ANALYSIS AND MODELLING OF SPACE SHUTTLE CHALLANGER ACCIDENT USING MANAGEMENT OVERSIGHT AND RISK TREE (MORT)

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Abstract

This paper presents the results of the desk-stop study to model and analyse the Space Shuttle Challenger Accident using Management Oversight and Risk Tree as a part of the SIRI Methodology. The study uses the NASA Summary Report of the Presidential Commission Investigations on the Space Shuttle Challenger Accident as an input document [8].

The aim of the case study is to learn all causal factors in producing the accident. It is assumed that popular explanations of the accident suffer from errors either blaming the launch decision or the behaviour of managers during the pre-launch decision making activity. Utility of the case study is in learning all the causal factors of the given effect, the Space Challenger Accident, which occurred on 28th January 1986 using the doctrine of causation (cause-effect reasoning) as the guiding principle [8],[12],[14],[17]

1 Introduction

Jearl Walker (2008) observed in a standard text book on physics that when physics is done correctly it is subject of countless articles in physics and engineering journals. When physics is done incorrectly it is subject of countless articles in newspapers and legal journals (pp306) [16]. Clearly, Jearl Walker had in his mind the case of the Space Shuttle Challenger Accident which has become a subject of numerous case studies. The consensus of the Roger Commission and participating investigative agencies is that the loss of the Space Shuttle Challenger was caused by a failure in the joint between the two lower segments of the right Solid Rocket Motor. The specific failure was the destruction of the seals that are intended to prevent hot gases from leaking through the joint during the propellant burn of the rocket motor. The evidence assembled by the Commission indicates that no other element of the Space Shuttle system contributed to this failure (pp17, Chapter4) [8]. An article by Piers Bizony (2010) in the IET Magazine raised the issue again [4]. This article gives rise to an impression that the first designers of the Space Shuttle had specific awareness of the safety conditions under which the space shuttle can be operated. Similar assertion was made by systems engineering expert, Bahill (2005). He stated that the political decision to launch in an environment for which the system was not designed was a validation mistake. The remedy suggested is get politics out of business and scientific decisions [3].

2 SIRI Methodology

The development of the SIRI Methodology is described in an online publication [1]. HAZOP, MORT, EBTA are methods forming part of the SIRI Methodology are accepted and recommended in the safety domain. SRK is a human factors framework is accepted in the human factors community and ECFA is method to generate information in the case of accident investigation is accepted by the UK HSE.

To identify hazards, the different steps followed in the SIRI Methodology are as follows:

a) Developing description of an operational system (through system modelling process)
b) Identifying hazards at the boundaries of various systems or sub-systems (hazards identification process using HAZOP method to detect safety critical deviation)
c) Modelling accident scenarios to learn about the status of barriers (causal analysis process using representations of EBTA/ ECFA/MORT method(s))
d) Performing risk assessment and developing Countermeasures (risk analysis to counter the causal factors identified)
e) Preparation of impact assessment and documentation of results (impact assessment process)

The above steps can be applied to prospective safety studies as well as modelling and analysis of accident(s). The barrier(s) shall safe guard against the dysfunctional interactions, design and operational errors. The accident model, which drives SIRI Methodology, is stated in an equation form in equation 1 and 2 stated hereafter.

Safety critical deviation, SCD + Barrier = Protection [1]

SCD (Hazard) + loss of barrier(s) = Accident [2]

The past applications of the SIRI Methodology and the details were published in the IET System Safety Conferences in 2006, 2010 and 2011[1].

The following text discusses the issues of recognition, cognition, recall of salient items, failings of memory, unconscious biases in information processing, confounding of causes and reasons in the explanations of accidents. The errors in reasoning over causation using event sequencing, false attribution of object property to the subject or vice versa, in using inductive and deductive reasoning are discussed. These errors have adverse impact on investigating causal factors contributing to accident(s). The justification for an inertial observer is presented. The sciences of physics, psychology, and philosophy cannot be applied in an isolated manner when studying human behaviour in organisations (pp16), [7].

