2. RESEARCH HYPOTHESES

Abstract

This paper reviews various models used for enterprise process management systems and public safety systems. These models are probabilistic functional safety models, accident models like Causal - Sequential Event Based Models, systematic models like FMEA, reliability models, systemic models like STAMP model, cognitive models etc. These models and their advantages and disadvantages are discussed in details. The existing public safety management system and enterprise process management system are also compared. It is observed that Public Safety Systems share similar attributes to Enterprise Process Safety management systems, and requirements for Communicating Safety Systems shall be similar. A Functionally Safe Communication Systems for Public Safety using latest wireless telecommunication system such as *LTE for Public Safety* is also discussed. Some of the evolving legislations towards Managed Energy and Managed Safety for both process and public management systems are elaborated.

1. INTRODUCTION

Safety Management Systems (SMS) is part of the management controls operational in the organizations. SMS intends to provide adequate safety in case of failures occurring during routine operational procedures. The failure can be systemic failures or systematic failures and may be caused by human and non-human actors. SMS has various stages like detection of failure, prediction of the failure, prevention and control of hazardous failures which have the potential to afflict large tangible and intangible loss to the human life and thereby the organization

Enhancing overall safety in the most efficient manner requires the adoption of a systems approach to safety management. Every segment and level of an organization must become part of a safety culture that promotes and practices risk reduction. Safety management is based on the premise that there will always be safety hazards and human errors. SMS establishes processes to improve communication about these risks and take action to minimize them. This approach will subsequently improve an organization's overall level of safety.

There are multiple safety regulations governing the occupational safety i.e. OSHA and NIOSH regulations, which predominantly speak about occupational safety. Asset Safety is governed by equipment safety regulations and Functional Safety and Safety Management Systems guidelines provided by respective industries and as per the ISO requirements for Quality Management (ISO 9001), Environmental Management(ISO 14001). Life and Fire Safety Codes perpetuated by organizations like NFPA mandate the compliance for the Fire and Life Safety regulations in built environments. The upgrading public safety communications need to consider the enablement of such compliance. The availability of the regulations helps us to get to know the operational boundaries of the systems. It is also understood that the regulations provide an operational framework and different industries and systems update them as per their requirement.

In a public safety system that monitors a particular space it is imperative that it is collaboration among the different safety management systems that protect the overall citizens in a particular place. By adopting Systems approach to Safety Management, the role of modeling in Safety management and Accident prevention becomes a norm. Different models for Accidents causes and prevention have been developed i.e. FMEA, FTA , STAMP, FRAM , Swiss Cheese Domino Model etc, give a fair understanding about the failure modes their prevention and sometimes the nature of cognitive and human roles in the accidents.

This work is part of an ongoing research on Safety Communication Systems Design using Public Safety Broadband LTE Networks. The public safety broadband LTE network is envisaged as specific broadband network for the public safety usage alone and it is being designed to replace TETRA and LMR services which do not have the capability to communicate large packets of data as compared to the Evolved Packet Core Architecture of LTE networks. Thus new applications emerge because of the availability of suitable bandwidth. This would help the emergency responders and regulators with situational awareness aiding in informed decision making. In this paper the existing Safety Management procedures were analyzed and the existing research of Accident Models in the Industry was considered to draw inferences about the need for Cognitive Modeling of Safety Systems and its Centeredness in the Human Factors. The needs of such a Safety Communication System is identified and corroborated with models being observed in the industry.

2. METHODOLOGY

The scope of the project was to design a standardized public safety communication system that yields a usable backbone for the Safety Management systems. As part of the nationwide operations of implementing broadband extensive research has been taken up to upgrade the Public Safety Communication Network Systems with LTE networking in the 700 MHz Spectrum. Hence this research has taken up the LTE Network as the communication back-bone channel. In order to find the suitability of using an LTE network the needs for this communication system had to be identified. Review of literatures indicated that the suitability of the networks is studied with scenarios under emergency management alone. The use cases have been built around just tackling an emergency situation i.e. there is a fire accident or a chemical

explosion or medical emergencies that include ambulatory transports. These use cases are sufficiently drafted to handle the emergency scenarios. Sufficient research and experiments on the suitability of the LTE networks has also been performed. The role of the Public Safety Management Systems in other aspects of effective safety management has not been considered. Hence this research focuses on the application models required by the other applications in safety management scenario. Thus a hypothesis was built i.e. the public safety systems could be built on similar lines like the safety management systems practiced in the Industry.

The enterprise/industrial safety systems are designed in a functionally safe architecture which include the overall system design and continuous monitoring and are realized as a combination of systems like the alarm management systems, safety sensing systems like gas controllers or fire alarm controllers, emergency shutdown systems, personnel protection systems, work procedure management etc. Alarm management systems help in visualizing, archiving and create situational awareness in case of process alarms as well as safety alarms. These systems also help in incident investigation and post incident analysis. The fire and gas safety controllers and detectors act as the layer of protection. The Work Management systems like the Hot Work Permits and Lock-out Tag-Out help to put human operational controls. Personal Protection systems and equipments provide personal layer of protection and hazard prevention. Thus the idea of continuous monitoring and design of public safety systems were examined with comparison to process safety systems. Additionally, the California Public Safety commission [1], has inferred from various literature that the most approachable and implementable solution would be a "Systems of Systems" approach rather than a single national broadband system.

