity, a system consisting of a single component is considered in this study, as shown in Figure 7. The component can have more than two states immediately after "switch on." In the following example four states are assumed:

- The operational state (desired operation performance),
- A non-operational performance state or complete failure, and
- Two partial operational states leading to less than desired operational performance, which do not necessarily have the same failures, and do not

directly result in system failure. However, their occurrences affect the probability of occurrence of the non-operational performance event and non-operational states (non-operational performance state or complete failure).

In this model, each component will have four possibilities to reach the failure state:

1. A direct failure (direct transition from operation state to complete failure state).
2. From operation state to complete failure state after transit from first partial failure.
3. From operation state to complete failure state after transit from second partial failure without passing first partial failure to failure state.
4. From operation state to first partial failure state to second failure state then to complete failure state.

When a component fails, certain repair work can be performed (either a complete repair or replacements repair). It is assumed that complete repair and replacement repair restore the failed component to an as-good-as new state. The replacement of a failed component by an independent and identical component (i.i.d) can be done via a backup system. In order to measure the system's component performance at any instant of time, system availability must be defined at that instant in time. In the general observation to predict component availability (A), both the failure and repair probability distributions must be considered.

$$A = \textbf{(operation time) /(operation time + Down time)} \quad (1)$$

$$= \textbf{(MTBF) /(MTBF + MTTR)} \quad (2)$$

$$A_o = \textbf{(MTBF) /(MTBF + MDT)} \quad (3)$$

Where,

Ao = operational availability, MTBF = Mean Time Before Failure, MTTR= Main Time to Repair, and MDT = Mean Down Time.

Equation (3) is known as the steady-state availability and can be expressed as a ratio or as a percentage.

One of the key assumptions in this steady-state model is the assumption of constant failure rate and constant repair rates. To expand these assumptions for evaluating the availability for interval, or mission ($t_o \rightarrow t_k$) where $k \geq 1$ is

$$A_{t1-to} = (r/(r+\lambda)) + (\lambda/((r+\lambda)^2 . (t_1 - t_o))) . [e^{-(\lambda+r)} - e^{-(\lambda+r)\,t1}] \quad (4)$$

Figure 7 shows λ_i, λ'_i, and μ_i, the failure rates and repair rate respectively. Now, with steady-state conditions, availability can be calculated as probability. If P_i is the availability probability of being in state i, the steady-state equations are

1. $-\lambda_1 P_1 - \lambda'_1 P_1 - \lambda_3 P_1 + \mu P_4 = 0$
2. $-\lambda_2 P_2 - \lambda'_2 P_2 + \lambda_1 P_1 = 0$
3. $-\lambda_3 P_2 + \lambda_2 P_2 + \lambda'_1 P_1 = 0$
4. $P_1 + P_2 + P_3 + P_4 = 1$

(5)

If the component is available in state 1, 2, or 3, the steady- state availability is given by

$$P_1 + P_2 + P_3 = \text{Availability}$$

Now the probabilities

1. $P_1 = [1 + (\lambda^{-1}_3 \,.\, [\,((\lambda_1 \lambda_2) + (\lambda'_1 .\, (\lambda_1 + \lambda'_2)))\,/\,(\lambda_1 + \lambda'_2)])$
   $+ (\lambda_1/(\lambda_2+\lambda'_2)) + ((\lambda_1 + \lambda_4 + \lambda_2)\,/\,\mu)]^{-1}$ (6)
2. $P_2 = P_1 .\, (\lambda_1/(\lambda_2+\lambda'_2))$
3. $P_3 = P_1 .\, \lambda^{-1}_3[\,((\lambda_1 \lambda_2) + (\lambda'_1 .\, (\lambda_1 + \lambda'_2)))\,/\,(\lambda_1 + \lambda'_2)]$

The Markov model can be extended to address the multi-component system using the transition rate, which can be expressed, more conveniently, in the form of a transition matrix.

$$P = T^{-1}\,b$$

Where P is the probability, T is the transition matrix, and b is Identity matrix.

CHAPTER IV

RESEARCH METHODOLOGY

4.1 Introduction

The purpose of this research is to develop a methodology to detect partial failure. By detecting partial failures early, one can improve performance and save costs. In the prior literature, many researchers used probabilistic techniques on designing BITE systems that can achieve certain levels of improvement in detecting failures. But still, these probabilistic techniques may not provide sufficiently high failure or partial failure coverage. The requirement is to provide a support technique to the BITE system. This can reduce the time gap between the accruing of partial failures and BITE system reaction, which can then imply maximum recovery in the number of failures recorded against system availability and performance that then require maintenance actions in order to continue the system to full operation and maximum performance. It also underlies the same reduction in the time and manpower required maintaining and servicing the system.

From previous experiments of system failure detection, researchers estimate two states that consist of either operational state or non-operational state. This type of states estimation in reality is going to cover system function failure only and not failure that occurred due to system performance, which include degraded failures, among which are partial failures. In such cases, a different approach is required to be taken into account to have maximum failures recovery for system performance and availability in addition to system function. This is can be achieved by inserting observation test points in proper selected areas in the system. In doing so, maximum monitor and control failure coverage are obtained. Table 3 summarizes the eight phase methodology, which are explained in detail in section 4.4.

Phase	Action
1.Problem Definition	• Performance characteristics selection. • Define partial failure • Identification of parameters • Model provides distributions of parameters

2.Criteria Selection	• Experts selection
	  o Qualification
	  o Knowledge of the system
	• Data selection
	  o Type and location of data (at sea, at workshops, etc.)
	• Establish a checklist for specialties

3.Define The Parameters That Cause Partial Failure	• Experts can recommend adjustments • Parameters weighted
4.Construction and Administration of Questionnaire	• Test information built into questionnaire • Using confidence type • E-mail, card, simple and direct questions
5.Results	• Raw data
6.Revision and Correction	• Expert opinion • Changes
7.Observation Point Insertion	• Identify the partial failure • Selection of observation points that enable each of the partial failures to be identified • Selection of a minimum set of observation points that provide partial failure coverage • Path tracing • Probability of partial failure detected by observation point
8.Validation of Methodology	• Survey and interviews • Follow-up questionnaire • Output methodology • Revision

Table 3. Summaries Methodology Outline

4.2. Proposed Approach

4.2.1. Development of a Model to Base Maintenance Decisions.

Markov chain, k-out-of-n: G: system, and failure path tracing techniques are employed to develop a New Testing Technique (NTT). Based on this technique, observation test points are inserted, which may enhance system performance. For this research, the NTT is developed in one of the technology areas associated with Tracking Radar (TR) Fire Control Systems that are currently installed onboard Bahrain Naval Royal Force ships. A simple questionnaire is used to develop a fault detection technique to identify failures that are not detected by a specified set of test patterns.

The second part of the questionnaire makes a comparison with the best previous results for other test point insertion methods used for that specific system. This is achieved with the knowledge obtained from experts in this field. This comparison is used to validate the results obtained from the NTT.

The result can then be used for further study to support a fault diagnostics procedure or to validate the effectiveness of BITE equipment capability.

4.2.2. Test Validation

The main objective for this study is the development of a model on which to base maintenance decisions that can account for support and manage maintenance with BITE to monitor and predict dynamic system partial failures before they significantly damage the system or its subsystems. Validation is accomplished using a structured expert elicitation technique. Experts are solicited using a questionnaire that highlights a series of parameters related to test point insertion that impact overall operation for the Fire Control System TR. For each parameter, a manufacturing company was asked to indicate the impact of the parameter on support requirements of the specific system. Each parameter has a series of Fire Control System attributes that may impact that parameter. For each attribute, the expert assesses the percent improvement that the attribute has on associated parameters.

It is conceivable that with this new approach, maintenance decision-making can be improved, thereby enhancing system performance and reducing the cost of the technology adopted. This consequence of the NTT model is not fully validated, but tentatively investigated using a questionnaire issued to the experts, which assesses a comparison between the new and old technology and their impact on the performance and cost.

4.2.3. Application of Technique

Officials from the Bahrain Royal Navy and experts from the related company will provided feedback on the results. Then the result of ongoing research with the experts' feedback data will be used to increase the effectiveness of TTN in the future.

4.3. Data Needs and Resources

System data is divided into two parts. The first part is designated as the primary parameters. Primary parameters are the main factors used to detect failure. This means that if the primary parameter is controlled or monitored by observation test points, most partial failures can be detected. Some of these parameters could be voltage, current, etc. The second part is designated as the secondary parameters. Secondary parameters are those that can be affected by the primary parameters due to the controlling or monitoring of partial failures (i.e., increase or decrease of mean time to failure, increase or decrease of mean time between failure, etc.). Some of these parameters are MTTR, MTTF, and MTBF.

Data received from external resources is in two parts. Data received from the system manufacturing company, is treated as secondary parameters. This type of data is already normalized and is used directly in the research model. Data that is collected from the field from similar TR(s) systems is treated as primary parameters. The same maintenance group collects this data for the duration of three years from August 1998 to July 2002. This data is normalized by the system manufacturing company.

4.4. Partial Failure Detection Phases Methodology

Figure 8 shows the research methodology flow chart, which is developed to detect and monitor partial failures of the dynamic system and to improve performance. The methodology consists of eight phases and is derived from the study of literature related to failure detection by k-out-of –in: G: system, test point insertion and critical path, and Markov techniques. The phases from the problem definition to methodology validation are described following Figure 8, and in the following sections.

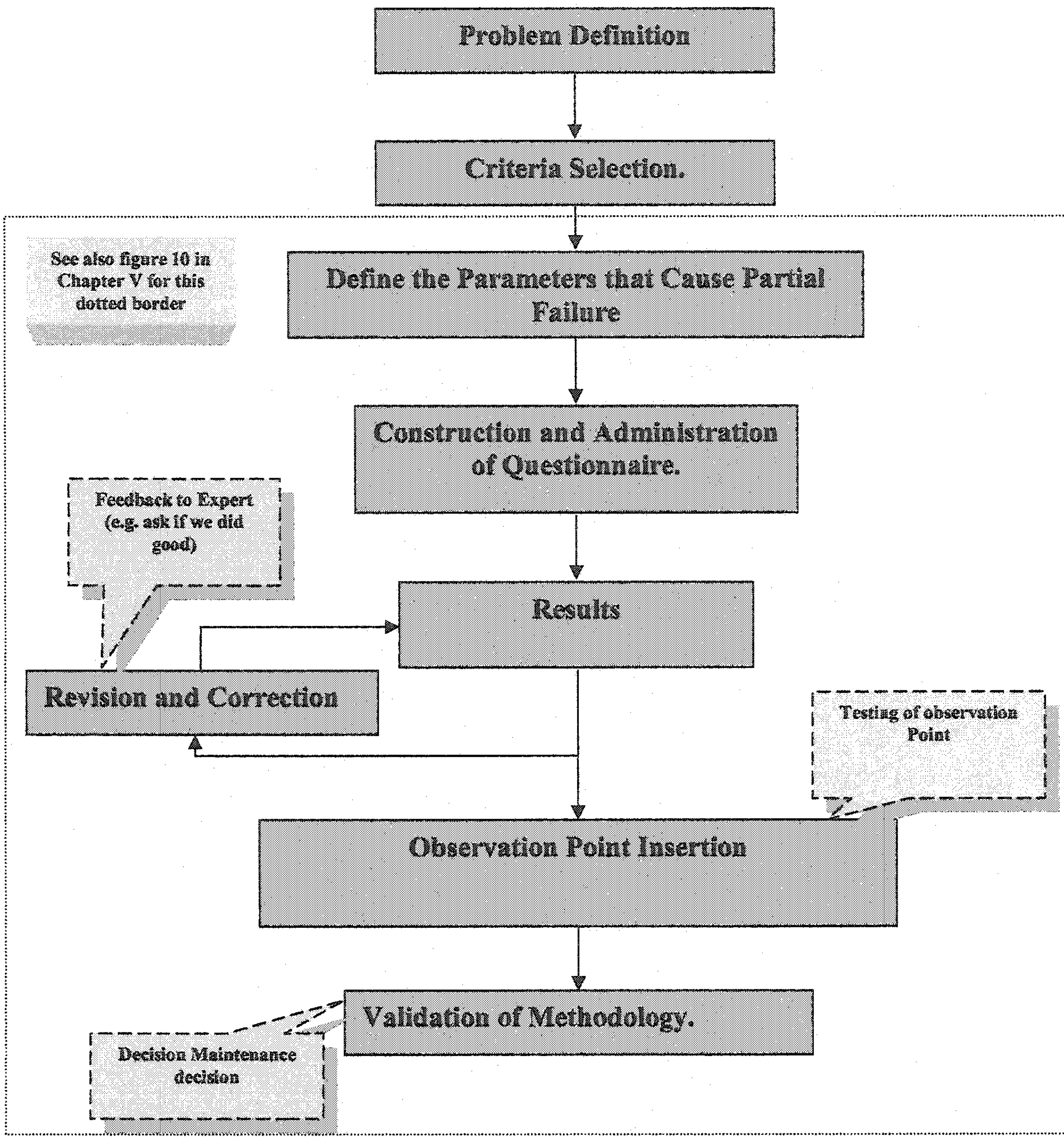

Figure 8. Partial Failure Research Methodology Phases Flow Chart

4.4.1. Phase 1: Problem Definition

In this phase of the methodology, it is assumed that the system is already in operation with continuous use, and with continuous change states depending on the order it receives. The design team, due to a variety of detection approaches, has identified partial failures, which can occur without necessarily shutting down the system. The design team then selected the critical performance characteristics to be included in the system analysis study together with the input parameters whose values are subject to change due to partial failure occurrence. The NTT methodology will be utilized to identify these partial failures and the possibility to control them.

