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Determination of the most important General Failure Types based on Tripod-DELTA

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ABSTRACT
Prior research on the occupational incidents show that job-related accidents are majorly caused by two types of failures: a) active failures (technical and human errors), they directly affect the occurrences and totally happen in the beginning of work, b) latent failures, though hold unseen and steady for a long while in the system, they are rooted in the decisions of top-ranking officials. Tripod-DELTA is a tool that exposes latent failures. It classifies all possible latent failures in to 11 GFTs. By analyzing an operation using the GFTs, DELTA assesses where the most problematic areas of an operation are. The process of action itemizing DELTA facilitates the removal of latent failures.
***Keywords*–**Tripod- DELTA, General Failure Types, Latent failures

I. INTRODUCTION

Today in the era of globalization and competition, Accidents occur every day in all of the organization, especially in manufacturing organization. Therefore, Workplace fatalities and injuries bring great losses to both individuals and societies. For example, every year 10 million of the 150 million workers in the European Community are affected by accidents or diseases at work. In the United States, work-related injuries have been estimated at $125 billion per year. 17 employees die every day as a result of industrial accidents- a total of 63,589 deaths from 1980-1989. In 1992 alone 3.3 million work-disabling injuries were reported, and some 370,000 employees suffered work-related injuries[1]. Thus, every year the organizations and firms loss valuable resources such as people, environment, asset, and etc. The alarming numbers of accident and important indicate an urgent need for preventing accident methods. The dictionary defines an accident as “a happening or event that is not expected, foreseen, or intended”, while based on occupational health and safety management system (OHSAS18001:2007) terms, an accident is an incident which has given rise to injury, ill health or fatality. Furthermore, a near-miss, as another kind of incident,Refers to an incident has occurred where gives rise to no injury, ill health, or fatality has occurred. To the safety specialist, every accident has one or more identifiable causes. There are two fundamental types of accident causes: unsafe acts and unsafe conditions. Accidents involve either of these two causes or both. Many scholars have tried to identify the portion of incidents caused by unsafe acts compared with unsafe conditions, among them Heinrich analyzed is well-known. Heinrich analyzed 75,000 accidents and found that 88% were caused by unsafe acts, 10% by unsafe conditions, and 2% by unpreventable causes. This is Heinrich’s 88:10: 2 ratios. A study in 1960 by the Pennsylvania Department of Labor and Industry found that both unsafe acts and unsafe conditions were contributing factors in more than 98% of the 80,000 industrial accidents analyzed. Heinrich introduced another important concept. He said that preventive actions should focus primarily on accidents and their causes (unsafe acts and unsafe conditions). Less attention should be placed on effects, like injuries and their immediate causes. To demonstrate this point, he developed the 300:29: 1 ratio from a study of accident cases. For every group of 330 accidents of the same kind, 300 result in no injuries, 29 produce minor injuries, and 1 results in a major, lost-time injury. Thus, there are many opportunities to implement preventive actions before minor or serious injuries occur. Others have tried to duplicate Heinrich’s ratio. In another study, Bird and Germain included prevention of damage-causing accidents, not just injury-causing accidents. It showed a 500:100: 1 relationship among property-damage accidents, minor-injury accidents, and disabling-injury accidents. Fletcher reported a ratio of 175:19: 1 for no-injury accidents, minor-injury accidents, and serious-injury accidents[2]. It is true that there exist no agreement on the exact ratio among incidents and various kinds of injuries or results; yet the fact remains that unsafe act is the main cause of occurred accident. Needless to say, organization should focus on prevention accident in order to decrease rate of them. Due to major proportion of unsafe acts in accident cause, the organization should more and more focus on unsafe acts in order to prevent accident.