James Reason (1990) observed that if a person were to be asked: what has four legs, barks, wag its tail, is usually friendly, has an acute sense of smell, cocks its legs, and is called man's best friend? –there is little doubt that he or she would answer 'a dog' (pp. 110,111) [13]. If the same person were asked to generate exemplars of the category '' four legged animal', there is also strong possibility that the response 'dog' would occur very early in the output list, probably in the first position. However, James Reason used this example to highlight the distinction between the convergent and divergent memory searches and responses generated in the former case which rely upon similarity matching of supplied cues and later case of frequency gambling with the imprecise cue of class of animals with four legs. However, Arthur Schopenhauer (1813), argued that memory is not store-house of representations always at our disposal, but a faculty of a knowing Subject which enables it to obey the will more readily in repeating representations, the oftener they have already been present to it. This capacity for being exercised is called Memory.

The idea or property of companionship between dog owner and dog was examined by ancient philosopher, Plato (427B.C -327 B.C). He defined a watch-dog as a creature which distinguishes the sight of friend and foe simply by knowing one and not knowing the other. And a creature that distinguishes between the familiar and the unfamiliar on the grounds of knowledge or ignorance must be surely be gifted with a real love of knowledge. A dog has a remarkable quality that it is annoyed when it sees a stranger, even though he has done no harm: but it welcomes anyone it knows, even when it has never had a kindness from him. This disposition is truly philosophical in nature…. But is not philosophy a love of knowledge. (pp127, 128) [10]. Commenting on the ancient Greek text in the footnote, the translator, Desmond Lee, wrote that a dog who knows his mater becomes a philosopher. Plato's pupil and philosopher, Aristotle, used the Empedocles's doctrine of ''like is cognised by like'' to reason that knowledge of what is variable and invariable requires some affinity and similarity between subject and object, the two parts of the soul that are naturally adapted to the cognition of the two different kinds of objects that are themselves different in kind (pp204) [2]. The idea of an object and its representation are one and the same is stated by Arthur Schopenhauer. However, it is an error to attribute qualities of the object to the subject and vice versa is learnt from Arthur Schopenhauer's works (pp 128) [14]. Further, ideas of Space, Time and Causality are not external information conveyed to us, but an internal representation and an operation of faculty of Understanding is learnt from Arthur Schopenhauer (pp. 66) [14]. Similarity (degree of likeness) and frequency (frequency of prior occurrences) information appear to be processed automatically without conscious effort, or perhaps awareness, regardless of age, ability, cultural background, and motivation or task instructions is an established result in empirical psychology literature in 1984(pp. 103),[13]. Arthur Schopenhauer noted that empirical psychology concerned itself with the investigation of immediate presence of representations produced by dreams and the imagination (pp35) [14].

Following Arthur Schopenhauer's metaphysical system, this paper takes cognitive psychology approach to study errors types. Jens Rasmussen, had first proposed the SRK Framework to assist study of human performance in the context of man-machine system in 1983 [12]. He argued that a clear difference is necessary between causes of improper physical functions (such as electrical, mechanical, chemical processes of components and equipment) that depend upon changes in properties in the physical or material world which propagate upward in the level of abstraction hierarchy of the observer and reasons for proper functioning are derived top down which propagate down the level of abstraction hierarchy from the functional purpose and should be distinguished. Two models of abstraction operate in the abstraction hierarchy. Jens Rasmussen noted that this difference between propagation of causes of faults and reason of functions in man-machine systems has been argued by Polyani [12].

Henri Poincare taught that mathematical induction i.e proof by recurrence – is, on the contrary to physical induction, necessarily imposed on us, because it is only the affirmation of the property of mind itself(pp 13) [11]. Henri Poincare taught that induction applied to the physical sciences is always uncertain, because it is based upon belief in a general order of universe, an order which is external to us. However, astronomers are aware that astronomy is not the whole of physics, and know that Newton's law of universal gravitation cannot be verified by an experiment but assume it is verified by experiment given the fact that laws of Kepler regarding relative motion of planets have been verified to be true. Anthropomorphism plays a considerable historical role in the genesis of mechanics, but cannot be foundation of a really a scientific or philosophical character (pp94-107) [11].