4.4.2. Phase 2: Criteria Selection

This phase has two parts. The first part is the selection of experts. In this case, expertise will have two meanings. The first is general familiarity with fire control system tracking radar system design, and the second is specific knowledge of tracking radar system operation and maintenance.

The second part of criteria selection is data selection. This part will depend on the researcher's knowledge of the system. Fundamentally, for this methodology, this means that if the researcher is one of the expert team involved in the domain of system knowledge, the collection of data will be easier. The connection between the selection of experts and the selection of data is important in preparing any checklist. Some of the criteria expected to be included in the checklist.

- System knowledge
- Technical skill
- Decision strategies

4.4.3. Phase 3: Determination of Parameters

The fire control system tracking radar is a small, compact system. There are, however, many parameters that have a major effect on partial failures. The expert could act individually in identifying parameters that are to be included in the analysis. The parameters are selected based on their effect on the degradation of system performance due to partial failures. Many methods can be utilized to identify parameters and system performance characteristics. Some of the methods are: aggregation, correlation, and averaging.

4.4.4. Phase 4: Construction and Administration of Questionnaire

The construction of the questionnaire related to new testing techniques starts by defining expert opinion with respect to their knowledge of involvement and technical skill concerning the system under study. The questionnaire can be categorized under three levels: (1) expertise, (2) study, and (3) subject.

Measuring and Reading Elements

To be more effective in data collection, the type of measurement and way of reading, if it is specified, can improve queuing of data collection. This action may be useful in helping experts to achieve their opinion. An important point is that to be more effective; anchoring must be consistent and repetitious, and use identical methods for testing a particular response pattern.

Test Elements

For this research, the NTT is developed for experts in one of the technology areas associated with Tracking Radar (TR) of Fire Control Systems that is currently installed onboard Bahrain Naval Royal Force ships. A simple questionnaire is used to develop a fault detection technique to identify failures by a specified set of test patterns. A second part of the questionnaire attempts to make a comparison with the best previous results for other test point insertion methods used for that specific system. The questionnaire was made available to experts via E-mail, a simple and clear-printed card, and a simple example with unambiguous language.

4.4.5. Phase 5: Results

The questionnaire concerning new testing techniques yielded data in the form of ship log books, workshop defect books, and E-mails, as well as the raw attribute range and confidence level data for judgments on the selected parameters and characteristics.

4.4.6. Phase 6: Revision and Correction

After collecting data, correction from experts was required, to increase the confidence in the analysis. This action serves as feedback to avoid any misunderstanding of questions, and allows experts more time to revise their opinion based on the data summary.

4.4.7. Phase 7: Observation Point Insertion

Experts record all the different measurements of the required available parameters; potentially this reading could fall more in the **estimation-instrumented domain** than in the **real instrumented domain,** depending where the measurement was held (at sea, in workshops, or along the sea wharf). Consequently, taking the average reading of all possible measurements obtained from expert responses to the new testing techniques can help to estimate parameters more accurately. As in this technique, the intention is to identify partial failures that do not propagate to a higher primary output. In other words, the investigation measures more than two status states (including partial failure state(s)).

New Testing Technique

The observation point is an additional primary output that is inserted in the system to increase the detection of partial failures in the system, subsystem, or equipment. Partial failures that do not shut down the system immediately are the failures that require observation test point in addition to the system function point in order to be detected. See figure 9 below.

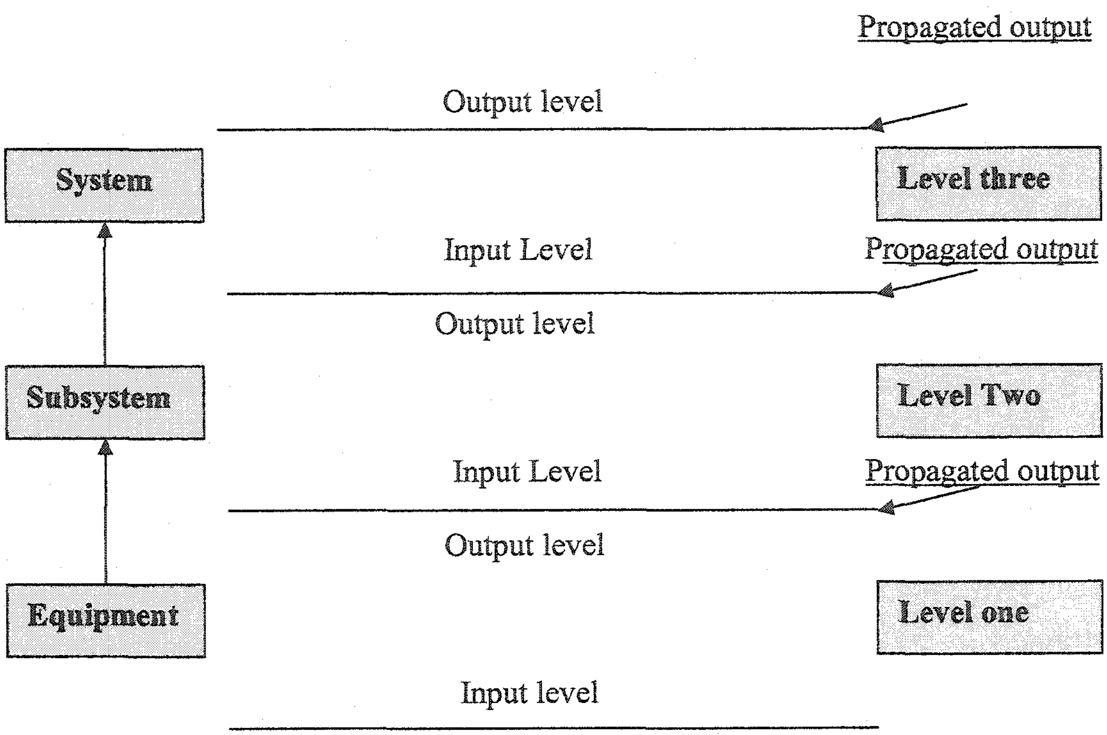

Figure 9. Propagation of partial failure using observation points

The New Testing Technique can be simplified in the following steps:

1. Identify the partial failures.

   As stated in phase 1, the design team, due to a variety of approaches, identifies partial failures, which can occur without necessarily shutting down the system. This can be performed for the set of test patterns applied to the system, subsystems, or components under investigation to determine which partial failures are already undetected and which require observation points in order to be detected.

2. <u>Select observation point that enables each of the undetected faults to be detected.</u>

   For each of the partial failures that require observation points, a set of observation point solutions is computed such that if any observation point in the set is inserted into the system, subsystem, or components, the partial failure will be identified.

3. <u>Select a minimum set of observation points that provides complete failure coverage.</u>

   Given the set of observation point solutions for each partial failure, a set covering procedure is used to find a minimum set of observation points that enable all of the partial failures to be detected.

4. <u>Path tracing.</u>

   To find the set of observation point solutions for partial failure that was provoked by a particular pattern, path tracing can also be used to identify the position that the partial failure can propagate.

5. <u>Probability of partial failure detected by observation point.</u>

   Any observation point that gives a detection solution to a partial failure will satisfy the detection probability state of this partial failure, based on the assumption of the multi state Markov model. The probability of partial failures of the example in section 3.3.2 was calculated as:

$$P_2 = P_1 . (\lambda_1 / (\lambda_2 + \lambda'_2))$$
$$P_3 = P_1 . \lambda^{-1}_3 [((\lambda_1 \lambda_2) + (\lambda'_1 . (\lambda_1 + \lambda'_2))) / (\lambda_1 + \lambda'_2)]$$

The assumption was that for two partial states in addition to one operation and one complete failure state

Where,

P_1 = the probability of the operation state, P2 = the probability of first partial failure, P3= the probability of second partial failure, λ'_2 = failure rate of the first partial state to failure state, λ'_1= failure rate of operation state to the second partial failure, λ_2 = failure rate first partial state to second partial state, λ_3 = the failure rate from operation state to non-operation state, and λ_1= the failure rate from operation state to first partial failure state.

4.4.8. Phase 8: Validation of Methodology

Validation of the methodology in this research means building the right support test system: that is checking system performance by continuing to monitor and detect partial failure to make sure that the system does what it is supposed to do. Bahill (1991): explains this clearly in the statement "[...] Validity refers to the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure."

Many researchers have classified validity into three forms. The first is face validity, which is concerned with how a measure or procedure appears. Does it seem like a reasonable way to gain the information the researchers are attempting to obtain? Does it seem well designed? Does it seem as though it will work reliably? Unlike content validity, face validity does not depend on established theories for support (Fink, 1995). The second is criterion related validity, also referred to as instrumental validity. It is used to demonstrate the accuracy of a measure or procedure by comparing it with another measure or procedure, which has been demonstrated to be valid. The third is construct validity, which seeks agreement between a theoretical concept and a specific measuring device or procedure (Adelman, 1992).

The forms of validation are contingent on the modes of communication. There is three well documented modes of communication: face-to-face, telephone, and mail. The face-to-face mode works best for obtaining detailed data. It, however, consumes more time and is expensive. The second mode uses telephony capabilities, which can be substituted for the mail mode only if limited bits of information are being communicated. The third mode is the mail mode, which works well for sending and receiving simple data from a large sample of experts. When compared with face-to-face surveys, mail surveys cost less (Meyer and Booker, 1991).

In this research, the principle mechanisms used to validate the methodology are surveys, telephone and E-mail, and indirect interviews in which the expert is interviewed alone, with exchange of the data between the researcher and experts. This process of expert judgment testing will give the opportunity to provide feedback on the usefulness, ease and applicability of the testing process. Additionally, face validity was used to validate the methodology to ensure that the questionnaire is measuring what it is supposed to be measuring thus ensuring a more realistic output than other output forms with respect to time.

CHAPTER V

RESEARCH FINDINGS

5.1. Introduction

This chapter documents the verification outputs and analysis results. The initial stage of the methodology, as it was explained in previous chapter, is to identify system and/or its subsystems partial failure parameters. This is an important factor to insert the observation point to detect and monitor partial failure. To do so, there are two requirements, which are running in parallel. As shown in Figure 10, the first requirement is the three major steps that reach down to a level of observation point insertion. These major steps are: 1) focus on the potential area inputs, outputs and the number of components involved during occurrence of partial failures; 2) minimize the potential area size down to a level of simple logic gates (Menor, 1991); 3) utilize critical path techniques to achieve exact position of observation point to solve the problem of the partial failure that affects the potential area and force it not to propagate to the higher level or to system primary output (Youssef, 1996).

The second requirement is using the questionnaire. The questionnaire was designed to run with the major steps in parallel to identify partial failures parameters and predict their averages and tolerances ranges. The questionnaire was also developed in an effort to document expert opinion on the parameters sought. The questionnaire utilized is provided in Appendix A, Appendix D and Appendix F to simulate the estimated system parameters output of each expert input histogram with different expert confidence. All sets of opinions derived from experts were implemented. Each parameter was arranged into three levels of measures, maximum (the parameter has positive value from normal), normal (the exact parameter value measure), and minimum (the parameter has negative value from normal). Each level of measures was also arranged in percentage as 75%, 50% and 25% as the expert's estimated input confidence of the parameters value. For each expert experience three levels of weight factors were selected as 75%, 50% and 25%. The senior expert among participants should have 50% or 25% weight factor more than other experts. The small percentage range was selected narrowly (75%, 50% and 25%) because the system under study is small and it requires a specific expert skill and knowledge.

In this research, the fire control system tracking radar detector unit was evaluated using NTT, which is currently installed onboard Bahrain Royal Naval Force ships. Table B1-Appendix B displays failure rates and repair rates for tracking radar detector unit as a subsystem. Three experts provided these data; two are from Contracted Maintenance Support Company (CMSC), and one from the Royal Naval electronic and electrical workshop. Table B1 shows also that the calculation of failure location time is based entirely on the BITE, with the estimation of two states of operation of go or no-go. This time can be longer if a certain Navy has only unskilled people that are unable to correctly interpret BITE information; the repair time calculation is based entirely on spare parts, people availability, and location.

Tracking radar system (MTBF) Total Mean Time Between Failure, (MTTF) Mean Time to Failure, and (MTTR) Mean Time to Repair were calculated (See Table B4 Appendix B) as follows:

The total MTBF is = 10^6 / ∑ subsystems Failure Rate = 10^6 / 838.32 = 1192.86 hrs.

The predicted MTTR is = ∑ (Failure Rate∗ (Location Time+ Repair Time)) /

(Total Failure Rate)

= 51256.31/ 838.32 = 61.15 mins

The predicted MTTF is then MTBF – MTTR = 1192.86 – (61.15/60) = 1191.84 hrs.