Analyses of major disasters, ship accidents, accidents in the exploration and production of oil and gas, railway operations, and aviation have shown that the contributing causes that occur in all these accidents can be captured with a limited classification system. These underlying latent causes can be categorized into a limited number of classes:

Latent risk factors (LRFs) which refer to factors that make errors more likely, or more dangerous. The choice of a particular taxonomic structure is driven by the need to capture all types of potential causes together with the need to identify where in the organization remedial actions can be put in place. These LRFs describe the total working environment, the setting in which accidents and incidents occur. Generally, a single underlying failure will be compensated for. It is when multiple factors come together that an incident becomes increasingly likely, as expressed in Reason's Swiss cheese model. According to Normal Accident Theory introduced by Perrow[3], certain types of accident will happen regardless of the number of safety devices. Perrow characterized systems according to two important dimensions: interaction and tight or loose coupling.

The relationship between normal accidents and modern technologies has been explored by Perrow(1984) through examining complex organizations. Perrow proposing that tightly coupled systems can present enormously difficult challenges in establishing accident or error causation; there is no crumple zone when a collision (or error) occurs, and no space for recovery. More importantly, Perrow proposes that complex systems actually facilitate organizational accidents (and errors), although this does not meanSystems are the cause of accidents. Reason originally proposed Swiss cheese model [4][5]. It is developed for domains such as oil and gas, aviation, railways, and nuclear power generation. It revolutionized accident investigation worldwide and has since gained widespread acceptance and use in healthcare. This model has the advantage of explaining why accidents are so rare, even in high-risk activities. The holes in the Swiss cheese slices demonstrate the potentially porous nature of defenses, be they owing to latent conditions or active failures. Importantly, the holes in the defenses (or cheese slices) will sometimes align to allow a hazard through, and although these defenses are not always porous, the hazards are always present.
Figure 1 indicates Reason's Swiss cheese model.

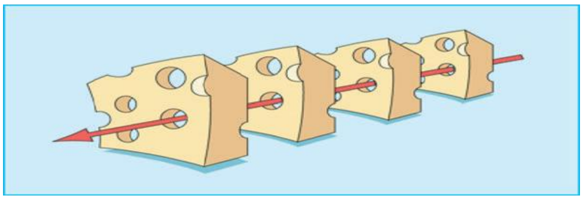

Figure 1. The Swiss cheese model [6]

The conceptual clarity of Reason's Swiss cheese model has also been questioned. When 159 volunteer health professionals were asked about the utility and meaning of the Swiss Cheese model [7], they showed considerable inconsistency, a dominant theme being an overemphasis on latent conditions or systems factors to the neglect of active failures. Perneger concludes by preferring the model of 1997, which explicitly shows the differing concepts of organizational and local workplace factors, as well as active failures (see Figure 2).

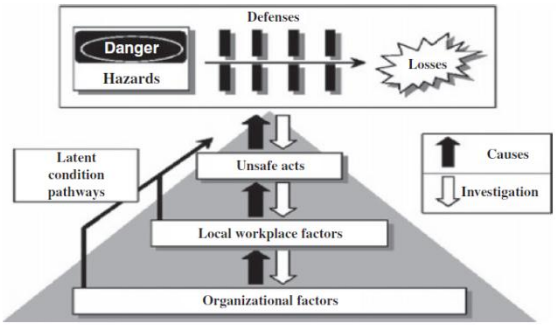

Figure 2. Stages in the development and investigation of an organizational accident [6]

Most incident analyses only describe 'who' was involved and 'what' occurred, with limited attention paid to the underlying causes that can be captured systematically by LRFs. Although the state of the individual LRFs could be assessed objectively, their effect on workplace safety and patient safety is unknown. Therefore, other techniques have been developed in which the immediate effects on workers and accidents have been studied, notably in the oil industry and aviation. The most significant development in this area was the development of the Tripod instruments. Tripod is the name used originally by Shell International for what elsewhere is known as the Swiss cheese model. Tripod is based on deficiencies in the working situation labeled as General Failure Types (GFTs) the equivalent to the LRFs discussed above. It provides an accident analysis method to identify and classify problem areas into underlying causes, scored as GFTs that led to the accident. The reactive understanding of how accidents happen described by Tripod led to the development of a specific proactive instrument, Tripod-DELTA. The questionnaire is applied to workers and is based on their experience in the workplace. Where Tripod is retrospective, the