The SIRI methodology relies upon Arthur Schopenhauer (1813) philosophical system of universal causation which has its basis in the Upanishads by Arthur Schopenhauer's own admission [14].
This is represented in the diagram in Figure 1. According to the Upanishad teachings, the first cause of the whole universe is the Brahman (Introduction) [15]. This teaching is accepted in this paper. Plato's teaching that soul is immortal is taught last in his philosophy, but the Upanishads teach that atman (soul) is of three kinds at the beginning of the Vedanta Philosophy [10], [15]. The notion of God as unmoved mover is derived from Aristotle, as far as Western thought is concerned is a fact noted by Alfred North Whitehead [17]. It must be remembered that consciousness cannot be both subject and object of cognition (pp. 165) [14], [15].

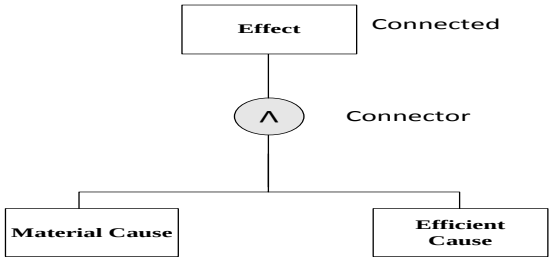

Figure 1: Simple diagram of Universal Causation.

Aristotle was predated by Indian and Buddhist thought is also noted by Alfred North Whitehead (pp. 342, 343) [17]. In the case of man-made artefacts, then additional cause formal cause is postulated thus, keeping continuity with the Aristotelian analytical philosophy of causation (354-358) [2].To learn how to reason using the pattern of above diagrammatic representation in Figure 1, let us consider an example.

In the case of process of education, the prior form is the teacher (the material cause), the latter form is the student (efficient cause), the *connector* is the teaching, and the *connected* is the knowledge. This form of reasoning is described in the Taittirya Upanishads [15]. Similar pattern of reasoning can be extended to all perceivable events.

To offer an adequate explanation of a phenomenal event, infinite chain of cause and effect relations cannot be advanced. Otherwise, the subject matter cannot be grasped. For example, the rising of the quick silver (mercury) in a thermo-meter, is the consequence of increased heat according to the law of causality (pp.155)[14]. The subjective idea of heat and cold cannot be into translated into numbers, and the mind of a scientist whose skin is a poor conductor of heat cannot sense whether something is hot or cold would use a thermometer to measure the temperature(pp106) [11].

Those familiar with Management Oversight and Risk Tree (1974) logic would recognise the parallels of hierarchal logic contained therein, law of causality described by Arthur Schopenhauer and representation of causation in the Upanishads [6],[13],[15]. The same pattern of reasoning can be seen in the writings of British philosopher and mathematician, Alfred North Whitehead on the theory of extensive connection and theory of sets(pp 294-301)[17]. He suggested the usage of terms 'connection' and 'connected' in the place of extensively connection and extensively connected. Author suggests that the type of relationship between connected and connector can be understood only in terms of flow or transmission of knowledge from the teacher to the student and not vice-versa. The representation of universal causation is not an accurate representation of reality but is proposed as a model to overcome cognitive limitations.

The benefit of Arthur Schopenhauer's system of philosophy is that errors in other philosophical systems are not entertained. Some of these systems are described. System which propagates the doctrine that all substances are actual (materialism), world is a product of mind (Kant's transcendental idealism), all knowledge is derived from sensations (Hume's empiricism), mind is superior to matter (Descartes' dualism), to name few schools of philosophy.