Based on the theories of system safety, the existing accident models were analyzed to control the systemic faults. These faults are random in nature and controlled through fail-over / fail-safe mechanisms. The control of systematic faults is a function of the design and continuous monitoring. The communication system design will then cater to the needs of both systemic and systematic fault avoidance at an overall system level. The existing functional safety models have established that the overall safety integrity is function of the levels of integrity of each of the participating sub-systems. For a Sustainable Safety Management System, the system should be participating in other aspects as well, i.e. *planning, preparedness, periodic monitoring.* It also

involves the *human participation* in the process. The existing theories on *socio-technical systems* were studied for understanding the human factors impact on this design.

a. PUBLIC SAFETY SYSTEM

Public safety is the administrative actions and management of safety in the civic society by providing near immediate response to emergencies and disasters. The safety system also controls such scenarios through emergency medical response, firefighters, jurisdictional police agencies, criminal justice systems, operators of the Mission Critical 9-1-1 Services and the regulatory authority monitoring the environment and pollution. The common need of the Public Safety department is to save lives and property in a sustainable manner. Every government has a department of public safety that is concerned with identification, prevention, and control of safety hazard incidents in a civic society. It is also entrusted to monitor the environment and pollution at controllable and sustainable levels. As civic societies also contain the industries and associated work-forces, this department has the need to provide adequate safety measures to the Industry and its workers as well as the society in which the industry thrives. However, there are a number of instances when such public safety system fails as found in the sad examples of the Bhopal gas tragedy of India, the Gulf-oil leaks at US, and the recent City of West Fertilizer plant tragedy. These incidents necessitate for better and periodically monitored safety management systems with system of systems approach.

The incidents of safety failures and their hazardous impact mainly depend on the inadequate knowledge of regulations, implementation of the regulatory requirements and training on the hazardous material. In a recent report to the US Senate on the explosions in the City of West and another explosion in Louisiana, Dr. Sam Mannan, , noted, "*Overall, from what is known, the storage of ammonium nitrate at West Fertilizer Company did not provide adequate measures to prevent overheating and propagation of fire, which eventually led to the explosion," and added that the status of the compliance to OSHA and DHS regulations is not clear and had they been met such incidents could have been prevented* [2]. He also added that, that proper training on the hazards of ammonium nitrate and knowledge about a potential violent decomposition might have allowed firefighters to take a different approach when responding to and fighting the initial fire. It is evident from the older cases and the newer cases that a-priori

information and continuous compliance management would eventually help the industries and environment from such disasters. These cases further confirmed the needs executing Disaster Management on the principles of Plant Safety Management and enable compliance.

b. ENTERPRISE PROCESS SAFETY SYSTEM

Process Safety Management Systems (PSM) are dedicated to control the Process in the industrial plants to prevent, predict and control disastrous incidents in the Industrial Plant. Process Safety Management has evolved over the years in multiple dimensions due to strong focus on the business needs and economic value created by running processes safely. It will also lead to lesser downtimes and minimize expenses and losses from catastrophic accidents. PSM have been using computer aided safety engineering methodologies for over a decade now and many of the PSM systems work under the premise of systemic safety integrity governed by probabilistic functional safety models. Figure 1 illustrates the PSM model.

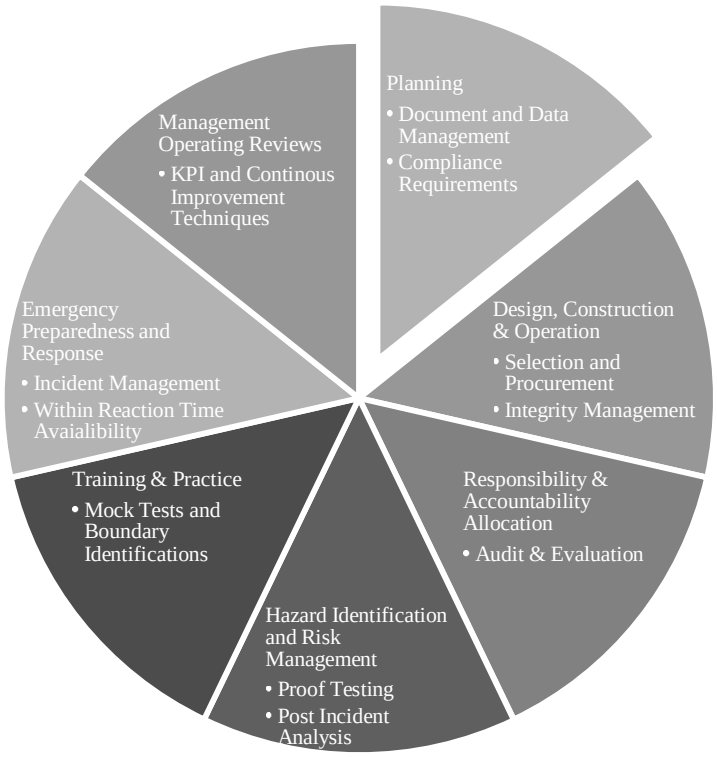

FIGURE 2 PROCESS SAFETY MODEL USED IN INDUSTRIES

In the above model, it is observed that these elements of safety management act as a solution similar control Engineering problems. There are seven macro steps in the organizational process such as planning, design and operation, audit, risk identification and management, training and practice, emergency preparedness and response, and management operating reviews. These steps play a very critical role in the industrial process control engineering, beginning from planning till the process is successfully running. Being a management system, the outputs of many of these steps produce a well documented procedural methodology. The real test and measure of this is observed in the economic value the safety management system.

The impact of the Safety Management as a process lever is felt to deliver value by use of process safety management techniques to take control over the operations management.

They also concur in having a compliance with IEC-ISO standards for Risk Management, Quality Management, Environmental Protection and Local Labor Laws like the OSHA or NIOSH standards.