Tripod-DELTAinstrument is prospective. Prospective methods offer significant theoretical advantages over retrospective methods. They do not rely on an adverse event having occurred. They allow the identification of latent factors in the system that may lead to hazards but that have yet to become manifested in incidents. Tripod-DELTA measures the ‘safety health’ of an organization rather than waiting for accidents to happen or even observing what actual unsafe acts people were performing. The approach taken is analogous to a health check, assessing a limited number of well-chosen diagnostic vital signs. In the prospective survey, items can be either indicators of either potential problems or good practice. Possessing the former or lacking the latter can both be treated as indications that there are latent failures present in a particular LRF and generate a negative score. Failure to find indications of problems and possession of the factors that are evidence of good practice both contribute to a positive score. The sum total of poor and good indicators can then be represented as a standard score indicating whether there is a serious problem or cause for relief. Incident research shows two kinds of failures are evident in many incidents. Active failures (technical or human) have an immediate impact and are often committed at shop floor level. Latent failures, however, lie hidden in the system for a lengthy time period and often stem from decision made at a much a greater level of the organization. Latent failures can encourage active failures or act in combination with active failures to cause incidents. The Tripod theory and methodology has been developed at the Rijksuniversities Leiden and the Victoria University, Manchester for the oil and gas industry and concentrated on workplace safety and lost hours due to incidents and in to the contribution of human behavioral facts in accidents [9]. The project led to an instrument that’s today largely applied [12]. The Tripod DELTAtool was implemented on a pilot basis in one enterprise in the automotive sector in France [8].

This paper is organized as follows. Firstly, Sect. 2 presents the methodology the Tripod-DELTA. To demonstrate the proposed model, a case study is illustrated in section 3 and then Tripod-DELTA is implemented through our case study .In section 4, results of proposed Tripod-DELTA in case study is presented. Finally, conclusion and further study of this paper is presented.

II. TRIPOD-DELTA METHODOLOGY

2.1 The Theory of Tripod

1.1.1 Background

Tripod DELTA is a comprehensive questionnaire-based tool that exposes latent failures. Tripod theory is a structured approach for managing hazards, aiming at determining the underlying causes of accidents. Theory's name is taken from three key aspects; it is a trilateral diagram which is shown in Figure 3.

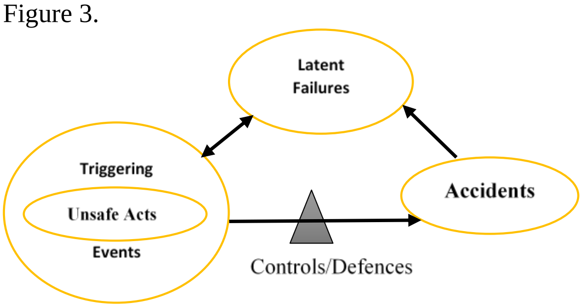

Figure 3. Tripod Framework [9]

1.1.2 General Failure Types

Based on the Tripod philosophy, these latent failures could be categorized in a restricted amount of ways, the General Failure Types (see Table 1). The GFTs are the consequence of brainstorming, audit report studies, accident scenario inquiries and demonstrate through considerable area studies to be valid for many industrial applications [10].

Table 1. The eleven GFTs [11]

10 Preventive GFTs		1 Mitigation GFT
Specific for a branch	Generic	
Hardware (HW)	Communications (CO)	Defenses (DE)
Design (DE)	Organization (OR)	
Error enforcement conditions (EC)	Training (TR)	
Housekeeping (HK)	Procedures (PR)	
Maintenance management (MM)	Incompatible goals (IG)	

To be much more specific, ten of the GFTs influence the process resulting in the operational disturbances (the ten “Prevention” GFTs) and one GFT is targeted at controlling the consequences when the operational disturbance has happened (the “Mitigation” GFT) [11].