Arthur Schopenhauer (1813) postulated that empirical matter is endless till eternity and is that which undergoes transformation according to apriori law of causality and material objects are objects of senses. Kant's philosophical system is found to be in error over the doctrine of causation is learnt from reading of Arthur Schopenhauer's critique of David Hume's as well as Kant's philosophical systems. It is noted by the author that both David Hume and Kantian perspective on causation is challenged by Schopenhauer (pp 106) [14]. The meaning of the word, understanding, is used in a strict sense to represent the faculty to grasp the relations between cause and effect in determining changes in empirical reality. This usage of the word, understanding, has been there since the ancient times. In the modern context, it has been correctly defined by David Hume. As per David Hume's system, understanding is the faculty to comprehend relation between 'cause' and 'effect' (pp23, 24) [11]. But, we should be careful in the analysis of cause and consequences charting as we learn from Arthur Schopenhauer that both David Hume and Immanuel Kant had fallen into opposite errors in their proofs. Hume asserted that all consequence is mere sequence; whereas Kant asserted that all sequences must be necessarily be consequences (page106) [11]. David Hume accepted that reasoning about cause-effect relations results in a sequence of events whereas Immanuel Kant reasoned that a sequence of events presupposes cause-effect relation.

Long before Henri Poincare (1905) or Albert Einstein (1905), or Alfred North Whitehead (1924), Arthur Schopenhauer asserted that starlight perceived by human eye is not simultaneous with us (page 109) [14], [5], [11], [17]. The idea of difference between an identical proposition 12=12 and synthetic proposition 5+7=12 owes its origin to Kant's philosophical system and is retained in the Arthur Schopenhauer philosophical system.

In terms of decision making, the decision model inherent in the MORT method is used in addition to the SRK model of decision making and is applied to the individual or collective decision making within SIRI methodology to avoid committing short cuts in the activities of decision making between the stages of goal selection, evaluation of options, goal chosen and predicting consequences of the selection [6], [12]. Thus, the basis of the cause-effect analysis cannot rest upon the event sequence diagram is concluded from the above discussions.

3 Application of SIRI Methodology to Space Challenger Accident: ECFA, EBTA, MORT & SRK Results

When human perception is involved, then it should be borne in mind that there is a perceived order in different sensory modalities. Albert Einstein (1920) stated that the order of experiences in time obtained by acoustical means can differ from the temporal order gained visually, so that one cannot simply identify the time sequence of events with time sequence of experience (pp140)[6].

From Einstein's cosmological point of view, inertial observer is not necessary. According to this perspective, an event is localised in time but also in space. However, from a psychological perspective, the Newtonian concept of space being at rest must be used in the safety studies. Otherwise, it is difficult to describe the real event of an accident on 'as it is' basis to comprehend root causes and prevent re-occurrence of the accident. Therefore, it is necessary to construct the Event Causal Factors Chart to comprehend the accident free working to compare situations involving accidents to learn about the flow of events and missing barriers which could inhibit the dangerous flow of events.

From the inspection of the enlarged version of ECFA chart in displayed in the Figure 2, the event SS-02, the opening of the tag and clevis was not followed up by the expected event of O ring closing the gap and sealing the joint. Instead, the breach in the joint expanded and hot gases escaped from the joint which ignited after 73 seconds into the flight. Thus, the mission 51-L was doomed (para 9,10) [8].

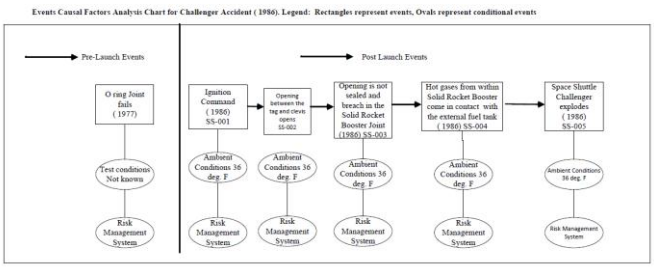

Figure 2: SIRI Event Causal Factors Charting for Space Challenger Accident (part)

