# RFID Assisted Smart Conveyor System with Industrial Robot Hand

H.M.D.B.Herath, R.S.V.Piyasena, P.P.G.C.Prasanna, Y.W.R.Amarasinghe

## Abstract

*In this paper a prototype smart conveyor system is developed with the integration of Radio Frequency Identification (RFID) technology and a robot hand for product handling in a manufacturing environment. A novel Flexible Manufacturing System (FMS) with customer based production is introduced using web-services technology and a real-time updatable inventory database to enhance operational efficiency of the manufacturing environment. The FMS designed is a fully automated system with RFID tags/detectors, intelligent control systems, robot arms and sorting mechanisms, smart conveyor system and a real time updatable inventory database with application software. This study demonstrates the significance and benefits of a smart conveyor system with the integration of RFID technology for product identification and handling, specifically in the manufacturing industry.*

## 1. Introduction

The automated transportation of raw materials, finished/unfinished products etc. between two manufacturing cells is a common process on a factory floor. Different types of conveyor systems are used in manufacturing environments to achieve this basic function. Smart conveyors equipped with sensors, wireless devices and intelligent logics, are able to achieve one or more functions: sense (detect), identify, interact, decide and act. Unlike traditional conveyor systems, a smart conveyor has the ability to identify its loadings and adjust speed and direction according to the real-time field data in the manufacturing environment. Therefore a smart conveyor has an intelligent ability for self controlling. An advanced product identification method such as Radio Frequency identification (RFID) technology could be effectively used to advance the sense/detection method of smart conveyor systems.

In supply chain industries RFID technology is adapted for the ease of product identification at different stages of the supply chain. RFID technology is still novel to the local industry. Although many research projects have been carried out related to RFID technology and its applications in wireless communication, only a few have been carried out related to product handling in manufacturing environments. Despite the potential limitations perceived early on in the development of RFID technology, several recent studies have indicated that investing in RFID technology is promising and is an excellent long-term capital investment. This study is specially focused on the development of the applicability of RFID technology in product handling and smart conveyor systems.

RFID technology has a wide range of applications in logistics [1], airlines industry [2], construction [3] etc. RFID technology is used for the purpose of identifying products which lead to a better identification than existing barcode systems. Many difficulties faced in barcode systems and other object identifying methods such as the need for proper alignment, closer proximity reading etc. are overcome by the implementation of RFID technology. Furthermore, large data could be embedded in to the tag and could be placed inside the product to avoid damages. With the support of RFID technology for product identification the smart conveyors are designed for effective product handling and sorting.

A RFID system consists of three main components; RFID transponders (tags), Transducer (reader) and RFID middleware as shown in Fig. 1.1.

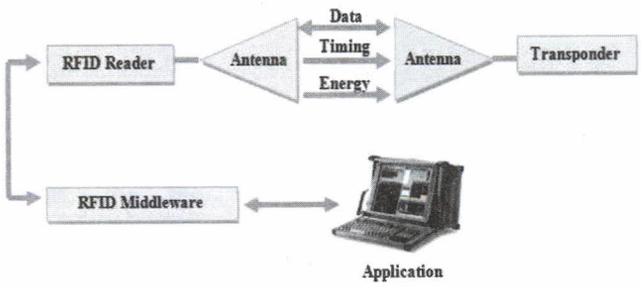


Figure 1.1 – RFID system

Through the RFID product identification, various user interfaces and applications are developed for real-time updatable databases such as a real-time updatable inventory database. Web Services technology has been widely applied to the manufacturing field in recent years. In adopting RFID technology for manufacturing industries, web technologies could be used effectively to manage the services to enable them to be easily registered, published, searched and invoked by users or the third systems. Large worldwide electronic distribution companies such as "RS Component" and "Digi-key" use web-based ordering and distribution systems to satisfy customer requirements. RFID technology could be effectively adapted for such industries for efficient sorting and real-time product traceability which benefits the industry itself as well as the customers.