2.2 The mechanism of Tripod-DELTA

2.2.1 DELTA profile

A DELTA profile is “Failure State Profile”. GFTs are shown on the X pivot, and "the Increasing Concern" is shown along the Y pivot (See Figure 4). The more GFT’s value is, the more will be the signs of latent failure which are found within GFT. Thereby any high value of a GFT is a threat to the staff.

The biggera GFT bar, the more threats can direct resources to regions of their operations where they’re most needed. It’s important that a profiling exercise should run before an incident has occurred. Improvements are created before personal injury, material and reputation loss or environmental damage have happened.

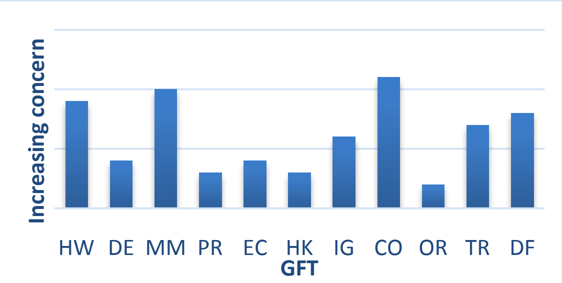

Figure 4. An example DELTA profile

2.2.2 Prior to implementation

Not absolutely all operational units are ideal for DELTA. Before implementation suitability for utilization of the tool ought to be confirmed. To facilitate the implementation of DELTA critical success factors have already been identified and ought to be put in place.

2.2.3 Implementation

The tool for diagnosing the current presence of latent errors involves utilizing a checklist approach followed with a structured diagnosis resulting in defined remedial actions. The checklists are composed of a number of indicator questions, where an indicator is just a small pointer that most isn't just like it might or should be [9]. Indicator questions are the heart of DELTA (See Table 2). Generating god indicator questions is time consuming so a process called customizing has been developed to greatly help the implementation process. Following customizing the database can be utilized to create questionnaires, profiles and action item points. When the organization is prepared for DELTA, implementation can be performed in a few days (subject to prerequisites being in place). The questionnaire is specific to the operational unit and as an equal number of questions for all the11 GFTs (normally 20 to 25). The questionnaire is answered by line personnel and a DELTA profile is generated showing the GFTs against a variety of increasing concern. For specific GFTs a specialist ought to be area of the group (e.g. for Maintenance Management or Training). The manager who would be the recipient of the profiles also needs to take part in at least one such group session to make sure that he understands the background to the questions. The generation technique involves three stages:

1) Define 'The Perfect World', some desirable features, for every GFT.
2) Generate indicators. They are small, objective and preferably auditable, indicators that a feature, defined by the Perfect World, either has or hasn't met. These indicators are phrased as yes/no questions.
3) Validate the indicators by submitting them to management for acceptance in when it comes to their relevance, objectivity and understandability.

Table 2. Examples of indicator items for different GFTs.

Questions	GFTs
Are the melting procedures manuals indexed at the present time?	Procedures
Are there more than two air conditioning units on the platform at the present time?	Hardware
Has there been a lost time injury on the workshop of casting Operation in the last three months?	Incompatible goals
Has the maintenance department been consulted in 80% of purchases of new equipment in the last six months?	Maintenance Management

When sufficient experience has been gained in the utilization of database, future calibration could be made to verify every individual indicator question correlates positively having its respective GFT.

2.3 Running DELTA

2.3.1 Answering the questionnaire

The questionnaire is completed with a small number of site personnel (no a lot more than four) who, collectively, have the knowledge to answer the questions. An answering group on a workshop of Thermal and Plating Operations, are the salt furnaces supervisor, maintenance engineer and safety officer. The questionnaire includes 220 to 275 questions. Most questionnaires can completed in 2-3 hours (over a flexible period of time). Once completed a DELTA profile is automatically generated.