Even-though the enterprises have developed their internal safety management processes to build and operate their processes they face challenges like

- Compliance
- Presumptions
- Tracking & Measurements
- Business impact
- Systematic fault avoidance, which impacts the overall safety performance.

In a recent paper in Hydrocarbon Processing, Turk & Mishra [3], explain the role of Process Safety Management beyond functional safety principles by identifying the Key Performance Indicators (KPI) and Safety Performance Index by constructing a four stage model as illustrated in Figure 2 and 3 respectively. Here the KPI Framework refers to the Key Performance Index and the LOP and LOE refers to the Layer of Protection and LOE stands for Line of Equipment. They list down the following nine steps for effective industrial management that goes beyond functional safety in an organization as way to monitor and control the risk and safety in the industry.

- Establish the organizational arrangements/relationships needed to implement indicators.
- Decide on the scope of the indicators.
- Identify the risk-control systems and decide on the outcomes.
- Identify critical elements of each risk-control system.
- Establish the data collection and reporting system.
- Review (benchmark against the IE PSM Framework or equivalent).
- Deploy the KPI model and SPI calculations.
- Educate management on the importance of PSM.
- Establish management roles and actions for review of KPIs, SPIs, estimated asset value-at-risk and estimated production value-at-risk.

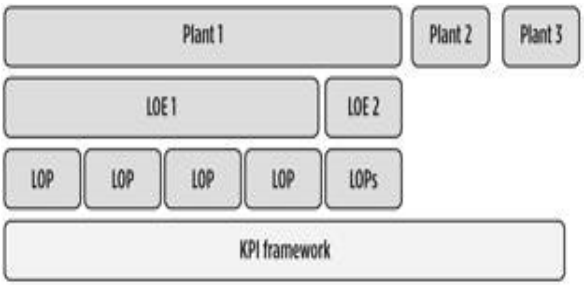

FIGURE 4 – KEY PERFORMANCE INDICATORS FOR A PRODUCTION LINE

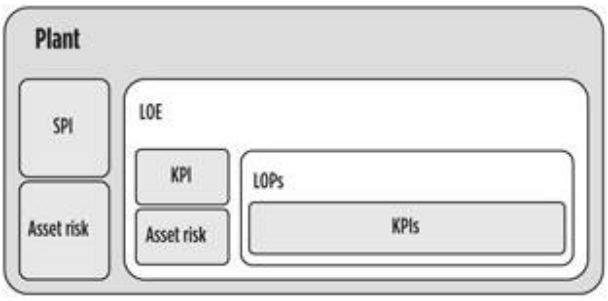

FIGURE 3 – SAFETY PERFORMANCE INDEX FOR A PLANT

The Abnormal Situation Management Consortium has been focusing its research on plant safety from situation management and human factors perspectives. Their research has led to identifying human factorial effects and the cognitive implications [4]. The international association for Oil & Gas Suppliers has rolled out models of the role cognitive assessments for the plant and environmental safety. The industrial safety management is designed from the foundation principles of functional safety management with addendum Layers of protection. Based on this, the research started looking at the functional safety models available and their applications as well as the cognitive aspects of the socio technical systems.

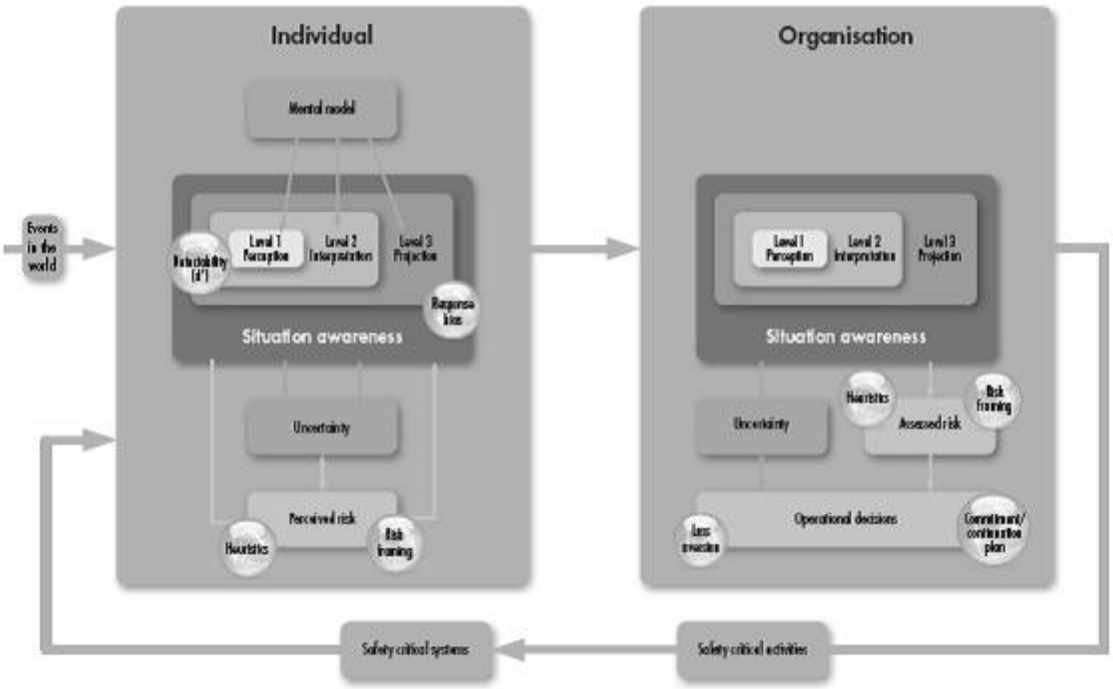

FIGURE 5 - COGNITIVE MODEL IN PROCESS SAFETY SYSTEMS

3. MODELS

The existing safety models were studied to understand the cause of accidents used both in investigation and prevention. Some of these models form the basis of the IEC/ISO regulations on functional safety. Additional ongoing research on system-safety was also studied to understand the causation behaviors and impact of human in the process loop. The following summarizes the relevance of different models in the context of Public Safety Management Systems.