Automatic Identification and traceability have been identified as key factors for efficient manufacturing shop floors. Some concept cases which used RFID technology to capture real-time manufacturing data could be seen in production line [4] and work-in-progress (WIP) inventories management [5]. Wong et al. [6] adopts an authentication method to apparel products using RFID

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passive tags and lightweight cryptography. Yingfeng Zhang et al. [7] adopt an agent based gateway system for real-time ubiquitous manufacturing. Several studies have been carried out [8] to discover how RFID technology could be used to enhance various aspects of the healthcare industry.

## 2. System development

The overall system introduced consists of two main parts, hardware and software. The hardware includes a web and application server, a sensing and product identification system using RFID technology and Infra-Red, a prototype smart conveyor system and a robot hand. In terms of software, a web based application software, Relational Database Management System (RDBSM) and embedded control software for controlling smart hardware are introduced. A system overview is shown in Fig. 2.1.

In the system proposed, the customer is able to place the order for the desired quantity of products through the web based application software. Then through the main server, application software checks for the availability of components required for production using the inventory database. The integration of all the communication interfaces, connectivity of the smart conveyors and the robot arm are the responsibilities of the main server.

Once the order is placed through the web-based application, the sub parts referring to the specific products requested are moved to the main conveyor from the inventory to be sorted for assembly lines. Each subcomponent of the inventory is tagged with a passive RFID transponder which enables identifying of the objects and sorting. As the RFID reader identifies the objects on the main conveyor, the inventory database is automatically updated to display the current amount of subcomponents available in the stocks. The real-time updatable inventory database developed assists real-time traceability and visibility.

The main function of the three Degrees of Freedom (3-DOF) robot arm is the sorting of subcomponents and placing them on the sub conveyors. The controlling of the 3-DOF robot arm is done by the micro-controller which is programmed using MicroC. The RFID tagged components are identified from the unique identification number and sorted accordingly.