2.3.2 Action itemizing

The profile will disclose both strong and weak regions. Generally the three worst efficiency GFTs (highest bar) are examined in more detail during an action itemizing exercise. The aim of the exercise is to determine around three regions of improvement per GFT and to put corrective action into place. This process involves brain storming conducted with a choice of the answering group, line personnel and management, probably at a slightly higher level than the team that completed the questionnaire. Each item of improvement follows a 'what', 'when', 'who' format. What the action is, when it is going to be completed by and 'who' is responsible for its implementation. The action itemizing meeting usually takes 2-3 hours. In order to assist the process specific grid and instruction have already been developed. Action itemizing points are line created and usually minimal budget [12]. The testing results were positively received by the company management, and helped to demonstrate that safety of work is largely dependent on such factors as management concept, maintaining order and cleanliness, and efficient communication. In addition, the results of the implementation of the Tripod Delta questionnaire allowed the development of a more comprehensive plan of corrective actions, the improvement of communication between the management staff and employees, and the creation of conditions under which the employees could express their opinions and be involved in actions being directly related to them [13].

III. Implement Tripod-DELTAmethodology in case study

3.1 Case Study: An investment casting plant

To validate the proposed method, a case study was conducted in a manufacturing company. FAKOORI is a manufacturing organization that is engaged in production parts and components using by different production methods such as turning, milling, and investment casting. It produces car parts, turbines for aerospace, power generation, and oil and gas industries. It has 450 employees and is located in Tehran. Since 2006, FAKOORI has been involved in more than 20 projects valuing over 50 million euro. Investment casting (See figure 5) is one of the oldest manufacturing processes that Examples of this industrial process have been found across the world such as in Egypt's tombs of Tutankhamun (1333–1324 BC), Mayan Mexico, HarappanCivilization (2500–2000 BC) idols, and the Benin civilization in Africa.

Figure5. The pictures of investment casting

Investment casting is a manufacturing process in which a wax pattern is coated with a refractory ceramic material. Once the ceramic material is hardened its internal geometry takes the shape of the casting. The wax is melted out and molten metal is poured into the cavity where the wax pattern was. The metal solidifies within the ceramic mold and then the metal casting is broken out. This manufacturing technique is also known as the lost wax process. Investment casting has several advantages that some of most important are mentioned below:

1. Production Extremely complex parts, with good surface finish gives rise to reduce the need for secondary machining
2. It is ideal for low volume production
3. It can be used to cast intricate forms with undercuts
4. A very smooth surface is obtained with no parting line.
5. Un-machinable parts can be produced using by this method with near net shape

There are a variety of material can be used for the investment casting which can be mentioned as stainless steel alloys, aluminum, brass, magnesium alloys, and so on. These materials should be melted and poured into the cavity. At this insight, the factory needs to equipment such as furnaces, autoclave, tongs, crucibles, wax injectors, etcto melt metal. Molten metal is a serious hazard in melting pouring applications of metal casting. Workers who execute tasks with or near the molten metal are highly prone to risks, such as coming in contact with metal splashes or be exposed to electromagnetic radiation. Consequently, in this study we use Tripod-DELTA method to prevent of incidents.

3.2 DELTA implementation in case study

3.2.1 General View

Tripod- DELTA begins with a particular operation unit. The said unit includes a low incident rate. The questions for the investment casting unit are created specifically, and then DELTA attempts to evaluate the latent failures through GFTs and the answers supplied by the personnel of every unit.
The outcomes could be observed in the DELTA profile. An overall look at the profile permits us to recognize the threatening GFTs just before take the corrective action(s).

3.2.2 DELTA profile

The aforesaid questionnaires will be answered by three groups of the staff who have been informed about the research and its procedures. They are the manager of investment casting unit, HSE manager, a skilled supervisor and maintenance unit manager. After questionnaires are filled by the determined persons, the appropriate and inappropriate answers are separated, and then after questionnaires are analyzed as Table 3, a schematic DELTA profile is provided as Figure 6

Table 3. Analyze of questionnaires

Questionnaire	***1***		***2***		***3***		
GFTs	Desirable	Not desirable	Desirable	Not desirable	Desirable	Not desirable	Results
HW	10	10	13	7	12	8	25
DE	9	11	6	14	13	7	32
MM	7	13	9	11	7	13	37
PR	3	17	5	15	6	14	46
EC	7	13	14	6	12	8	27
HK	4	16	7	13	10	10	39
IG	13	7	9	11	15	5	23
CO	14	6	11	9	11	9	24
OR	8	12	8	12	9	11	35
TR	17	3	15	5	13	7	15
DF	12	8	13	7	15	5	20