a. IEC FUNCTIONAL SAFETY MODEL

International Electro-Technical Commission has developed the core framework for functional safety i.e. as IEC 61508. This framework elucidates the functional safety as a lifecycle in the design, commissioning and operational faces of a product or a system. The model is extensively based on the probability theory of failure and the reliability of the components, and they go onto

develop the hazard analysis based on the perceived or potential risk by means of techniques like *Failure Mode Effect Analysis (FMEA)* and develop component level analysis by *Fault Tree Analysis.* [5]. The framework extends to the safety integrity by continuous monitoring through fault diagnosis and proof tests for systems and sub-systems. The 61508 model has got itself manifested into specific application classes for Nuclear (*IEC 61513*), Medical (*IEC 62304*), Automotive (*ISO 26262*) and Process Safety (*IEC 61511*), Rail (*IEC 62279*) Classes. The latest development is in the foundation classes for smart grids [6]. Over time, system designers have resorted to such functionally safe designs, by increasing the perceived reliability by means of redundant architectures to fail-safely take over operations and continue the operations.

The 61508 framework is reliably the best known technique to date to develop safety culture in electrical, electronic programmable electronic systems. A public safety and emergency management system has lot of human interactions in the loop. With mostly automated systems, it is good to comply to the 61508 framework with additional knowledge on accident behaviors and associated human factors in accident.

b. COGNITIVE MODEL

Systems are mixture of complex components including human in the loop. Most of the systems are built to meet human needs. Moreover, human interactions always remain as an object of use. Hence accidents are the results of mishandling or dysfunctional interactions amongst components, rather than component failures. Safety can be viewed as a control problem, and safety is managed by a control structure embedded in an adaptive socio-technical system" says N. Leveson "A New Accident Model for Engineering Safer Systems," Safety Science, vol. 42, no. 4, pp. 237–270, 2004.

The evolution of safety of systems started with classical failure analysis aimed towards risk mitigation**,** with drive towards continuous improvements and safety controls as a business function. Since all systems and processes are designed for human use, these have continuous interactions with social and technical systems. Thechallenge in systems design is to Integrate the other systems with system of systems approach. The process of wider system integration

includes the human Interaction such as intuition of the user and his/her cognitive ability, the fundamental underlying process knowledge, and the impact of information and communication between systems and users. Human cognitive abilities have been always linked to the safety of the system and as well as the safety culture in a society that could be a workplace or a living-space. Development of modern techniques, have evolved the way man works with these newly designed systems and new failure modes have evolved in the way man and machine interact. People working in the area of cognitive systems engineering, have developed models to validate this in the order of Cognitive Reliability and Error Analysis Methods (CREAM). Erik Hollagnel is the developer of this techniques and he tried to apply it to two variants i.e. on the *road safety* and the *maritime safety*.

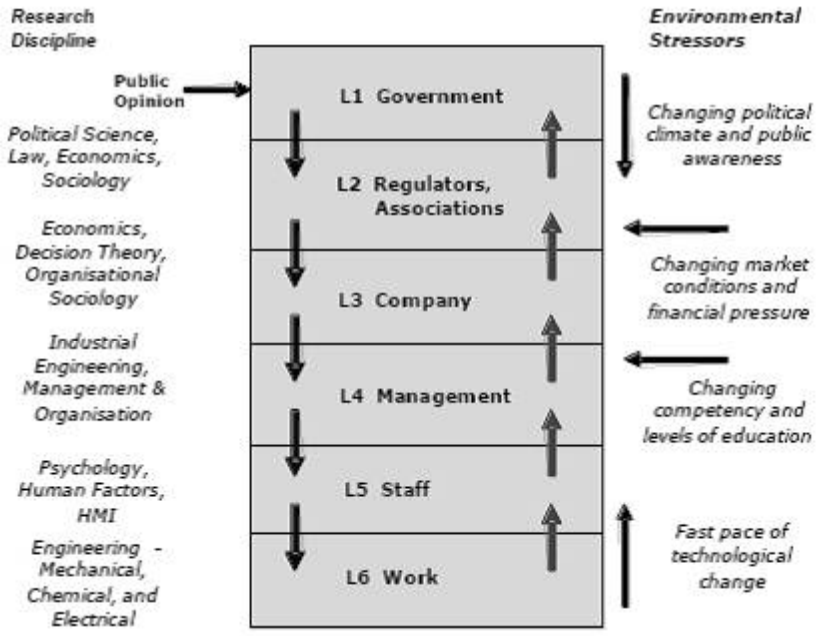

FIGURE 6 – IMPLICATIONS OF HUMAN FACTORS IN THE SAFETY SYSTEMS

Functional Resonance Accident Models (FRAM) is yet another technique developed by Hollagnel to identify the interactions between procedures, methods, systems and techniques in which functional entity or processes are analyzed. The parameters used are *input, pre conditions, control, time and resource*. *The parameter 'time' could be time slot in the execution cycle or an event index order in the execution time frame.* Thus, when analyzing the interactions between the various functions and processes, the interactions between the functions lead to a common mode

and resonate to cause failures. This is an excellent model that dissects the system by systemic functions to develop predictable and controllable models of the system rather than the system structure. *System structures produce fault models at component levels while this (FRAM) model helps to predict and control processes and methods.* [7]