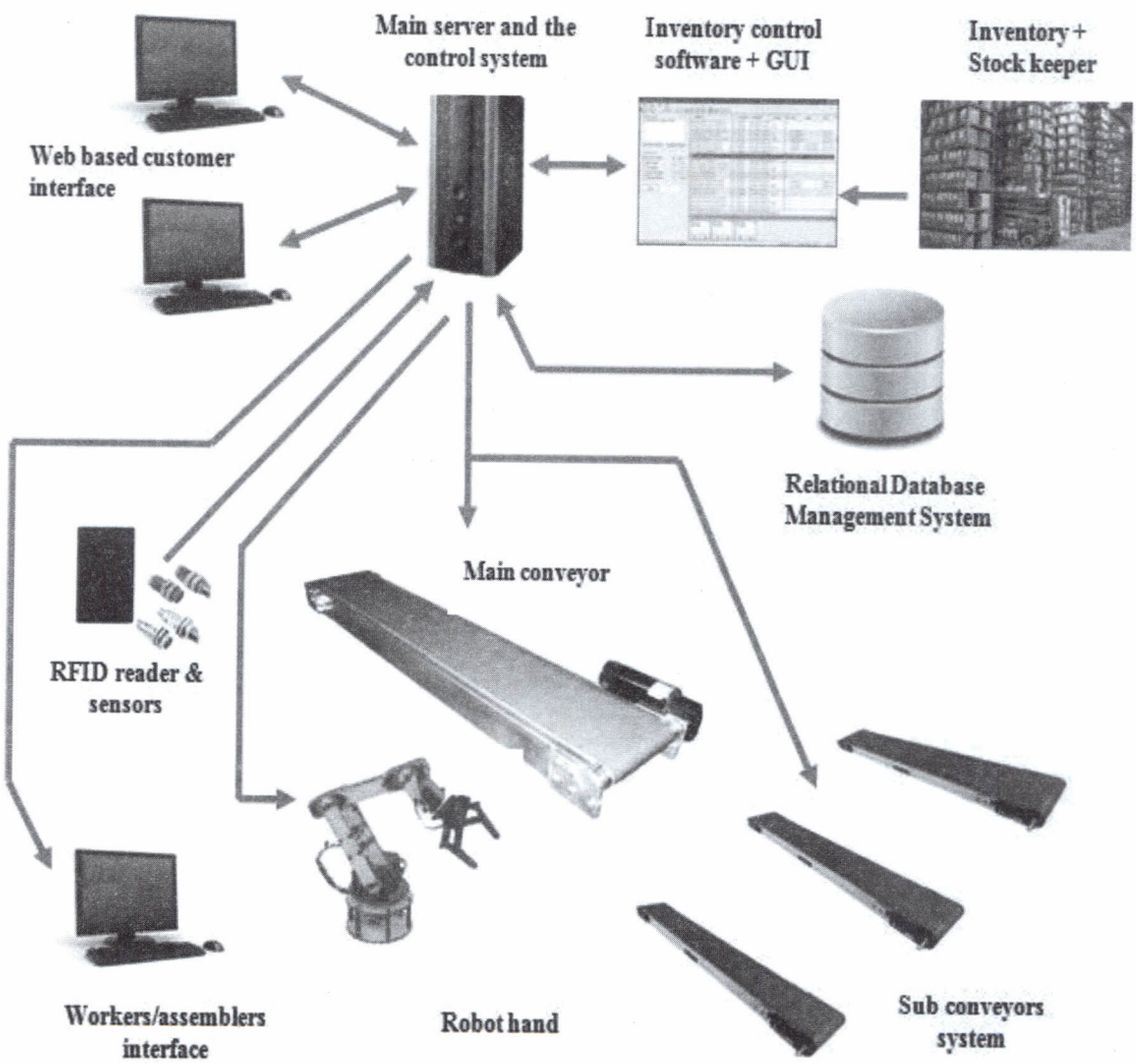


Figure 2.1: Overall system

*2.1 Architectural Framework*

Layers-

- Sensing & Product identification layer
- Processing and decision making layer
- Work-flow layer
- Application layer

Sensing & product identification layer-

The first layer is a data capturing front-end system with IR sensors and RFID transponders and transducers. IR sensors are placed at the start and end points of the conveyors which are used for the detection of product presence on the conveyors and its positions. Products are tagged with RFID transponders. Each tag consists of a unique identification number with 10digits. These identification numbers correspond to the product type and information about the product such as its price and manufacturing details. The products are identified using the RFID readers located in close proximity to the conveyors. The embedded middleware system in the RFID reader assists in the filtering, aggregation, and routing of RFID data.

Processing and decision making layer-

The captured data are classified and stored on databases which are specifically responsible for storing the manufacturing date and time (ex- expiry dates for food items), and monitoring and controlling the sorting of products respectively. According to the identified product type and details decisions are made to sort the products to the relevant sub conveyors. Also speed & position controlling signals are sent to the robot arm and the main conveyor.

Work-flow layer-

The work-flow layer is used to coordinate, manage, and integrate the processes within the system. The integration of the main conveyor, the robot arm and the sub-conveyors is the main function of this layer. When a certain product is identified, it is guided to the relevant sub-conveyor using the pick & place robot arm. The relevant sub conveyor starts functioning only after the product is identified by the IR sensor, once it is placed on the conveyor. The speeds of the three independent control zones of the main conveyor are controlled to synchronize with the working speed of the robot arm.

Application layer-

The application layer provides the necessary application interfaces for data exchange between the databases. It consists of the main server, inventory databases and graphical user interfaces. The main server integrates all the communication interfaces and is responsible for the connectivity of the smart conveyors and the robot arm.