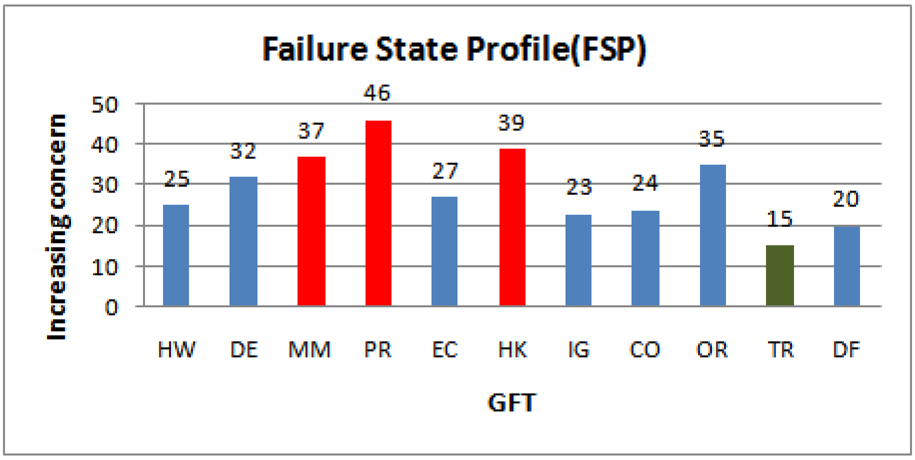

Figure 6. DELTA profile

IV. Results and discussion

As is possible observed from the diagram (See Figure 6), the Procedures (PR), Housekeeping (HK), and Maintenance management (MM) units are present in the critical area, additionally the resources should be directed toward the GFTs, also the required corrective actions are supposed to be taken. The order of criticality of GFTs for arranging corrective actions, preventive actions and dedicating the resources is as below:

PR>HK>MM>OR>DE>EC>HW>CO>IG>DF>TR

Much of the evidence providing that there are problems in an organization is scattered about, of has become invisible and accepted as part of the conditions under which people work. In this study, the Tripod-DELTA diagnostic procedure samples the hazard management health of the investment casting unit by answering a list of 660, indicator questions which indicate whether a particular GFT is present in the operation or organization. The lists of questions are selected randomly from a pre-stablished database of indicator questions relevant to the operation being examined. The responses to the questions indicate a 'desirable' or 'undesirable' condition relating to the GFT. The Failure State Profile (FSP) shows the relative state of each GFT (See Figure 6).

V. Conclusion and further study

Tripod-DELTA is an exercise that takes place outside the environment of accident investigation and is thus a proactive rather than a retrospective hazard management tool. The quality and effectiveness of a business is a wonderful indication of its safety record. The greater run the business, the reduced its incident frequency. DELTA is really a tool that helps business become better by exposing potential shortcomings and remedying them before incident occurrence.

The advantages of DELTA are numerous. It discusses safety in a fresh light, examining the whole organization for latent failures rather than 'traditional' safety problems. It offers feedback on potential incident causes before any incident has occurred. It identifies the strongest and weakest regions of an operation, therefore allowing prioritization of resources. As a self-diagnostic tool it's run by the line efficiently and is flexible so can avoid peak work periods. It delivers steady improvement by giving a method of learning and improving that will not depend on having suffered human, material or environmental loss.

Future studywill be evaluating the reasons for violations of procedures, attempting to develop measuring instruments and managerial tools.To increase reliability, future research should be done to measures the weight of General Failure Types through one of Multiple Criteria Decision Making (MCDM) methods such as Fuzzy Analytic Hierarchy Process Method. Complete synopsis will give opportunities for researchers to use or improve methods and approaches to promote accident prevention in the manufacturing sector that suffer from lack of knowledge in this area.

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