The emergent property is the perception of danger of explosion involved in the actions taken by various people who were involved in the accident situation and directly connected in the perception –action mode in the sense of affordance is as follows:

a) The expected event, fall of ambient temperature during the launch next day, was perceived and cognised by Thiokol and NASA engineers as an unsafe condition for the launch but did not foresee the failure of joint sealing mechanisms (chapter 6, summary para 2) [8].

b) NASA managers making the decision on the launch were unaware of the unsafe condition and did not know that the launch decision would lead to the disaster (chapter 5, summary and para 1) [8].

c) The stakeholders organisations (NASA and its contractor) did not know the required sealing actuation time nor case-to-case joints interfacing requirements (chapter 4, Chapter 6, para 59[8].

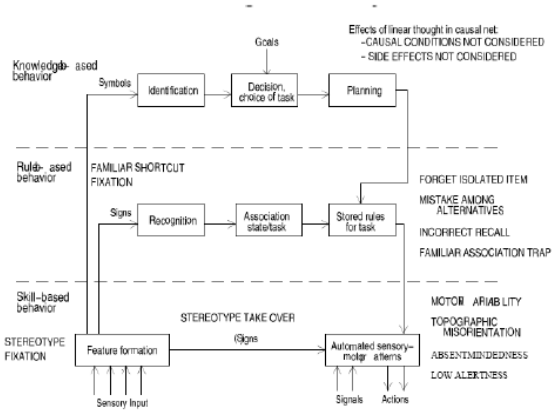

Figure 3: SRK Model for Human Behaviour which is applied to the data of the Challenger Accident

Harmful Energy Flow or harmful Agent, adverse environmental condition SB1	**Target Vulnerable Person(s) or Assets SB2**	**Barriers or Controls to separate Energy and Target SB3**
Thermal hazard of Space Shuttle explosion	Seven crew members and Space Shuttle Challenger	System of Empirical Risk Management (ineffective)
		Re-design of the joint (did not design)
		Application of high energy physics (ineffective)

Table 1: EBTA Chart for Space Shuttle Challenger Accident

Based on the set of evidences drawn from the NASA Report, and other cited documents, following S/M branch events are

listed with reference to the EBTA Chart and decision making inherent in Johnson's MORT (1974) Chart. The concepts of energy and barriers as described by W.G. Johnson and his team in 1980s are stated in the electronic version hosted by the nri.eu.com website [6].

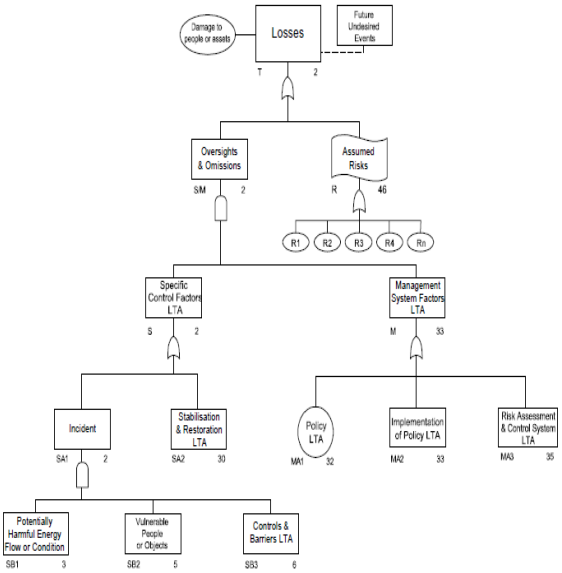

Figure 4: MORT Tree Top (part)

Management oversight and risk tree (MORT) is an analysis technique for identifying safety related oversights, errors, and /or omissions that lead to an occurrence of a mishap or an accident. The process of applying MORT is to start with a pre-defined tree (see Figure 4) to comprehend its structure.

The MORT User Manual provides the analyst with the complete list of questions that need to be answered in the process. The MORT User Manual is freely available for downloading [6].