These experts categorized the BITE failures detection in the fire control system tracking radar into three levels as shown in Table B2 in Appendix B.

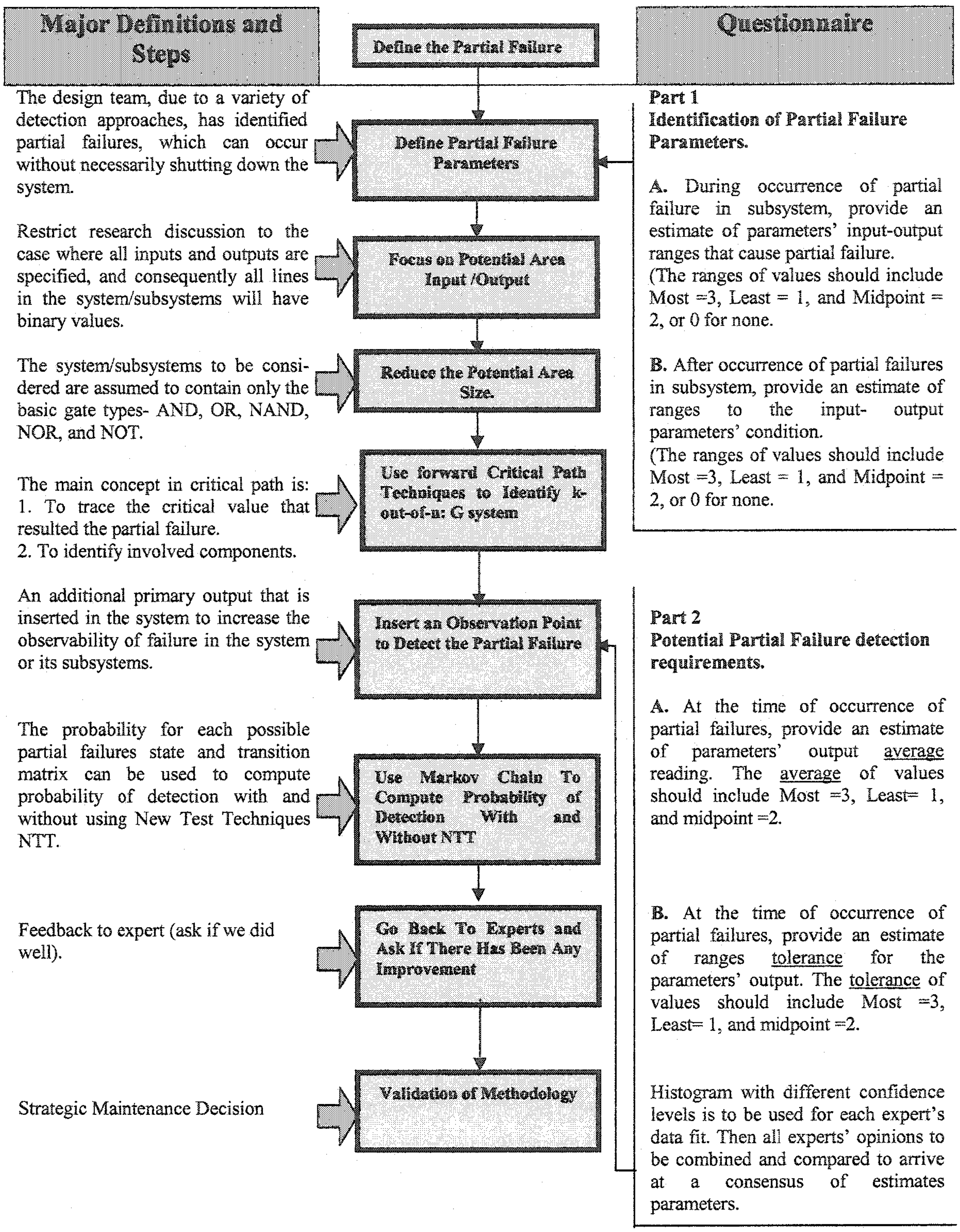

Figure 10. Research Flow Chart Process

5.2. The New Test Technique (NTT)

5.2.1. Major Steps Analysis

Detecting and monitoring partial failures of dynamic systems NTT was applied on the detector unit (as subsystem unit) of the tracking radar system. As explained earlier in chapter III, the design team, using a variety of detection approaches, has identified the partial failure. This type of partial failure that is induced in the detector unit can be explained briefly as follows: detector unit consists of two detection channels, elevation and azimuth. Each elevation and azimuth channel is divided into a course correction detection channel and fine correction channel. The outputs of these two channels are then fed to the elevation synchro and azimuth synchro. The outputs of both synchros are then fed to the elevation and azimuth hydraulic motors, which then move the radar director antenna to the exact target position. Figure 11 shows a simplified detector unit and its follow-up system block diagram.

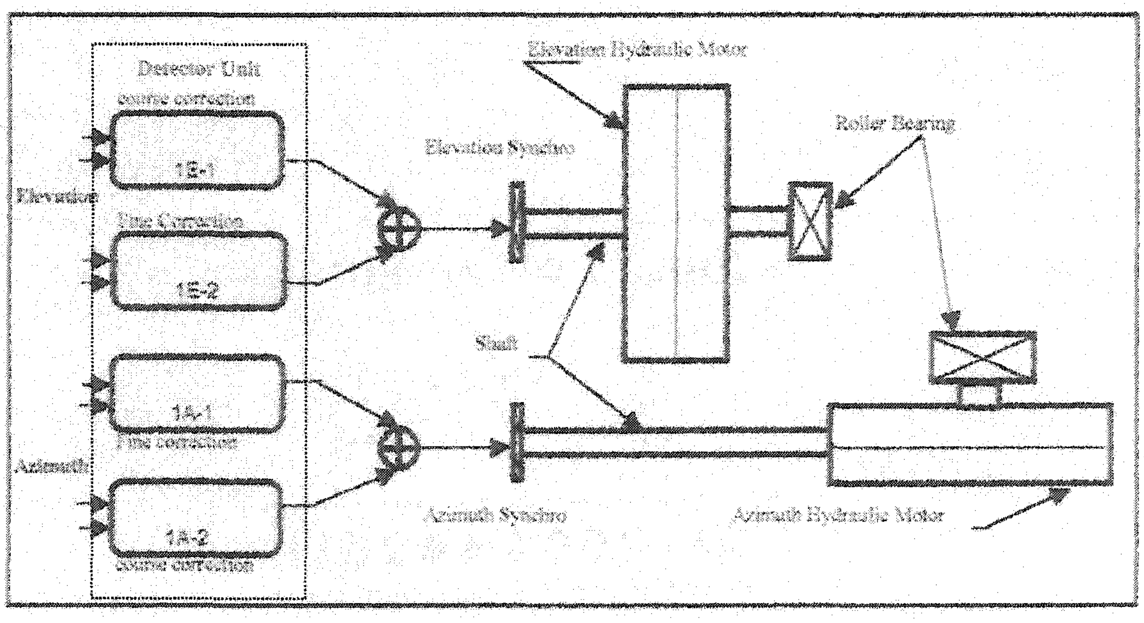

Figure 11. Simplified Detector Subsystem and Follow-up System Block Diagram

Figure 12 shows the potential area minimization by reducing its size in each display of elevation and azimuth circuits (Unit 1E-1) as single logic gate diagrams. This is because the partial failure occurs at a specific system operation cycle. This means that not all inputs and outputs of the circuits are required to be considered at that particular operation (Menon and Abramonvici, 1991).

5.2.1.1. Critical Path Execution

Figure 12 demonstrates tracking radar detector unit partial failure and how it is possible to detect this partial failure by insertion of observation points. In this partial failure case, gate A output must be closed to logic zero value after tracking the target. But this partial failure occurs because at gate A output a value equal to 1 is induced, which means that, an output failure at gate A has occurred.

To detect this partial failure, path tracing was used to identify the best observation point that can help the partial failure to propagate and then to be identified and monitored. Forward path tracing (**Bold Line**) from the partial failure potential area site is used to identify the propagation path for the specific partial failure. It was noticed that this partial failure is propagated through gates E and G, but is blocked at gate H and J and therefore doesn't propagate to a higher level (i.e., from components level to subsystem level) or to a primary output. Inserting an observation point *x* between the inputs of gates G and H or an observation point at output gate G would enable the partial failure to be identified. Therefore these two suggested observation points form one set of solutions for this specific partial failure detection problem in the tracking radar detector unit.

Based on the above discussion, this partial failure shows that not all components of the tracking radar detector unit performed correctly. In other words, not all components that are equal to k number of components-out-of-n number of components on this specific operation cycle performed correctly.

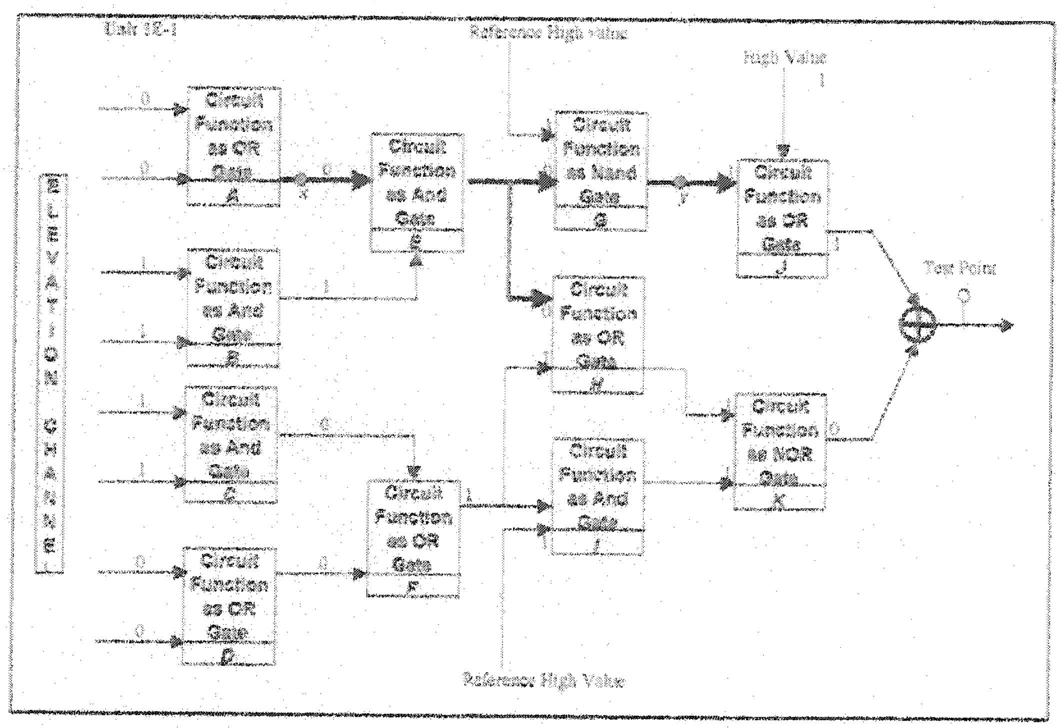

Figure 12. Elevation and Azimuth Circuits (Unit 1E-1)

5.2.1.2. Markov Chain Technique

Tables B2 and B3 indicate that BITE capability in detecting partial failures is not enough. Probability of .2 to .8 of undetected partial failures by BITE can cause degradation of system performance and a high cost of repair, especially when these partial failures occurred and spread over the entire system. Tables B2 and B3 in Appendix B show the BITE detection failures capability in relation to repair activity.

Based on these tables' strategy, the probability for each possible state can be calculated using the transition matrixes shown in Figures 13 and 14a and b.

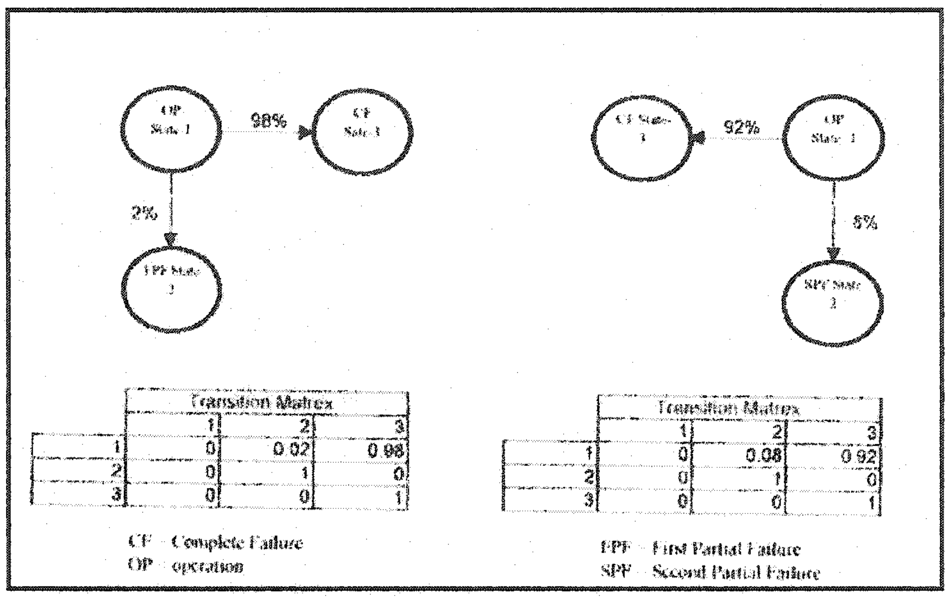

Figure 13. First and Second Partial Failure Detection Probability Using Markov Process

Based on the BITE maintenance strategy, with the use of NTT as a support system, Markov chains can be utilized. Figures 14a and b show the transition matrix and the BITE detection technique with NTT process using Markov chains. Matrix elements 1, 2, 3 and 6 are the transit states, and 4, 5, 8, 7, 9, 10, 11 are the trappings states.