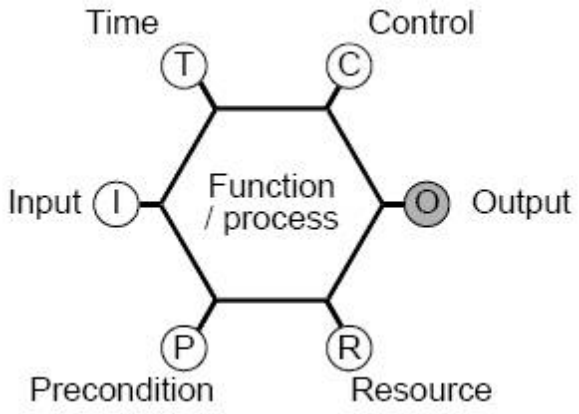

FIGURE 7 – FRAMEWORK FOR PROCESS SAFETY MODELS

c. ACCIDENT MODELS [8]

Causal - Sequential Event Based Models, Heinrich's Domino Model of Accident Causation, mostly containing single element as a root cause for the subsequent chain of events and one of the oldest and most sought after models. The model is illustrated in Fig. 7. The model performs well in a uni-causal systems i.e. sub-system level analysis. This is attributed by the more or less linear trajectory of path between the cause and effect. However Zahid Querishi of Defense Systems Institute, University of South Australia and Nancy Levenson of Dept. of System Safety at Massachusetts Institute of Technology opined that this model is quite unsatisfactory, as most system failures are attributed to multiple sources. The applicability of this model is limited to

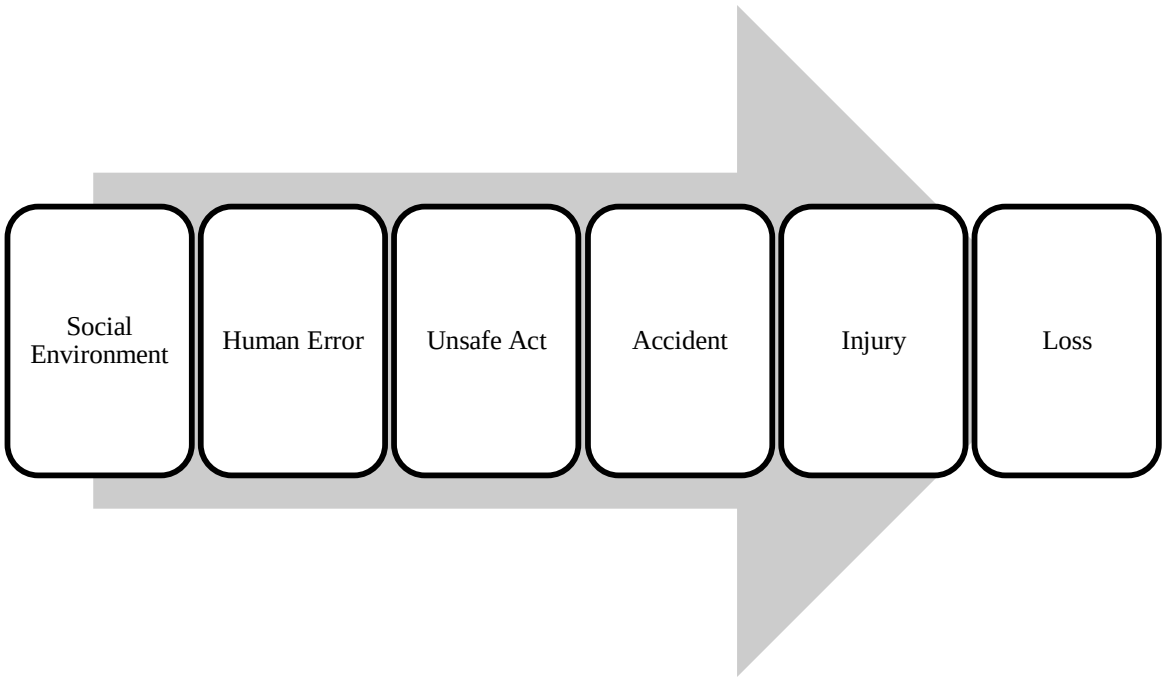

FIGURE 8 - CAUSAL ACCIDENT MODEL

d. SYSTEMATIC MODELS (FMEA, RELIABILITY ETC.,) [9]

Systematic way of looking at safety has been a higher functional need and attributed to the success of probabilistic models of the system components failures and their reliability analysis. A most commonly known technique is the Fault Tree Analysis, which uses the fault trees to identify (or) describe the state of the system as illustrated in Fig. 8.