MORT considers two explanations for an incident:
• First, that the incident was due to problems in the planning, design or control of work/process; and,
• Second, that the incident was an acceptable outcome of the risk management process – an assumed risk.

The application of MORT question set to EBTA Chart shown in Table 1 using information contained in the NASA Report, and other available documents to seek the status of barriers and controls over the hazard as well in preventing the flow of hazard has elicited following answers.

S/M. Branch Oversights and Omission S-Factors (1974 version)

SA1 event (Final Cause): On January 28, 1986, when Space Shuttle Challenger (mission STS-51-L) broke apart 73 seconds into its flight, leading to the deaths of its seven crew members. The spacecraft disintegrated over the Atlantic Ocean, off the coast of central Florida at 11:38 EST

SB2 event: Evasion Action LTA: The crew members were functional part of the system. They were exposed to safety risk without any safe guards.

From SRK classification, the cognitive control was knowledge based behaviour where the understanding breaks down due to inability to comprehend the connection between factors of desired goal, cause and effect to plan ahead. This was a KBB error. From MORT perspective, the danger was perceived and cognised but time and material conditions did not permit any physiological response. This can be inferred from the evidence in the page 7 and Chapter 9 para graph 1 of the NASA Report [8]. Had the crew been required to evacuate the Orbiter on the launch pad, they would have been running on an icy surface.

Aristotelian Material and Efficient Causal Factors

- **SB3. Event: Barriers and Controls LTA:**
- **SC1 Event. Control of work and process LTA**
- **SC1.SD1. Technical information systems LTA**
- **SC1.SD1.b2. Communication LTA**

The conclusion of the Chapter 4 of the NASA Report: The failure was due to a faulty design unacceptably sensitive to a number of factors. These factors were the effects of temperature, physical dimensions, the character of materials, effects of reusability, processing and the reaction of the joint to dynamic loading [8].

Problem reporting requirements are not concise and failed to get critical information to the proper levels of management (Chapter 7, para 3)[8].

NASA's system for tracking anomalies for Flight Readiness Reviews failed in that, despite a history of persistent O-ring erosion and blow-by, flight was still permitted. It failed again in the strange sequence of six consecutive launch constraint waivers prior to 51-L, permitting it to fly without any record of a waiver, or even of an explicit constraint. Commission noted that tracking and continuing only anomalies that are "outside the data base" of prior flight allowed major problems to be removed from and were lost by the reporting system.

Little or no trend analysis was performed on O-ring erosion and blow-by problems (chapter 7, para 4) [8]. The Mission Control Team did not have any warning of impending disaster. Even if there had been warning, there were no actions available to the crew of the Mission Control Team to avert the disaster (chapter 9, Summary) [8].

The errors within this question are KBB type performance errors. Thus, answer to this question set is set to LTA.

- **SC1.SD1.b1 Knowledge LTA**
- **SC1.SD1. d5. Previous Investigations and analysis LTA**
- **SC1.SD1.b7.Were there routine inspections of work/process**
- **SC1, SD1.b11. Statistics and Risk projection LTA**
- **SC1.SD1.a4. Triggers to hazard analysis LTA**
- **SC1.SD2.a1. Verification of operational readiness LTA**

The design of Solid Rocket Booster Joint and Seal was found LTA (pp. 33) [8].Prior to this event, NASA and its contractor did experience a similar event of space vehicle explosion. NASA failed to investigate the causes and reasons for the Apollo 13 Mission failure and its recovery made by its operators despite the failure of its design and management team (pp 271-281)[9]. The modelling and analysis of the Apollo 13 Mission using SIRI methodology would form a totally different case study as the SA2 Branch of the MORT Fault Tree plays a dominant role [1], [6].