	Transition Matrix										
	1	2	3	6	5	4	7	8	9	10	11
1	0	0.92	0	0	0	0	0	0	0.08	0	0
2	0	0	0.83	0.09	0	0	0	0	0	0	0
3	0	0	0	0	0.92	0.92	0	0	0	0	0
4	0	0	0	0	0	1	0.94	0	0	0	0
5	0	0	0	0	1	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0.07	0	0	0
7	0	0	0	0	0	0	1	0	0	0	0
8	0	0	0	0	0	0	0	1	0	0	0
9	0	0	0	0	0	0	0	0	1	1	0.01
10	0	0	0	0	0	0	0	0	0	1	0
11	0	0	0	0	0	0	0	0	0	0	1

Figure 14a. Transition Matrix

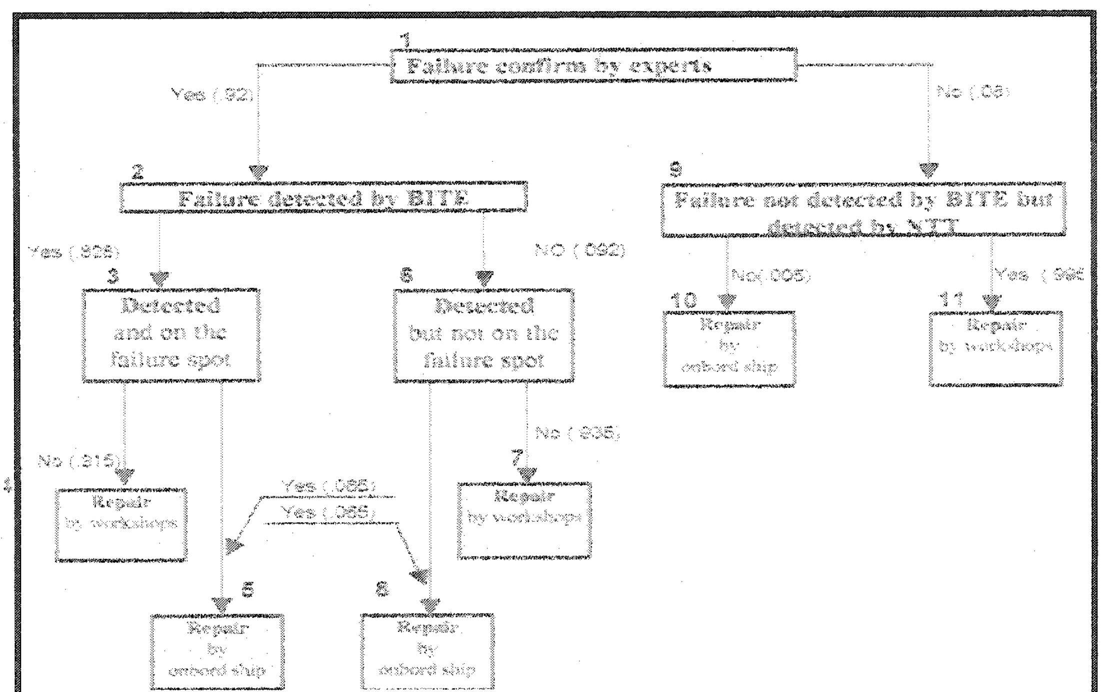

Figure 14b. BITE Detection Technique with NTT Process Using Markov Chains

The matrix of number of visits can be calculated as follows:

$$E = (I - Q)^{-1} = \begin{pmatrix} 1 & 0.92 & 0.762 & 0.085 \\ 0 & 1 & 0.828 & 0.092 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The matrix of probability of visit from the transit state to the trapping state is:

$$A = E.\,R = \begin{pmatrix} 0.697 & 0.065 & 0.0055 & 0.0775 & 0.08 & 0.0004 & 0.0796 & 0.0775 \\ 0.758 & 0.0704 & 0.006 & 0.00842 & 0 & 0 & 0 & 0.00842 \\ 0.95 & 0.085 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.065 & 0.95 & 0 & 0 & 0 & 0.95 \end{pmatrix}$$

Calculating the cost of repair for the complete detector unit or its simple module unit (1 E-1) using the matrix of probability is as follows: the probability from state 1 to state 10 is .0004 and the cost of repair using Figure 14b is:

= Complete detector unit failure per year x .0004 x labor cost x average actual repair time.

In case of unit (1 E-1) then

= Partial failure module unit (1 E-1) per year x .0004 x labor cost x average actual repair time.

5.2.1.3. System Performance and Availability

Tables B1, B2, C1, C2, and C3 in Appendixes B and C show that the availability of the system and system performance can be improved by maintaining (1 E-1) channel unit instead of repairing the whole unit of the detector unit, of which (1 E-1) channel unit is one part.

From Appendix A, part 1, the failure rate for (1 E-1) channel unit is equal to 5.371 F/m (failure per million). This failure rate excludes the connectors' failure rates, the feedback correction circuits group, the synchro unit, and environmental effect. So to adjust this failure rate, this research utilized an approximate approach provided by Green and Bourne (1972), which uses various K factors multiplied by the failure rate data. These various K factors were used to relate the data to other conditions of the environment and stress, where K is the environment factor adjustment coefficient used to represent the components' stress levels altered by environmental conditions. Typical K factors are given in Appendix C where K_1 relates to the general environment of operation, K_2 to the specific rating or stress of the component, and K_3 to the general effect of temperature. The equipment on the fire control system tracking radar is considered to be exposed to an outdoor marine environment. For this partial failure, a K_1 factor of 2 is used and K_2 and K3 are 1.

The adjusted failure rate λ' is

$\lambda' = \lambda\, K_n$

$\lambda' = 5.371 \times K_1 \times K_2 \times K_3 = 10.74$ failure per million operating hours and

$$MTBF = 1/\lambda'$$

$$= 1/10.74 = .03717x\ 10^6$$

1 E-1 Channel unit MTBF shows that the addition of observation points at point x or y can extend the availability with high performance of the system by the amount equal to

$$Availability = MTBF/\ (MTBF + MTTR)$$

$$= .3717/\ (.3727 + MTTR)$$

Where, availability is the Inherent Availability, which is based solely on the failure distribution and repair time distribution. See figure 15.

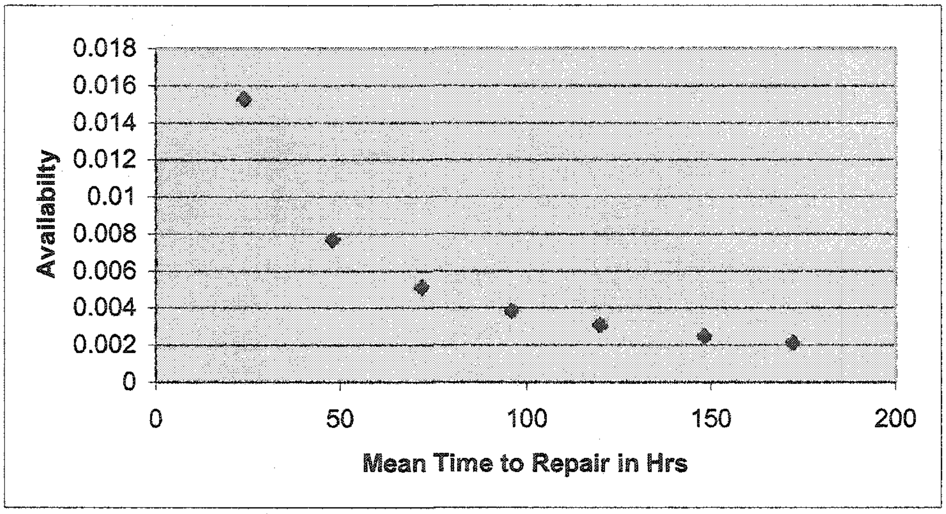

Figure 15. The System Availability with Respect to Main Time to Repair

5.2.2. Questionnaire Analysis

Analyzing the data, which experts provided for the detector unit, shows that their estimates were different. This usually occurs due to experts making different assumptions from the same partial failure data. The experts provide their knowledge and opinion about the potential problem area via their observation of the system's behavior during occurrence of partial failure. To solve this problem of opinion difference, Vose (1996) clarified the idea of the experts' opinion differences by combining two dissimilar expert opinions if confidence in both opinions is similar after conferring with someone more senior in the same field. In this research, the experts' opinions were required to provide a strategic maintenance decision between getting the benefits of inserting best observation points to support the current BITE to identify and monitor partial failures, or to stick with current BITE as go or no-go method. However, in this particular partial failure evaluation, case maintenance decision-making is required. This is designed to help decide between replacing the complete detector unit (the whole subsystem) or repairing it, or replacing a module (component) or repairing it. Table B3 show tracking radar detector maintenance and logistics costs.

Two categorization questionnaires were delivered to the experts to get their opinion on the tracking radar in general and the detector unit in particular during and after occurrence of partial failure using NTT. These questionnaires were also designed to identify potential parameters, and to see the partial failure effect on the system and/or its subsystems during and after occurrence. To do this, each participating expert was weighted in percentage depending on his or her level of experience. Also each estimated answer was weighted as a percentage depending on each expert's measured confidence level.

The first category results of the questionnaire are presented by three-dimensional figures that display the expert's opinion on the input and the output of the parameters' condition for the detector unit during and after occurrence of partial failure. Appendix D figures D1 a, b, c, and d display these opinions. Along the z-axis, each expert's opinion is presented as a vertical single slot. Along x-axis, three ranges minimum, normal and maximum in percentage, is used to display the estimated expert input confidence level to defined parameters that were involved to generate this particular partial failure. Finally, the y-axis is used to display the number of input or output parameters. The color code is used to show the weight factor in percentage as the confidence level for each expert opinion. In this research the input and output parameters for the detector unit were specified and weighted as follows:

- Minimum = below the average line (on negative side) but within the average reading.
- Normal = on the average line.
- Maximum = above the average line (on positive side) but within the average reading.

The second category of questionnaire was designed to identify the most influential parameters among those identified. Figure D1e displays the most influential parameters. In the detector unit, the experts concluded that voltage and current were the most influential parameters inducing this type of partial failure. This is because voltage and current can affect other parameters like internal components vibration and increase in temperature. So the other two parameters – vibration and temperature – were dependent on the current and the voltage in this case. It can be concluded that without identifying and repairing this type of partial failure, the effect can spread to the whole system's components or its subsystems to cause complete failure.

The questionnaires were utilized to identify the parameters, and among those parameters the most effective parameters were identified. To insert observation test points, the experts' opinion was required also at this level. This is because expert opinion can support the estimation of the observation point average and tolerance limitation. As stated earlier, each expert has three rating confidence factors to select: minimum, normal and maximum. Each level of confidence consists of three estimated partial failure occurrence accuracy of 75%, 50%, and 25% with respect to normal value. Choosing none or 0% means the parameter is never changed and stayed constant. However, each expert also was weighted depending on his or her experience (Vose, 1996). The weighted factor was divided into three levels of confidence, 75%, 50%, 25%, and none or 0%. Choosing none or 0% means that the expertise between the experts is the same (Chytka, et al 2003).