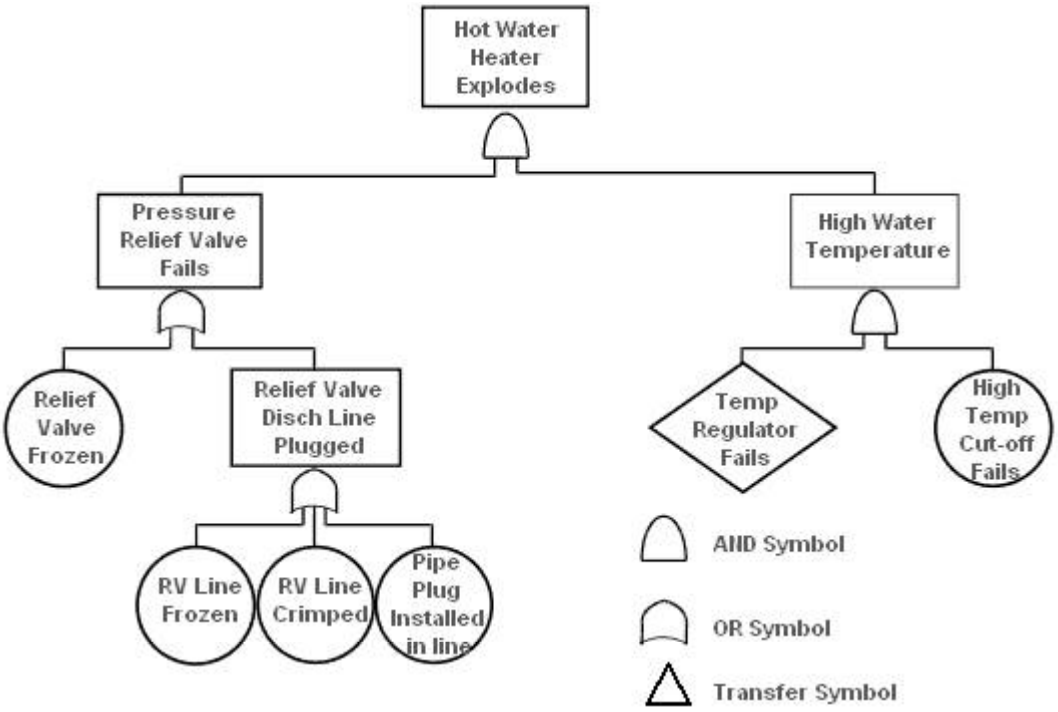

FIGURE 9 – SYSTEMATIC HAZARD ANALYSIS TECHNIQUES

e. SYSTEMIC MODELS

In systemic models, an accident occurs when several causal factors (such as human, technical and environmental) exist coincidentally in a specific time and space (Hollnagel, 2004). A system is not regarded as a static design, but as a dynamic process that is continually adapting to achieve its objectives and react to changes in itself and its environment. The system design should enforce constraints on its behavior for safe operation, and must adapt to dynamic changes to maintain safety. Accidents are treated as the result of flawed processes involving interactions among people, social and organizational structures, engineering activities, and physical and software system components (Leveson, 2004). Leveson, thus proposed a stronger model called STAMP which has its roots from Ramassuens Socio-Technical Framework for complex systems.

f. STAMP MODEL [10]

STAMP stands for Systems-Theoretic Accident Model and Processes and attributes systems failures to be not able to meet certain conditions which Leveson describes as systemic constraints or lack thereof. The other element applied in the STAMP model is the flaw in the control loops between the systems during various phases of its design to deployment.