## 3. Sub-system functionalities of the prototype

*3.1 Smart conveyor system*

In this prototype one main conveyor and two sub conveyors are designed. For the main conveyor we adopted the 'Independent zone control concept' where individual speed and direction control zones are available along the conveyor length. This enables the conveyor to adjust its speed and/or direction using the feedback gained from external factors. If a certain product item is sensed from the IR sensor but does not get identified by the RFID reader, the independent zone control concept could be effectively used to remove the item from the conveyor belt.

The main conveyor is directly linked to the RFID system. The RFID system identifies the product type and sends signals to the control system to guide the product to the relevant conveyor line using the robot hand. Simultaneously the speed of the main conveyor is adjusted to synchronize with the robot hand for the precise pick and placing of products. IR sensors are used to identify the product locations along the conveyor belts and to optimize the controlling of the conveyor speeds.

| | Main Conveyor | Sub Conveyor |
|---|---|---|
| Length | 700mm | 350mm |
| Width | 80mm | 80mm |
| Motor | 12V- Plastic geared DC | 12V- Plastic geared DC |

Table 1: Conveyor specifications

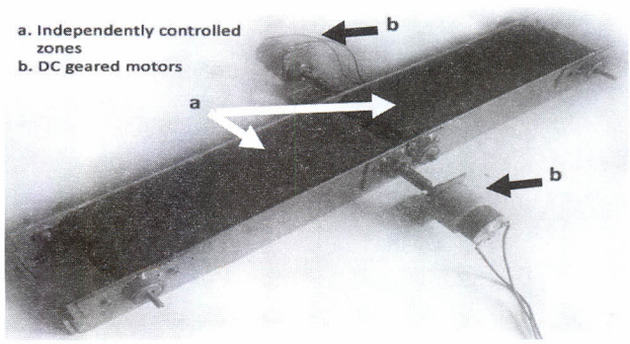


Figure 3.1: Main conveyor

*3.2 Radio Frequency Identification*

- RFID tags- The RFID transponders (tags) used for the product identification in the system use EM4100 protocol. EM4100 compatible RFID transponders carry 64 bits of Read Only memory (ROM).

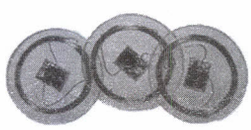

Figure 3.2: EM4100 tags

- RFID Reader- For the product identification, a Low Frequency transceiver (reader) is used with an operating frequency of 125 kHz which communicates with the main server through a USB interface. The reader supports EM4100 and EM4001 protocols which are common data formats for RFID transponders. It has a reading distance of 5-8cm. The transceiver reads the first ten digits of the RFID transponder with a communication speed of 106Kbits/s.

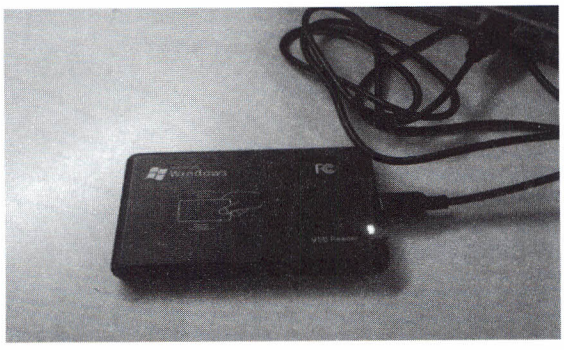

Figure 3.3: RFID reader

*3.3 Robotic Arm*

An industrial robot hand is defined as automatically controlled, re-programmable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications. In this research project we designed a robot arm with three degrees of freedom (3-DOF) and an end effecter for gripping. Each degree of freedom is a joint on the arm, a place where it can bend rotate or translate. For this application a pick and place robot with 2-DOF for the rotation and 1-DOF for the translation in the vertical direction is sufficient. The robot arm designed comprises of two linked-arms for the horizontal movement and a telescopic mechanism for the vertical movement. The free body diagram (FBD) of the robot is shown in Fig.3.4.