5.2.2.1. Average Limitation Values of Observation Point

Calculating average and tolerance limits of selected observation points using the experts' opinion is as follows:

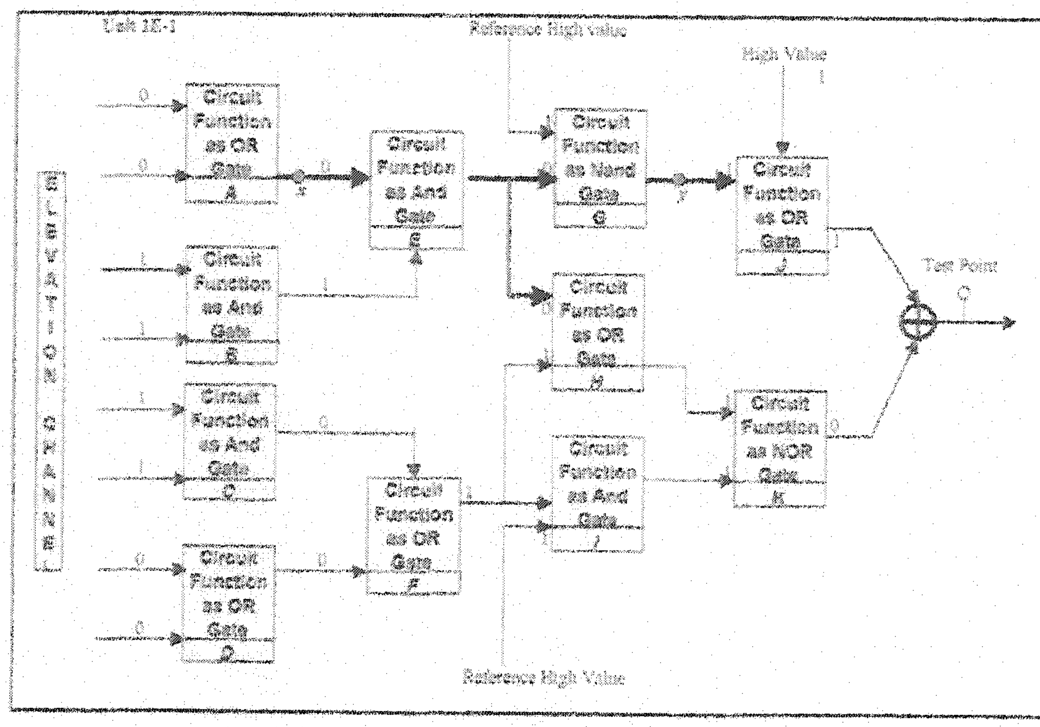

Figure 16. Calculating Average Limitation for Selected Observation Point

Figure D1e in Appendix D shows the probability that the partial failure occurs at the maximum voltage limitation area, as estimated by two out of three experts is 75% and 25%, respectively. The senior expert's input opinion for occurrence of this type of failure was 50% higher than the other expert. The experience weight factor for the senior expert was 75% and for the other expert it was 25%. Occurrence of partial failure due to maximum voltage can be calculated as:

{Estimated values for expert 1 input x estimated experience weight factor for expert 1} + {estimated values for expert 2 input x estimated experience weight factor for expert 2}= (.75 x .75) + (.25 x .25) = 0.625 = 62.5%

The estimated tolerance range level selected by only two experts was above 0.33% and below .66% of + 5 volts. See Appendix D.

and

(.75 x .5) = .375 = 37.5 % is the accuracy of partial failure as estimated by the third expert, and with estimated tolerance range level above .67% of -5 volts.

Now,

the external functional test point in Figure 16 as designed should read 24 volts +/- 5 volts for the director unit to function properly. But this partial failure occurred within the tolerance and between the average values of +/- 5 volts.

So,

one can conclude that to identify this partial failure, the observation point (at position x in Figure 16) tolerance limitation should read not more than .33% of the average values of +/- 5 volts, which is equal to +/-1.67 volts.

5.2.2.2. Validation of Results

Face validation form was used to validate the NTT methodology, which is provided by tolerated modes of communication such as surveys using telephone, E-mail, and indirect interviews, in which the expert is interviewed alone, with exchange of the data by the researcher to other experts.

The reasons to use face validity rather than other types are:

1. To ensure that the questionnaire, is measuring what it is supposed to be measuring.

2. Within the context of this study, in which the researcher does not act as an passive observer, but rather a active participant in the execution of the NTT, assurance is provided that the researcher is an expert in the tactical decision- making problem domain (Adelman, 1992).
3. Assurance is provided that the experts know which type of information the researcher is looking for; that they actually can use the context to help interpret the questions and provide more useful, accurate answers (Hunter and Hunter, 1998), and
4. This is provides a more realistic output of future judgment, even though, most of the researchers count this reason as one of face validity's disadvantages. If the researcher, however, is looking to expert opinion to validate a new methodology for system integration technology, face validation is a suitable form to apply.

To validate the results, the questionnaires were delivered to the experts to get their opinion on the tracking radar as a system in general and the detector unit as a subsystem in particular, and to evaluate the methodology. The experts' confidence level of the output results as approval or disapproval in percentage is applied using experts' feedback to measure the accuracy of the NTT methodology. The questionnaire feedback used to validate the results of detector unit partial failure is presented in Appendices A, B, and D.

The results validated by the experts relate to the voltage of the detector subsystem of the TR system outputs and insertion points, which are used to determine whether a partial failure exists. See figure D1e and Appendix A, part 6 voltage table.

Table 4 represents the validation result for the experts' opinion with respect to the results of the estimated most important parameter that can cause partial failure in detector unit as derived by the NTT. The expert feedback was in essence the same a predicted by the methodology.

Expert code	NTT		Expert feedback	Remarks
E1	Voltage	.75	.75	-
	Current	.75	.75	
BRN	Voltage	.75	.75	-
	Current	.75	.75	
E2	Voltage	.75	.75	-
	Current	.75	.75	

Table 4. Comparison of Parameters That Cause Partial Failure in Detector Unit Using NTT and Expert Feedback

Table 5 presents the experts' validation feedback showing that the series-parallel and parallel-series configurations can cause partial failure more than other configurations.

Subsystem	Configuration	Most to Least					
Detector Unit	Series	1	.75	1	.75	1	.75
	Parallel	1	.5	2	.75	2	.5
	Series- Parallel	1	.75	2	.75	1	.75
	Parallel- Series	2	.75	3	.75	3	.75
	Series- Parallel- Series	2	.5	0[a]	0	0	0
Expert Code		E1		BRN		E2	

[a]Judged to be the same as a series-parallel configuration.

Table 5. Presents Sensitivity Results for Unit Configuration

Table 6 presents the NTT results and the experts' validation feedback on identifying partial failures that occur at the detector unit (see also figure 16), which would be detected by inserting an observation point *x* between the inputs gates G and H or an observation point at output gate G as b

Expert code	Observation test point using NTT	Observation test point from expert feedback	Observation test point using NTT	Observation test point from expert feedback	Remarks
	At position *x*	At position *x*	At position *b*	At position *b*	
E1	.75	Same	.75	.25	Observation *b* is more close to BITE measuring system close loop which can effect reading
BRN	.75	Same	.75	Same	No comment
E2	.75	Same	.75	.50	Not recommended to insert observation point b here due to many outputs connected at single test output which can effect the reading

Table 6. Validation of Proper Observation Point Insertion

Table 7 shows the validation results of identifying partial failures that occur at the detector unit. The reading of an observation point tolerance limitation should read not more than .33% of the average values of +/- 5 volts, which is equal to +/-1.67 volts.

Expert code	Current system voltage measure with tolerance	NTT Calculation	Expert feedback	Remarks
E1	24 volts with +/-5 volts	24% volts with +/- 1.67 volt	+/- 1.67 is agreed .50	Required to be measured by oscilloscope or digital multimeter
BRN			+/- 1.67 is agreed .50	Monitor and measure with digital multimeter
E2			+/- 1.67 is agreed .25	Very sensitive to be measured with un calibrated equipment

Table 7. Observation Point Tolerance Limitation Suggestions

Table 8 presents the validation results of the BITE detection technique with NTT process using Markov chains.

Expert code	BITE with NTT partial failure detection capability	BITE with NTT partial failure capability detection Expert feedback	Remarks
E1	.75 agree	Same	Required good and well organized system selection for partial failures. May produce a very sensitive failure detection system, which is not recommended in operational systems.
BRN	.75 agree	Same	Required good system to select, where partial failure can be monitored and detected
E2	.75 agree	Same	It may add more cost for short term, but for can be justified for long term

Table 8.Validation Results of BITE Detection Technique with NTT Process Using Markov Chains

The following table summarizes the validity of NTT results experts' feedback applied on fire control system tracking radar detector unit and with respect to BITE system.

S/N	Questionnaire	NTT	Expert Output Feedback	Remarks
1	Voltage as most important parameter that can cause partial failure in the detector unit	.75	.75	Same
2	Most system configurations that cause partial failures	Series- Parallel .75	Series- Parallel .75	Same
3		Parallel- Series .75	Parallel- Series .75	Same
4	Proper selection for observation point insertion	Point at position *x* .75	Point at position *x* .75	Same
5		Point at position *b* .75	Point at position *b* .50	Not the same
6	Voltage tolerance measure	.33	.37	Not the same

Table 9. Summarizes the Validity of NTT Results Output and Experts' Feedback Applied to Fire Control System Detector Unit

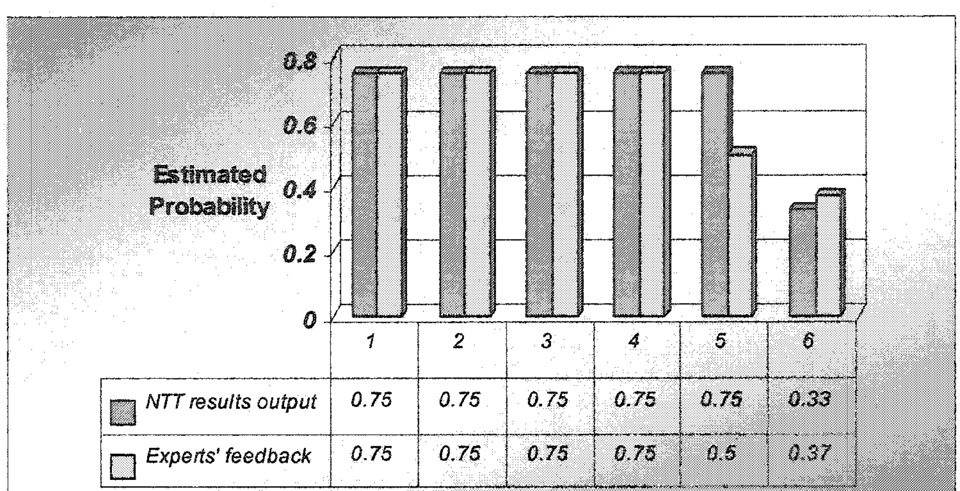

Table 10. Validation of NTT Results Output Using Experts' Feedback

From Table 9 and Table 10, NTT methodology validation results approve that it is capable to provide a good support technique to the BITE system. This then can lead to maximum recovery in the number of failure recorded against system and availability and performance, which will maintain the system in full operation and maximum performance.

Additionally, in Table 9 and Table 10, the validation of NTT results output and experts' feedback approved that the best insertion observation point to detect the partial failure that occurred in the tracking radar detector unit is point x. This is approved that using observation test point can increase the detection of partial failure, when used properly, can support BITE.

CHAPTER VI

DISCUSSION

6.1. Discussion

It was noticed in the prior literature that many researchers have developed technologies using probabilistic techniques to assist in the decision-making during built in test equipment (BITE) design. This implementation of such technologies may have been done for the best of reasons, but that cannot achieve certain levels of improvement in detecting partial failures. This research introduced a new methodology called New Testing Technique (NTT) to detect partial failures, which can detect and monitor the progress of the partial failures depending on strategic maintenance decision-making or mission requirements. This methodology consists of eight phases: 1) problem definition, 2) criteria selection, 3) definition of the parameters that cause partial failure, 4) construction and administration of questionnaire, 5) results, 6) revision and correction, 7) observation point insertion, and 8) validation of methodology. These phases were well defined in chapter 4.

Additionally, two methodology requirements were discussed in detail in chapter 5. These two requirements should run parallel to the implementation of NTT methodology. These requirements are a combination of a well-designed questionnaire (depends on the system under study) that runs parallel with major steps to identify partial failure parameters that cause the failure and then to predict partial failure their averages and tolerance ranges (see figure 10 for requirements process). Additionally, a questionnaire was developed in an effort to document expert opinion about the parameters sought.

NTT was applied on the fire control system detector unit to detect a specific partial failure, which is normally induced after the tracking radar tracks a target. Demonstration was done on one single subsystem of the total system, which in this case limits the methodology's overall capacity. Applying the methodology on the entire fire control system can provide more realistic information to check its capability.

It was noticed that the result using face validity could provide more realistic strategic decision-making regarding maintenance. This is because both research hypotheses points were achieved. The first hypothesis stated that partial failures on naval ships electronic systems could be detected by inserting test point in electronic naval systems. The second hypothesis is a completion of the first, which is to determine the appropriate place for test point insertion by using experts' judgment. Using the results of the expert questionnaire, one can insert observation points to support BITE to identify and monitor partial failure. Even though the number of experts was small, the detector as a subsystem under study was quite enough.

The questionnaire attempted to capture the experts' opinions about occurrence, detection and monitoring partial failure. Then the validation results from the experts are used as decision-making support for strategic maintenance decisions, although, more generally, these types of questionnaires can be used to obtain opinions about any system.

The modes of communication that were used, such as telephone, E-mail, and indirect interview discussions, are important because they give researchers an opportunity to indicate what the experts liked and disliked about the system, and how they would improve it. It has been noticed that short answers are important, because they attempt to quantify the experts' opinions.

As stated earlier, face validation form was used to validate the NTT methodology, with provided tolerated modes of communication such as surveys using telephone, E-mail, and indirect interviews in which the expert is interviewed alone, with exchanges of data by the researcher to other experts. However, face validation has a possible limitation such as realistic future output assessments. An example is this research, in which one tries to validate a new methodology technique for implementing a new integrating technology to detect and monitor partial failures. There is an additional limitation on the experts' side. If the experts know what information the researcher is looking for, they might try to "bend and shape" their answers to what they think the researcher wants. In other words, fake good or fake bad.