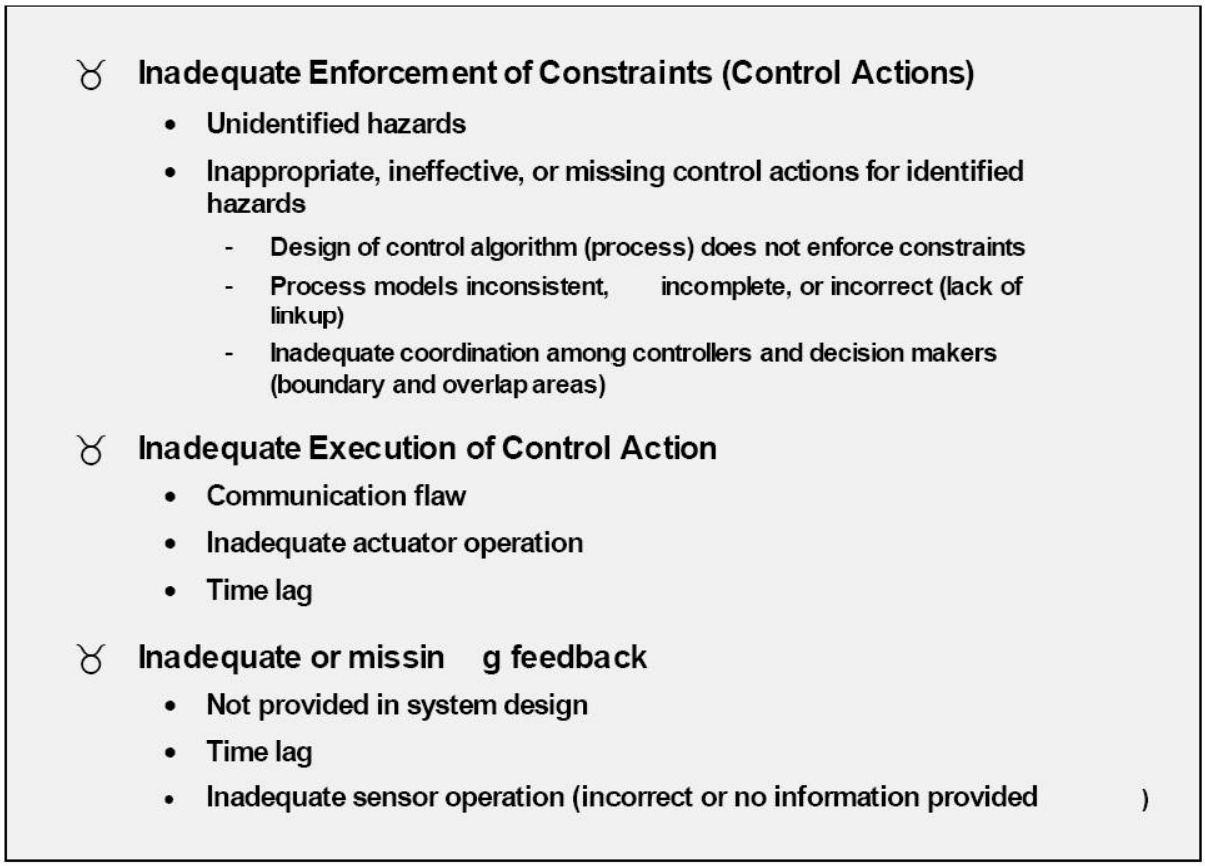

FIGURE 10 – STAMP & THEORY OF CONSTRAINTS

4. DISCUSSION

The comparison of the Enterprise/Process Safety Management Systems with the Public Safety Management systems took us to a level of understanding on the subject of modeling the public safety systems and its communication back-bone. The Enterprise Safety Management systems with both publicly standardized Safety Management procedures with additional Internal Control procedures still face the challenges mentioned in section 2.

Even when the same model is applied to the Public Safety Systems, the challenges would continue to remain and probably get amplified owing to the scale of the system increases from an enterprise to bigger geography with more people and more interactions. In one form the overall safety integrity is a function of the above challenges, it is a complex manifestation of the above factors as described by Turk & Mishra. In another form the challenge of Compliance Adherence remains a major threat with its associated situational manifestations as per the ASM Consortium.

SMS for Public Safety, Handbook for ESI and GSI companies New Zealand, has outlined what the Electricity and the Gas Distribution companies should adhere for creating public safety and how should they be complying with the jurisdictions and standard bodies. They also explain the implementation model in one of the distribution companies and its details are shared in the hand book [11] as illustrated in Fig.10.

<table>
<tr><th colspan="4">Vector's HSEQ</th></tr>
<tr><td>ISO 9001
Quality Management</td><td>ISO 14001
Environmental
Management</td><td>AS/NZS 4801
OH & S
Management</td><td>NZS 7901
SMS for Public Safety</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>HSE Act</td><td colspan="2" rowspan="2">Elements common to both standards</td><td>Amendment Act &
Gas Amendment Act</td></tr>
<tr><td>Employer – Employee focus</td><td>Public Safety and Public Asset focus</td></tr>
<tr><td rowspan="12">AS/NZS 4801
Occupational Health & Safety Management System</td><td colspan="2">Management Reviews</td><td rowspan="12">NZS 7901
Safety Management System for Public Safety</td></tr>
<tr><td colspan="2">Objectives / Targets/ KPI's</td></tr>
<tr><td colspan="2">Hazard Identification & Risk Management</td></tr>
<tr><td colspan="2">Incident Reporting & Investigation</td></tr>
<tr><td colspan="2">Emergency preparedness & Response</td></tr>
<tr><td colspan="2">Legal requirements</td></tr>
<tr><td colspan="2">Asset design , construction & protection</td></tr>
<tr><td colspan="2">Responsibility / Accountability</td></tr>
<tr><td colspan="2">Assessment / Auditing</td></tr>
<tr><td colspan="2">Competency / Training</td></tr>
<tr><td colspan="2">Document & data Management</td></tr>
<tr><td colspan="2">Management Plans</td></tr>
</table>

FIGURE 11 – PUBLIC SAFETY MODEL USED IN THE NEW ZEALAND 7901 MODEL.

Equivalently the electrical distribution industry has also seen an effective functionally safe distribution management system in the evolving Smart Grids. The IEC has standardized the various models for Smart Grids as illustrated in Fig. 11. Desirable properties of public safety network [12] elucidate the various needs and requirements of this new generation network. They also put forth the idea of Public Safety Interoperability Panel (PSIP), as similar to the Smart Grid Interoperability Panel (SGIP) as illustrated in Fig.12. In the ongoing research, a Public Safety Communication System similar to the smart grid hierarchy was conceived