Commission noted the following text on reliability issue. An estimate of the reliability of solid rockets was made by the range safety officer, by studying the experience of all previous rocket flights. Out of a total of nearly 2,900 flights, 121 failed (1 in 25). This includes, however, what may be called, early errors, rockets flown for the first few times in which design errors are discovered and fixed. A more reasonable figure for the mature rockets might be 1 in 50. With special care in the selection of parts and in inspection, a figure of below 1 in 100 might be achieved but 1 in 1,000 is probably not attainable with today's technology. (Since there are two rockets on the Shuttle, these rocket failure rates must be doubled to get Shuttle failure rates from Solid Rocket Booster failure.) NASA officials disputed the failure probabilities arrived at using engineering judgement (pp. 44, 45) [8].

Commission noted that the design of the Shuttle engines took up top-down approach to design as opposed to bottom up design approach in the military domain (pp. 47) [8].

Commission noted that the design aim of a lifetime of 55 missions equivalent firings (27,000 seconds of operation, either in a mission of 500 seconds, or on a test stand) has not been obtained (pp. 47) [8]. In a total of about 250,000 seconds of operation, the engines have failed seriously perhaps 16 times (pp. 47-48) [8].

Assurance of Mission Safety was found LTA. Commission recommended that NASA and the primary Shuttle contractors should review all Criticality 1, 1R, 2, and 2R items and hazard analyses (pp. 36) [8].

The errors within this question are KBB type performance errors. Thus, answer to this question set is set to LTA.

Aristotelian Formal Causal Factors:

Management Branch Errors, Oversights and Omissions
MA1. Policy LTA
MA2. Implementation of Policy LTA
MA3. Risk Assessment and Control System LTA
MB2. Programme Review LTA

The responsibility for NASA organisational risk management risk planning and acceptance was with the Mission Program Manager as per NASA Risk Manual (1970) read and reproduced by W.G. Johnson (pp. 90) [6].

The NASA program manager concluded that there was no launch recommendation by the contractor (pp18, finding 1) [8].

Prior to the accident, neither NASA nor Thiokol fully understood the mechanism by which the joint sealing action took place (pp. 20, finding 2) [8]. This conclusion dispels the false notion that the design was inherently safe.

The contractor organisation did not issue an unambiguous launch recommendation. An analysis of all of the testimony and interviews establishes the fact that Rockwell's recommendation on launch was ambiguous (pp18, finding 1) [8].

The Commission determined that the ice was not a cause of the 51-L accident and does not conclude that NASA's decision to launch specifically overrode a no-launch recommendation by an element contractor(pp 18, finding2) [8]. From an empirical risk assessment perspective, the NASA procedure for risk management did consider the frequency of hazards and their severity of the consequences, but there was no criteria against which the risk score could be compared or decision be taken whether risk is acceptable or not(pp90) [6].

The Presidential Commission talked of co-relation analysis between O-ring damage and low temperature (pp. 20, finding 6) [7]. However, Commission failed to consider the difference between analysis of causation and co-relation. It appears that they were following the logic of David Hume or Immanuel Kant philosophical systems. Errors in both systems were discussed in the paper earlier.

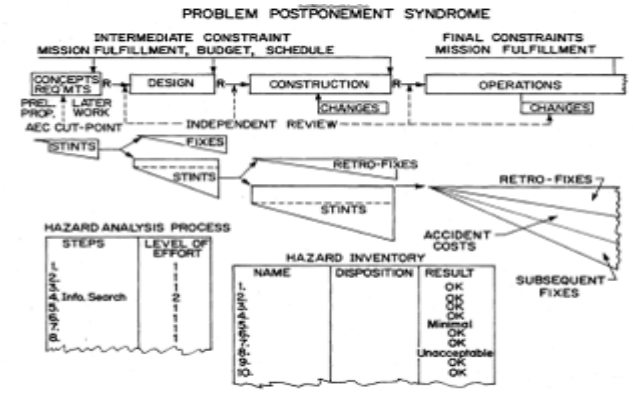

Figure 5: Problem Postponing Syndrome in project lifecycles at large organisations like NASA and AEC (pp 191) [6].