This research assumed that problems arising on the fire control system are purely hardware problems. This is to identify fire control system boundaries and also its subsystems that are going to be involved at that moment to complete system operation cycle. This assumption can raise a question(s) regarding adding the social part of system, such as wrong action by operator, bad training, and different system environmental conditions. These questions are good challenge for future research.

One observation point concerning the results is worth indicating. The selection of experts, depending on their system knowledge and specialty background, can be extremely helpful in calculating average and tolerance limits of selected observation points.

An interesting point that was not discussed and can create a good challenge for future research is applying NTT methodology on micromanagement systems. This is especially true when one considers the detection and monitoring of partial failure in any mechanical parts as any employee's behavior that detected and monitored by voice communication surveillance, video monitoring surveillance, and most recently computer and data communication surveillance. This detection and monitoring behavior can reflect negative effects and can be extremely detrimental to companies and their existing corporate culture.

In reality, detecting all possible partial failures is not possible in social systems because the boundary is not well identified and so the partial failure that occurs without notice can impact on overall organization performance. For example, one can consider that the people who work for a micromanager feel that their boss does not trust them; why else would the boss always be looking over their shoulder. This feeling can induce a chain of partial failures such as a little loyalty to the manager or the organization. Therefore, motivation is low, which is a great partial failure, or quality suffers, which can affect the performance and reduce the product's acceptable level.

Finally, one (generally!) can conclude that the go-no-go technique on designing BITE may not provide sufficiently high failure or partial failure coverage. The requirement is to provide a support technique to the BITE system that reduces the time gap between the accruing of partial failures and BITE system reaction. This then can lead to maximum recovery in the number of failures recorded against system availability and performance, which will maintain the system in full operation and maximum performance.

6.2. Validation

Validity in this research means the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure. Face validity form was used with principle mechanisms such as surveys using the modes of telephone, E-mail, and indirect interviews to validate research methodology.

Face validation was used to validate the output result. This is done by how the measurement procedure appears. Does it seem like a reasonable way to gain the information the researcher is attempting to obtain? Does the research process, in using new test techniques, seem well designed? Table 9 summarizes the validity of NTT results and the experts' feedback that was applied on fire control system tracking radar detector unit.

Two major companies dealing with Bahrain Royal Naval ships overhaul validated the result of the research finding after experts' feedback on how well we are doing. The first company is VSE Corporation, which is also the supporter research company. The company's management department stated that, "this research is a very interesting field of knowledge and integrating way of technology, which can support any system with BITE. The observation point suggested by the research author can give advanced detection and monitoring, especially with new integrated systems that's going on the Bahrain Royal Navy with the old systems." The other company is LÜRSSENS Logistics. This company evaluated and validated this research technically. LÜRSSENS' technical and quality department showed that the observation point process and testing techniques could be recommended in harbor and sea acceptance tests.

Finally, both companies recommended that evaluation results required collecting field data after implementation. This process requires years of effort. Appendix E shows the validation letters for both companies.

6.3. Summary

An objective of this research effort was to develop a methodology for detecting partial failures in dynamic systems such as fire control system tracking radar. This effort was achieved by satisfying two research hypotheses points. The first is by inserting observation test points using a critical path tracing technique. The second is by using the experts' judgment to determine the appropriate place for observation test point insertion. However, the methodology developed herein was based on the combined research of authors such as Yellman (1999), Corner and Angstadt (2001), Conway (2003), Vose (1996) and Youssef (1993). Other authors, such as Hadler and S.Mahadevan (2000), Corner and Angstadt (2001), and Ebeling (1996), provided an alternative meaning for partial failure, such as critical failure and non-critical failure, or such as fail danger or fail-safe.

The research also demonstrates that the use of expert opinion can focus more on the potential area inputs, outputs and the number of components involved during occurrence of potential failures. It also can utilize critical path techniques. Finally, the research shows that inserting observation test points can help develop improved decision -making on maintenance. That will support and manage maintenance with BITE(s) to monitor and predict dynamic system partial failures before they significantly damage the system or its subsystem.

CHAPTER VII

CONCLUSIONS

7.1. Conclusions

This study contributes to the Engineering Management body of knowledge by identifying a new kind of decision-making with an associated solution approach. However, this research provides a tool that permits a new practical way for identifying partial failures. In addition to the new way of testing, the combination of the wide spectrum of techniques and approaches, which have been developed by different and conceptually distinct disciplines, can enhance future studies in this field. This integrative approach was consistent with the philosophy of Engineering Management, which can be verbalized as creating maximum managerial utility from knowledge and technologies generated by different disciplines.

The go-no-go technique on designing BITE may not provide sufficiently high failure or partial failure coverage. The requirement is to provide a support technique to the BITE system that reduces the time gap between the accruing of partial failures and BITE system reaction. This then can lead to maximum recovery in the number of failures recorded against system availability and performance, which will maintain the system in full operation and maximum performance.

Estimation of two states that consist of either operational state or non-operational state in reality is going to cover system function failure only and not failure that occurred due to system performance. In such cases, a different approach is required to have maximum failure recovery for system performance and availability in addition to system function. This was achieved by inserting observation points in proper selected areas in the system. In doing so, maximum monitoring, and controlling failure coverage is obtained. However, this research, like all other research, is not risk free. Maintenance decision-making regarding the number of partial failures that required to be identified was important. As one increases the number of partial failures detected, the operation of the overall system becomes more sensitive, and thus the system's performance progress can be interrupted.

An important point that one should conclude about partial failures is that the underlying knowledge is scarce and not sufficient in most cases. The studies that investigate the partial failures and their impact on system performance are few, if any. They often address specific and isolated case areas. There is no previous research studying partial failures that impact the dynamic systems in a wide scale area.

Finally, the methodology that is proposed in this research was not considered before. This methodology uses a combination of Markov technique, multi-sate k-out-of-n: G: systems analysis, and critical path tracing techniques to solve the problem effectively by supporting decision makers associated with fire control system tracking radar, which is installed onboard Bahrain Naval ships.

7.2. Limitation

A limitation of the research is associated with the size of the system under study. The methodology was demonstrated on one single subsystem of the total system, which in this case limits the methodology's overall application capability. Testing the methodology on the entire fire control system will provide more realistic information to check its capability. Moreover, a restriction on most electronic equipment related to Naval systems adds anther company limitation. Adding wide rages of different types of electrical and mechanical systems can provide methodology evaluations. This is because output from the validation process can result in innovative ways to improve the testing process.

The selection of experts, based on their system knowledge and specialty background, can be extremely helpful in calculating average and tolerance limits of selected observation points. However, this increases the time required for selection, which sometime limits the numbers of experts participating. This is especially the case when the researcher used the telephone, E-mail and indirect interview mode of communication.

Another limitation in this study is the number of experts involved in the study. Additional expert opinion can provide a more effective focus on the potential area inputs and outputs so that critical path techniques can be more easily utilized. Also, this presents more feedback from experts to validate the methodology, which gives more reliable results than relying on only a limited number of experts. Additionally, in the field of expert opinion, data was fed manually. This process consumes time in calculating the results of the data, which then must to be validated. A new computerized strategy would make the process more efficient, accurate, and time saving.

Limitations in the support system can play a major factor on selection of which partial failures are to be controlled and monitored. Although this methodology has been demonstrated on a single partial failure that involves only a single subsystem unit, it is not anticipated that greater numbers of subsystems will increase the complexity of the implementation strategy.

The mode of communication used in this research, such as telephone and E - mails, limits detailed or extensive information. The telephone is not suited to asking the experts complex questions or to probing for the assumptions that the expert made in arriving at an answer. Similarly, the telephone mode should not be used to conduct the verbal report elicitation technique. E-mail is good for eliciting simple data. But its limitation was shown when the researcher had to send complex instructions or detailed problem solving data from one expert to another.

Face validation has a possible limitation if the experts know what information the researcher is looking for, because they might try to "bend and shape" their answers to what they think researcher wants. In other words, fake good or fake bad. Also, one major limitation in using face validation is the weakness in looking for more realistic output on the system's future performance. For example, this is especially relevant in this research when trying to validate a new methodology technique for implementing a new integrating technology to detect and monitor partial failures.

This methodology is not limited to any specific method for analyzing the data, but can be used with other design analysis tools with no change in implementation strategy.

7.3. Future Research

The ultimate extension of the research is that the methodology will be applied more efficiently when collected field data have validated the system results after integrating the system with the new technology to detect and monitor partial failures. This research might also be extended, using critical path tracing, to cover larger units in system design. Additionally, the research could be applied to the problem of partial failure involving more than two systems integrated together and more than three experts to provide opinions. The optimal solution would then be to use a single observation test point to detect more than one partial failure.

One interesting point for future research is when testing this methodology on a social system. As is known, the boundary and input and output of mechanical and electrical systems can be defined by their territory or by the physical space occupied or used by specific components during every different cycle of the system operation. But on the other hand, the boundary of the social system can also be defined by the people directly involved in the creation, production, or transformation of the input into output. One important major step in research methodology is to focus on the potential area by reducing it down to a level of logic gates such as AND, NAND, OR, NOR, and NOT with single input and output. This major point could be a challenging future research when applied on social systems where unexpected conflicts due to partial failure (i.e. system changes state, its purpose, product, boundaries, or environments) can occur for many reasons. Conflicts and ambiguities in the social system can also become an excellent opportunity to study the impact of partial failure.

An interesting point and good challenge for future research is applying NTT methodology on micromanagement to identify the partial failures that occur without noticing the impact on overall organization performance. For example, one can consider that the people who work for a micromanager feel that their boss doesn't trust them; why else would the boss always be looking over their shoulder. This feeling can induce a chain of partial failures such as a little loyalty to the manager or the organization. Therefore, motivation is low, which is a great partial failure, or quality suffers, which can affect the performance and reduce the product output standard.

Finally, studying the integration of two systems with different behavior, such as a mechanical or electrical system sharing the boundaries with a social system, can be an interesting point to research. This is because the movement of the mechanical or the electrical systems is designed (depending on commands it received) to move from one state of operation to other state of operation with a fixed number of components. This assumes that the components have fixed boundaries, whereas in reality the involvement of a social system with a mechanical or electrical system can create a flexible boundary.

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APPENDIX A
Input Parameter Questionnaire
(Expert Opinion on Technical System Field)

Part 1.

a. The name of the subsystem for analysis is detector unit.

b. The number of partial failures recorded from Aug 1998 to July 2002 was eight partial failures in the workshops and ships logs manuals. The failure part in the detector unit is module channel and its failure rate was equal to 5.371 F/m hrs.

c. The experts were weighted depends on their experience as follow:

- E1 = 75%
- BRN = 25%
- E2 = 25%

Part 2.

Subsystems defective recorded due to the partial failure from Aug 1998 to July 2002 is:

Subsystem	Partial failure Occurrences*	MTBF	MTTF	MTTR	Location Time
Switch	15	2.50E+07	3.89E-02	0.00112129019	0
Fan	0	3.00E+05	3.16E+00	0.172792013	0
Fan	2	3.00E+05	3.16E+00	0.172792013	0
Heating Element	3	3.33E+05	2.84E+00	0.15566848	0
Antenna	0	1.00E+05	8.56E+00	1.443362916	0
Monopulse Unit	4	1.49E+04	5.97E+01	7.2750501	N/A
Microwave Unit	7	5.00E+03	1.82E+02	18.1315011	N/A
Power Supply	0	7.38E+04	1.31E+01	0.420245252	N/A
TWT and Power Unit	2/9**	1.32E+04	7.05E+01	5.530107835	N/A
IF Preamplifier	5	5.53E+04	1.68E+01	1.316311194	N/A
COHO Unite	0	5.14E+04	1.88E+01	0.60323027	N/A
Detector	8	8.09E+04	1.18E+01	0.530775837	N/A
IF Gain Control	5	1.03E+05	9.40E+00	0.300839775	N/A
A/D Converter	7	2.75E+04	3.52E+01	1.126753507	N/A
Serial Link	4	4.97E+04	1.91E+01	0.983526577	N/A
Monitoring Unit	3	7.33E+04	1.32E+01	0.423346693	N/A
Gyro Unit	0	8.83E+03	1.07E+02	6.214762859	N/A
Stalo	0	5.52E+03	1.67E+02	14.24992843	N/A
Pulse Exp/Comp	8	2.62E+04	3.60E+01	2.090609791	N/A

* Per three years (1998-2002) duration- Bahrain Royal Naval Force Workshops log book.
** Two failures in number occur in TWT/ nine due to the power supply.
N/A Not available.

Part 3.

Estimate with confidence level a list of the subsystems that have most partial failure record without causing system to shutdown immediately. The ranges of values should include most partial failure causing = 3, Least partial failure causing = 1, and midpoint partial failure cause = 2.