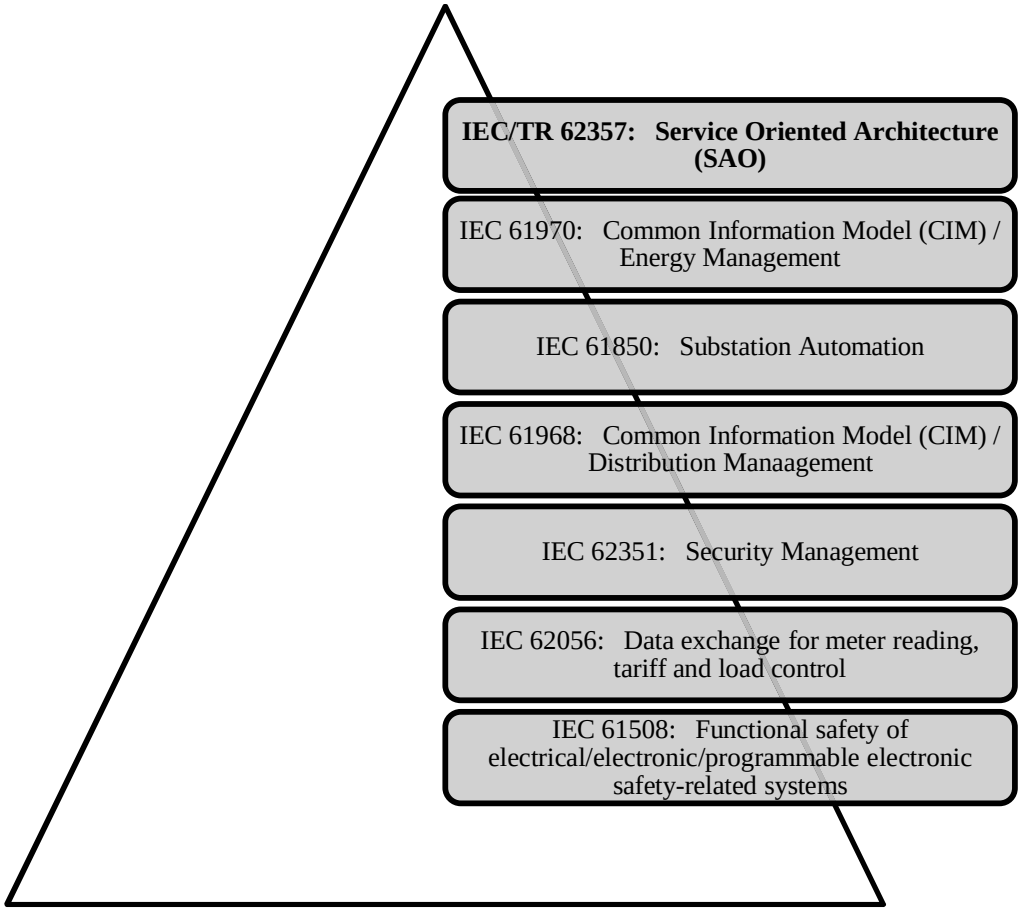

FIGURE 12 – SMART GRID INTEROPERABLE FRAMEWORK

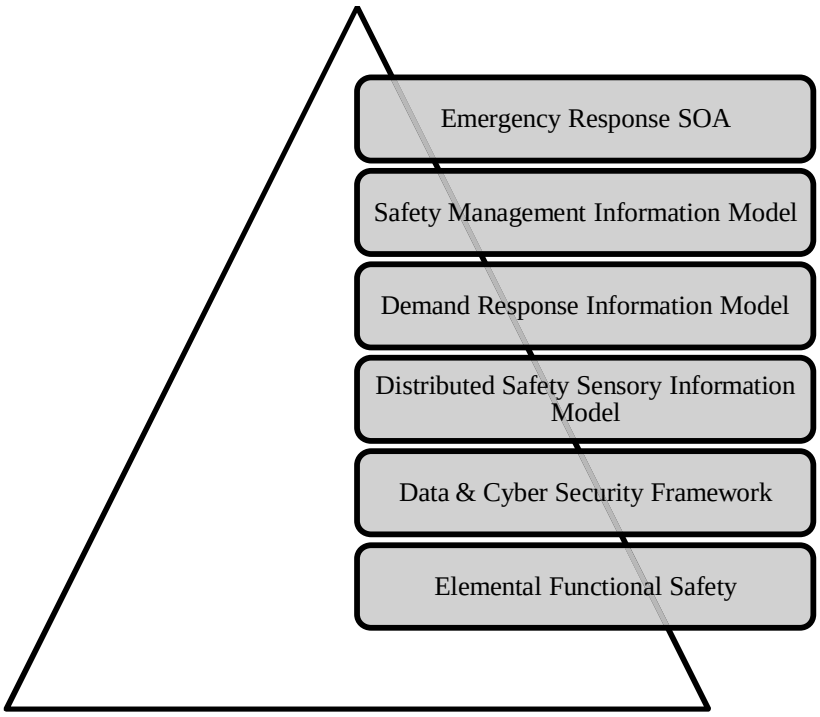

FIGURE 13 – SAFETY GRID INTEROPERABLE FRAMEWORK

In the Public Safety Communication Model Figure 12, the foundation principles are based on the elemental and cognitive functional safety models as the next generation public safety is a socio-technical system as discussed about the different models of functional safety. The accident models lay emphasis on the cognitive aspects and the functional resonance model and the STAMP model lay focus on the theory of constraints for the accident occurrence. The basic functional safety model puts forth the probabilistic models such as FMEA and FTA techniques as in hazard analysis techniques like HAZOP (Hazard and Operability Study), ALARP(As low as reasonably practicable) etc.

The safety management information model layer represents the HSEQ(Health , Safety, Environment & Quality) models similar to that described in the industrial world. As the next generation public safety communications is conceived in the flat-IP networks, it is important to have communication layers of protection as in any cyber security means. The emergency response service oriented applications form the last layer of protection to combat the disasters and this layer assists in disaster preparedness. The two other layers conceived are the distributed sensor management and the demand response layers which act as information providers and consumers on the safety loop.

The ongoing research on the public safety communications is focused on the emergency management system. This research would help in directing the other systems that would help in addressing the challenges in the Safety Management Systems.

5. CONCLUSION

In the process of design of communication systems and design for public safety systems, the journey began with the analysis of use cases put forth by the Public Safety Research Group which can effectively be used to describe the wireless communication characteristics required by the LTE network. Sooner the holistic role of the communication systems in the overall safety life cycle of the Public Safety organization was observed as a need to be accommodated in the systems design aspect. The proposal put-forth by California's Public Safety dept. to realize the Public Safety System as a Systems of Systems design and the New Zealand's Energy and Gas distribution association's Safety hand-book's requirements to cover the entire life cycle and the recent disasters in City of West, indicate the need for Communication Systems Design to cater to other areas of Safety Management as well. The approach to build the Public Safety System similar to an Enterprise-Process Safety System comes to light above and it would be critical for the communication systems design to aid in overcoming the existing challenges in the Process Safety Management Systems.

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