The design and management hypothesis that Space Shuttle Mission probability of success is close to 1 failed to be verified on that fateful day[9] (pp44) [8].

It is important to note that recovery from Cuban Bay of Pigs fiasco(1961) was made possible due to the discovery of the fact that Groupthink syndrome or bias can introduce genuine irrationality into the planning process(pp.41) [13], (pp. 163-173)[7].

The genuine irrationality injected into the NASA risk management process was that unevaluated (known hazard but not analysed), unrecognised (known and accepted at lower levels) hazard, and uncertainty in the analytic –decision process were the major causal factors of the NASA Space Shuttle Accident from MORT perspective [6].

In the MORT documentation, W.G. Johnson (1974) stated that these factors are accepted as oversights, omissions and errors (pp. 91) [6]. These may be called a result of problem postponing syndrome which is prevalent in the systems engineering activity in the project life cycles at large organisations like NASA and AEC as identified by the MORT team (pp. 191) [6]. Such biases can be countered by a hazard analysis process is shown in Figure 5. The traditional method of probabilistic risk assessment cannot uncover the contribution of human failures to the accident risk is noted in the literature on human error (pp221) [13]. Had the causes of failure of the seal were known to engineers then efforts to re-design the system would have been initiated. These efforts were initiated after the accident implying that the knowledge base was insufficient.

Author had published a case study showed that MORT, under SIRI methodology, can identify the latent causal factors overlooked by accident investigation process. This is discussed in the author's publication on the Herefordshire Level Crossing accident in the railway domain where failure to provide sufficient distance for the stop signal led to the accident [1]. The focus of attention under the SIRI Methodology is on the emergent property necessary for the success. Failure to attain and maintain the emergent property endangers safety [1]. The idea emerges that latent causal factors can be identified if the attention of the stakeholders is focussed on the emergent property of right cognition of danger.

The NASA accident case study is described by James Reason as study in organisational incompetence, selective blindness, conflicting goals, and reversed logic (pp192), [13]. The traditional explanations blame the O-ring design, the launch decision and management failure to heed risk warning given by Thiokol's Roger Boisjoly as causal factors for the accident. In other words, the particular hazard of vehicle explosion was not foreseen. This is an instance of failure of foresight by all organisations to recognise the root cause as suggested by Barry A. Turner in 1978(pp287)[13]. It is a fallacy to think that the Space Shuttle was a defended system made up of multiple barriers.

From the perspective of Groupthink bias, there was no conflicting evidence presented as an alternative hypothesis. Thiokol's Roger Boisjoly argued not to launch outside the known conditions. The root cause event of o-seal design defect did not surface during the discussions. All explanations assumed that the design defects was known and could have been acted upon (pp253)[13]. The bias inherent in the previous explanations of the accident is self- evident.

The errors within this question set are KBB type performance errors. Thus, answer to this question set is set to LTA. The list of S/M factors shows that material, technical and management factors caused the accident. The study has shown oversights, errors and omissions that caused the accident.

The MORT logic tree and study has shown stakeholders (individuals or organisations) involved were unaware of the manner in which the causal factors of material cause (defective seal and failure of interfaces), effective cause (failure of engineers, risk managers) and formal cause (failure of safety risk policy and implementation by all organisations) led to the accident.

4 Conclusions

The policy to plan and implement safety policy of inherently safer design was lacking at the technical as well as management levels of NASA and its contractor organisation as well. Unintended actions are not necessarily acts of God as it is assumed by James Reason (pp8) [13]. They can be man-made in nature. With due respect to Mr Allan McDonald, the then Chief Engineer at the Kennedy Space Centre, who experienced a change of heart due to God's Grace and attempted to stop the launch prior to the accident, whereas the record of events connected with the design of solid rocket booster under his care showed that it was defective to begin with (pp252-253) [13]. The effort to eliminate affordances for error lead to safer designs when it is assumed that human

errors do occur at all levels of organisation is learnt from this case study(pp236),[13].

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