Subsystem	Most to Least					
	Ranges Values	Confidence Level	Ranges Values	Confidence Level	Ranges Values	Confidence Level
TWT and Power Unit	3	.75	3	.75	3	.75
Monopulse Unit	2	.5	3	.5	3	.75
Detector	3	.75	3	.75	3	.75
Power Supply	3	.25	3	.25	3	.5
Microwave Unit	3	.5	2	.5	3	.5
Serial Link	2	.5	2	.75	3	.5
COHO Unite	2	.25	2	.25	2	.25
Heating Element	1	.5	2	.75	2	.75
IF Gain Control	2	.75	1	.75	1	.75
A/D Converter	2	.5	1	.25	3	.5
IF Preamplifier	1	.75	1	.75	1	.75
Monitoring Unit	2	.25	1	.25	1	.25
Gyro Unit	2	.75	1	.75	2	.75
Antenna	2	.5	1	.75	2	.5
Pulse Exp/Comp	2	.5	1	.5	2	.5
Expert Code	E1		BRN		E2	

Part 4.

List with confidence level all detector unit configurations, which can cause partial failure more than other configurations in this unit. The ranges of values should include Most = 3, Least = 1, and Midpoint = 2, or 0 for none.

Subsystem	Configuration	Most to Least					
Detector Unit	Series	1	.75	1	.75	1	.75
	Parallel	1	.5	2	.75	2	.5
	Series- Parallel	1	.75	2	.75	1	.75
	Parallel- Series	2	.75	3	.75	3	.75
	Series- Parallel- Series	2	.5	0	0	0	0
Expert Code		E1		BRN		E2	

Part 5.

During occurrence of partial failures in detector subsystem, provide estimate parameters INPUT- OUTPUT ranges that cause partial failures. The ranges of values should include Most = 3, Least = 1, and Midpoint = 2, or 0 for none. (Design problem)

Voltage	Input						Output					
Minimum	1	.75	1	.75	1	.75	1	.75	0	0	1	.25
Normal	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	3	.75	0	0
Expert Code	E1		BRN		E2		E1		BRN		E2	

Current	Input						Output					
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Normal	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	3	.75	3	.25	3	.5	3	.75	3	.75	3	.75
Expert Code	E1		BRN		E2		E1		BRN		E2	

Vibration	Input						Output					
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Normal	2	.75	0	0	2	.5	0	0	0	0	0	0
Maximum	0	0	3	.5	0	0	3	.75	3	.25	3	.5
Expert Code	E1		BRN		E2		E1		BRN		E2	

Temperature	Input						Output					
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Normal	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	3	.75	3	.5	3	.25	3	.5	3	.75	3	.5
Expert Code	E1		BRN		E2		E1		BRN		E2	

Part 6.

After occurrence of partial failures in detector unit, provide estimate ranges to the INPUT- OUTPUT parameters condition. The ranges of values should include Most = 3, Least = 1, and Midpoint = 2, or 0 for none. (See circuit diagram).

Voltage	Input						Output					
LOW	0	0	2	.5	0	0	0	0	0	0	0	0
Moderate	3	.75	0	0	2	.5	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	3	.75	3	.75	3	.75
Expert Code	E1		BRN		E2		E1		BRN		E2	

Current	Input						Output					
LOW	0	0	0	0	0	0	0	0	0	0	0	0
Moderate	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	3	.75	3	.75	3	.75	3	.75	3	.75	3	.75
Expert Code	E1		BRN		E2		E1		BRN		E2	

Vibration	Input						Output					
LOW	2	.5	0	0	2	.5	2	.5	0	0	2	.5
Moderate	0	0	3	.75	0	0	0	0	3	.75	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0
Expert Code	E1		BRN		E2		E1		BRN		E2	

Temperature	Input						Output					
LOW	2	.5	0	0	2	.5	2	.5	0	0	0	0
Moderate	0	0	3	.75	0	0	0	0	3	.75	3	.75
Maximum	0	0	0	0	0	0	0	0	0	0	0	0
Expert Code	E1		BRN		E2		E1		BRN		E2	

Part. 7

With respect to the external environment within the system, which of the following equipment(s) can cause partial failure if it's close to the detector subsystem.

Equipment(s)	**Specify measure unit**	**Normal**	**Minimum**	**Maximum**	**Recor d**
A. Main power Supply	**mV**			**3/ High**	**Max***
B. Installation in Hazardous Area	**N/A**	N/A	N/A	N/A	N/A
D. Vibration chock Proofed	**N/A**	N/A	N/A	N/A	N/A

*Maximum reading during partial failure occurrence, which means reading, is within the average but above the average line.

Part 8.

From your experience, which type of observation point is required to control or monitor output signals of these specific system partial failures? Most =3, Least =1, Midpoint =1.

Indication	3	3	3
Low Alarm	0	0	0
Expert Code	E1	BRN	E2

Part 9.

Installation Area.

Other – Specific Outdoor/ Indoor	3
	BRN

Part 10.

In supporting your confidence to detect these partial failures, Estimate an observation point insertion place.

1. Outside the located cabinet if possible.	0	0	0
2. Outside printed circuit board.	3	3	3
3. At the front of main unit	0	0	0
Expert Code	E1	BRN	E2

APPENDIX B
Tracking Radar Subsystems And Detector Unit Repair Cost Data

Subsystem	Failure Rate λ (F/mh)	Failure Location Time (Minutes)	Repair Time μ (Minutes)	Failure Rate * (Location + Repair Time)
Switch	0.04	23	0.5	.93
Fan	3.33	43	0.5	144.86
Fan	3.33	43	0.5	144.86
Heating Element	3	43	0.5	130.5
Antenna	10	118	3	1210
Monopulse Unit	67.02	88	3	6098.82
Microwave Unit	200	73	3	15200.0
Power Supply	13.55	23	3	352.3
TWT and Power Unit	76	58	3	4636
IF Preamplifier	18.09	58	3	1103.49
COHO Unite	19.45	23	3	505.7
Detector	12.36	33	3	444.96
IF Gain Control	9.7	23	3	252.3
A/D Converter	36.33	23	3	944.58
Serial Link	20.11	38	3	824.51
Monitoring Unit	13.65	23	3	354.9
Gyro Unit	113.26	43	3	5209
Stalo	181	63	3	11946
Pulse Exp/Comp	38.1	43	3	1752.6

Table B1. Failure Rate and Repair Time of Fire Control Tracking Radar Subsystems

Partial failures not detected by BITE and not shutting down the system immediately	**2% (Initial Start) - 8% (maximum)**
Complete failure detected by the BITE and on the failure area exactly.	**82.8%**
Complete failure detected by the Bite but not on the failure area exactly.	**9.2 %**

Table B2. Failures Levels

Terms	Detector Unite	Module channel
New Item Cost	$ 105,644.56	It varies, but < $ 9000
Cost of Repair by the Naval Workshops	$ 0	≈$ 0
Cost of Replacement by the Naval Workshops	$0	≈ $ 0
Cost of Shipping	$ 1415.59	Never shipped single
Cost of Replacement by Company Engineer.	$1500/engineer/day	≈ $ Not applicable
Cost of Repair Abroad	$ Up to 60% of new unit	≈ $ Never shipped single

Table B3. Tracking Radar Detector Maintenance and Logistics Costs

Subsystem	Quantity	MTTF (hrs)	MTTR (hrs)	MTBF (hrs)
Switch	1	3.89E-02	0.00112129019	2.50E+07
Fan	1	3.16E+00	0.172792013	3.00E+05
Fan	1	3.16E+00	0.172792013	3.00E+05
Heating Element	1	2.84E+00	0.15566848	3.33E+05
Antenna	1	8.56E+00	1.443362916	1.00E+05
Monopulse Unit	1	5.97E+01	7.2750501	1.49E+04
Microwave Unit	1	1.82E+02	18.1315011	5.00E+03
Power Supply	1	1.31E+01	0.420245252	7.38E+04
TWT and Power Unit	1	7.05E+01	5.530107835	1.32E+04
IF Preamplifier	1	1.68E+01	1.316311194	5.53E+04
COHO Unite	1	1.88E+01	0.60323027	5.14E+04
Detector	1	1.18E+01	0.530775837	8.09E+04
IF Gain Control	1	9.40E+00	0.300839775	1.03E+05
A/D Converter	1	3.52E+01	1.126753507	2.75E+04
Serial Link	1	1.91E+01	0.983526577	4.97E+04
Monitoring Unit	1	1.32E+01	0.423346693	7.33E+04
Gyro Unit	1	1.07E+02	6.214762859	8.83E+03
Stalo	1	1.67E+02	14.24992843	5.52E+03
Pulse Exp/Comp	1	3.60E+01	2.090609791	2.62E+04

Table B4. Tracking Radar Mean Time to Failure, Mean Time to Repair, and Mean Time Between Failure

APPENDIX C
Component Stress Levels

Overall Environment –C1

General Environmental Condition	K1
Ideal, static conditions	0.1
Vibration-free, controlled environment	0.5
General purpose ground based	1.0
Ship	2.0
Road	3.0
Rail	4.0
Air	10.0
Missile	100.0

Stress Rating - C2

Percentage of component nominal rating	K2
140	4.0
120	2.0
100	1.0
80	0.6
60	0.3
40	0.2
20	0.1

Temperature – C3

Component temperature (degrees C)	**K3**
0	1.0
20	1.0
40	1.3
60	2.0
80	4.0
100	10.0
120	30.0

APPENDIX D
Analysis Expert Opinion During and After Occurrence of Partial Failures

	Temperature	Vibration	Voltage	Current
Least				
Midpoint				
Most				

Q - 1 The amount of confidence during and after occurrence of partial failure in detector unit

Ranges I select					
1	Least	25%	50%	50%	75%
2	Midpoint	25%	50%	50%	75%
3	Most	25%	50%	50%	75%
0	None	0%	0%	0%	0%

Q - 2 The amount of Confidence on comparing yourself to your peers with respect to expertise

Ranges I select					
1	Less than	25%	50%	50%	75%
2	the same	0%	0%	0%	0%
3	more	25%	50%	50%	75%

Q - 3 After Identifying parameters that cause partial failure, estimate the two most important parameters that can cause partial failures.

Q- 4 At the time of occurrence of partial failure and after, estimate your confidence and provide an estimated tolerance range in relation to average value level.

tolerance ranges I select	Maximum Average		Minimum Average
1	0.33		0.33
2	0.67		0.67

i.e., if the expert selectd .33 of maximum average and the average is equal to + 5 volts, then the tolerance should read .3 X 5 = 1.65 volts more than the normal value

Part A5.

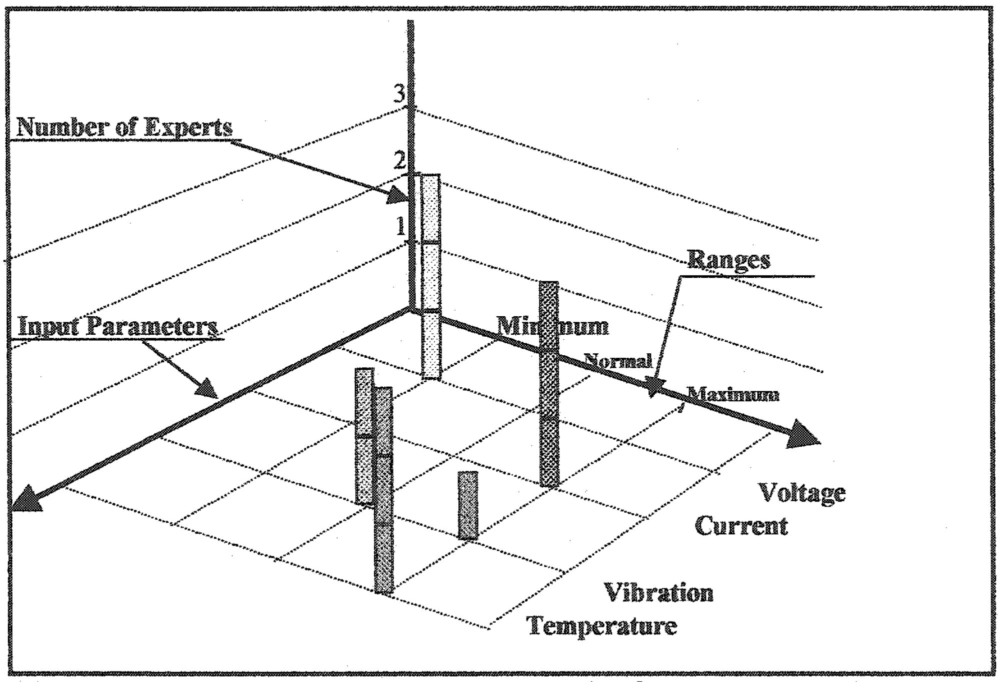

Figure D1a Estimated Input Parameters Ranges During Occurrence of Partial Failure in Detector Subsystem

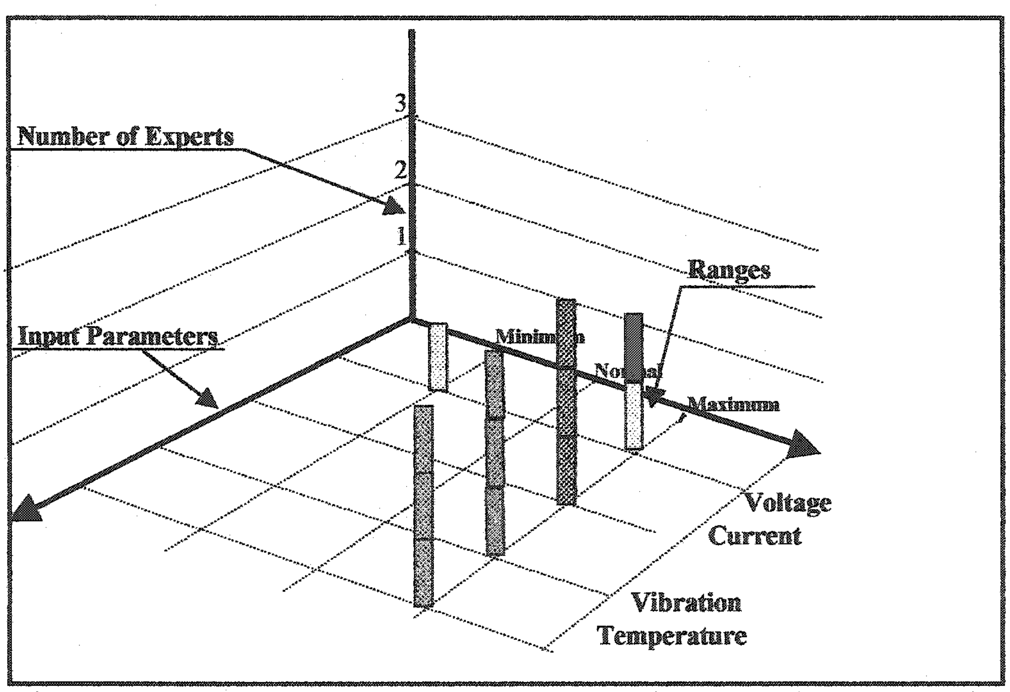

Figure D1b Estimated Output Parameters Ranges During Occurrence of Partial Failure in Detector Subsystem

Part A6.

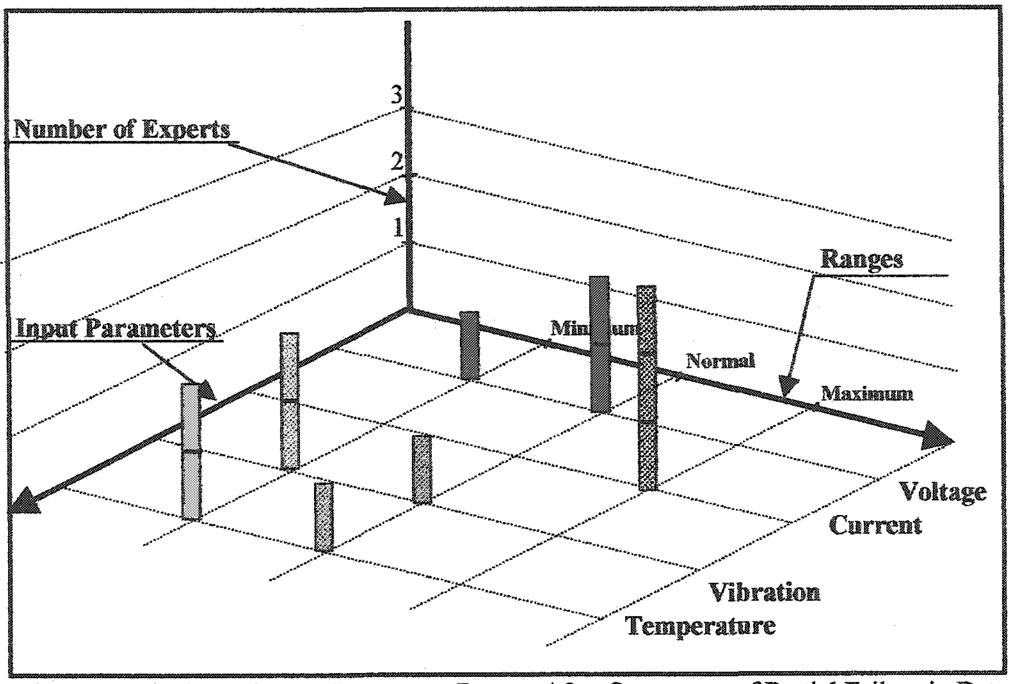

Figure D1c Estimated Input Parameters Ranges After Occurrence of Partial Failure in Detector Subsystem

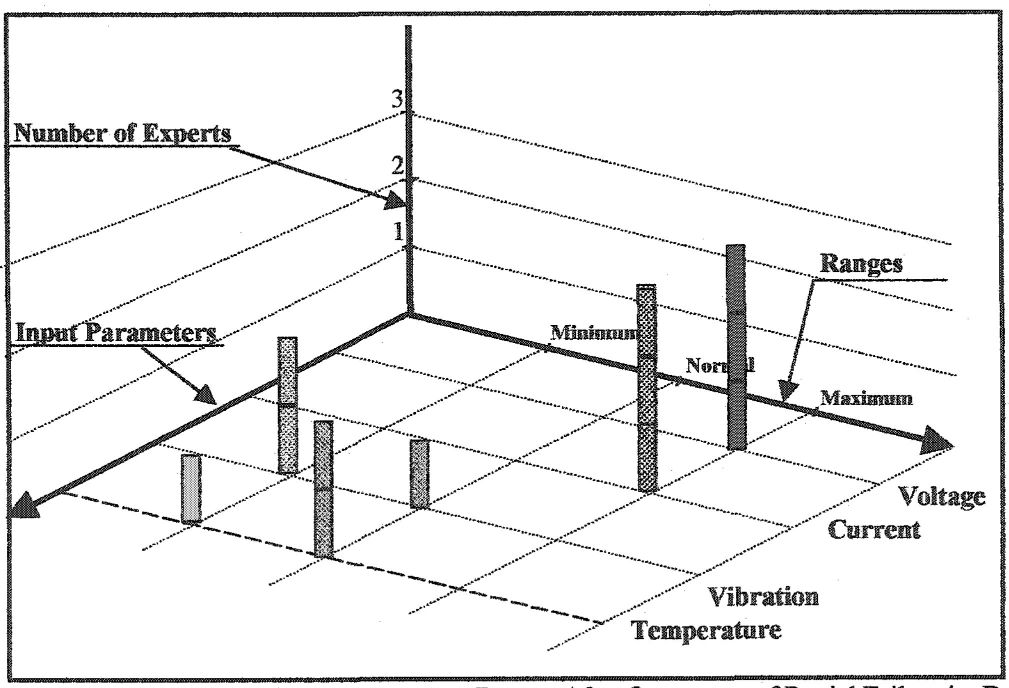

Figure D1d Estimated Output Parameters Ranges After Occurrence of Partial Failure in Detector Subsystem

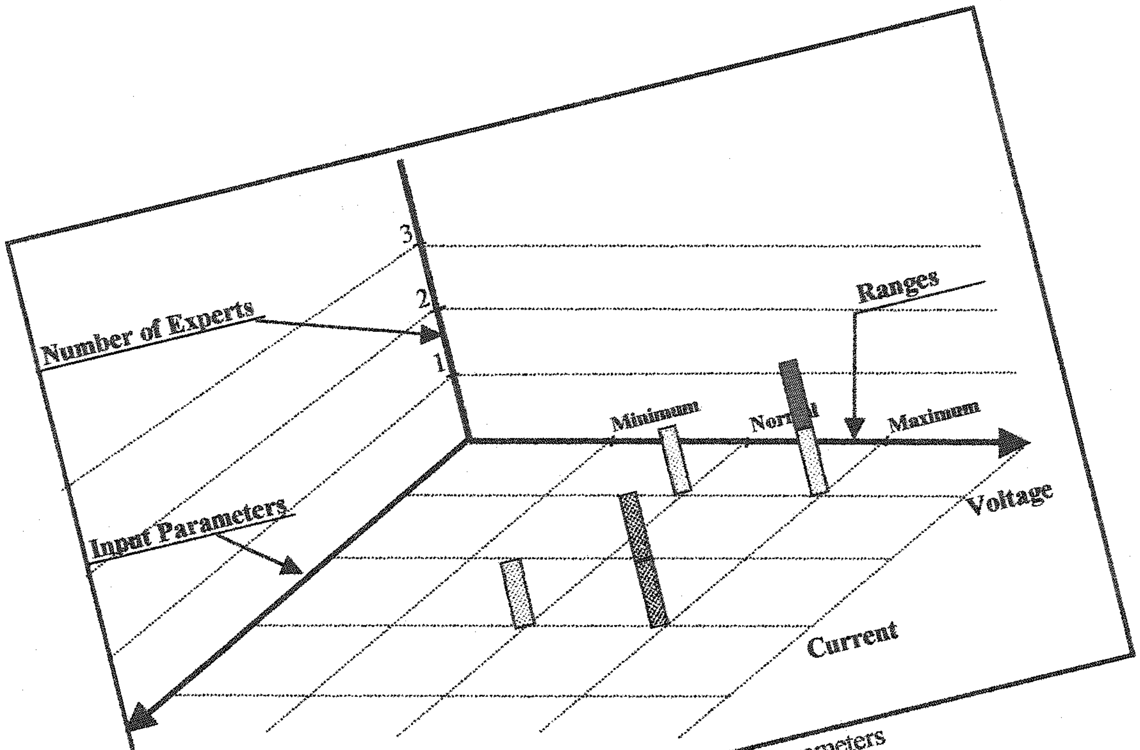

Figure D1e Estimated Most Parameters

Appendix E
Companies' litters of evaluation, recommendations and validation

LÜRSSEN
LÜRSSEN LOGISTICS

Lürssen Logistics GmbH
Zum Alten Speicher 11, 28759 Bremen Germany

Professor Resit Unal
Department of Engineering Management
ans System Engineering
Old Dominion University
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Datum/date
2003-06-30

Durchwahl/ext. +49 421 6604-
190 Fax 563

Unser Zeichen/our reference
(Bei Antwort bitte angeben/
please quote when replying)
LD-Wagenzink/kl

Mr. Anwar A. Al-Jowder works, on developing a methodology to detect partial failures for dynamic systems to improve performance, we found as a company LÜRSSEN LOGISITICS GmbH & Co. KG (Technical Department) working on the same field that this approach is capable to solve the problem of dynamic systems concerned. This methodology, which is developed by Mr. Al-jowder, can be also utilized to improve the SAT (Sea Acceptance Tests) and HAT (Harbor Acceptance Tests) standard procedures.

Moreover the observation points can be utilized and recommended for many dynamic systems when the action of BITE to detected and monitored partial failures is lagging in time.

LÜRSSEN LOGISTICS
GmbH & Co. KG

TECHNICAL DEPARTMENT

VSE CORPORATION

June 23, 2003

Professor Resit Unal
Department of Engineering Management
College of Engineering and Technology
Old Dominion University
Hampton Boulevard
Norfolk, Virginia 23529

Dear Professor Unal:

After thoroughly reading the dissertation of Colonel Aljowder about "Developing a Methodology to Detect Partial Failures for Dynamic System to Improve Performance", I found a very interesting field of knowledge and integrating way of technology which can support any system with BITE system. The observation point suggested by Colonel Aljowder can give advanced detection and monitor way, especially with new integrated systems that is going on at Bahrain Royal Navy with the old systems.

Sincerely,

VSE CORPORATION
INTERNATIONAL DIVISION

James M. Knowlton
Director

JMK:bln

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Appendix F
Expert Input Background Evaluation

The following questionnaire and format has been adopted from the work of Monroe (1997), Conway (2003), M&C® Productions, and the University of California technical questionnaire for human resources. Elements to incorporate specialist judgment new test technique have been added.

BACKGROUND

- Name or USER ID: ______________________________
- DEPARTMENT: ______________________________
- WORK TITLE: ______________________________
- RANK: ______________________________

- In this subject area, rate your own level of expertise on scale of 1 (least) to 3 (most)______, 1=25%, 2= 50%, and 75%.

- Think of others with similar experience working in this discipline. On scale of 1 (much less than peers), to 2 (about the same), 3(much more than peers), how would you compare yourself to your peers with respect to expertise? ________ (Selection of 0 % means their experience is the same).

- How many years of experience do you have in this area_________.

Provide a Quantitative explanation of your understanding of Normal, Minimum, and Maximum Confidence.

The amount of Confidence or variation of record input and/or output that I associate with Normal Confidence is:

0% 25% 50% 75%

The amount of Confidence or variation of record input and/or output that I associate with Minimum Confidence is:

0% 25% 50% 75%

The amount of Confidence or variation of record input and/or output that I associate with Maximum Confidence is:

0% 25% 50% 75%

Participant Signature: ________________________________.
Date______________.

VITA

Anwar A. Al-jowder

Colonel Staff. Anwar A. Al-jowder earned his Bachelor of Science in Electrical Engineering from Pakistan Naval Engineering College, Karachi in 1980. He received a Master of Science degree in Electrical Engineering from The Naval Postgraduate School, California, Monterey in 1995. His career includes 23 years with the Bahrain Royal Naval Force, from which he served as electrical officer onboard many ships, then as a flotilla electrical and electronic officer for Bahrain Naval Force. Before coming to pursue his doctorate in Old Dominion University, he was appointed as a Senior Commanding officer for major refit to all Bahrain Naval Force ships.