For the main components of the robot arm Perspex (3mm thickness) and nylon rods with different diameters were used. The horizontal movements of the robot arm are assisted by the two plastic geared servo motors (ZZTA0380) and the movement of the end effecter/gripper is controlled by a plastic geared mini-servo motor. The vertical movement of the robot arm is assisted by a 6V geared DC motor coupled to an 8mm bolt linked to the base of the robot arm. A hex nut is fixed to the robot arm base which allows the nut and bolt mechanism to assist the vertical movement. Microcontroller PIC-18F452 is used for the controlling of the servo motors and MicroC is used for the programming.

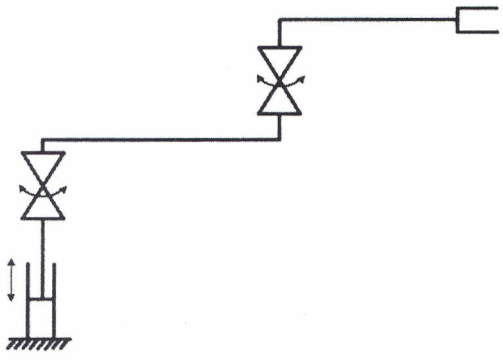

Figure 3.4: Free body diagram of the robot

- Robot workspace: The workspace is dependent on the DOF, angle/translation limitations, the arm link lengths etc. The rotation of the joints is limited to a maximum of 180 degrees and the vertical displacement of the robot arm is limited to a maximum height of 35mm. All the reachable locations of the end effecter are shown in Fig.3.5 in a 2D projected view.

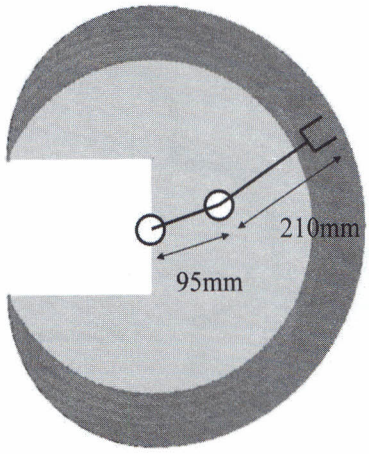


Figure 3.5: 2D view of robot workspace

- End effecter: We used a four bar linkage end effecter for the gripping mechanism of the robot arm.

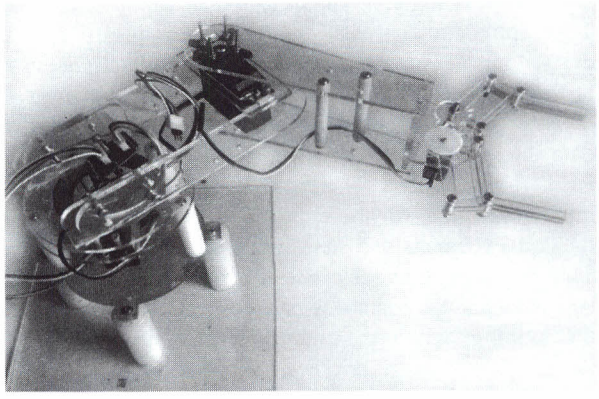

Figure 3.6: 3-DOF robot arm with end effecter

*3.4 Real-time updatable inventory database and web-based clients*

A Relational Database Management System (RDBMS) is introduced in the prototype system for the visibility of real-time updatable inventory. Through the web based interface, customers are given the opportunity to view the real-time status of the inventory stocks. This enables the customers to place orders depending on the availability of the stocks. The database server consists of specific databases such as product information, RFID tag information, availability and date/time corresponding to the products released from inventory. Also this sub-system provides a function to assist controlling and monitoring of the inventory stocks. If the stocks are below a pre-defined level, a warning is displayed in the user interface provided to the administration. This helps to prevent stocks from running out and maintain safety stocks.

For the communication between the RFID reader and the main computer a Java client application is developed to write data through the Human Interface Device (HID) to the Relational Database Management System (RDBMS). Once the order is placed via web-client, the php server is notified through http POST message protocol.

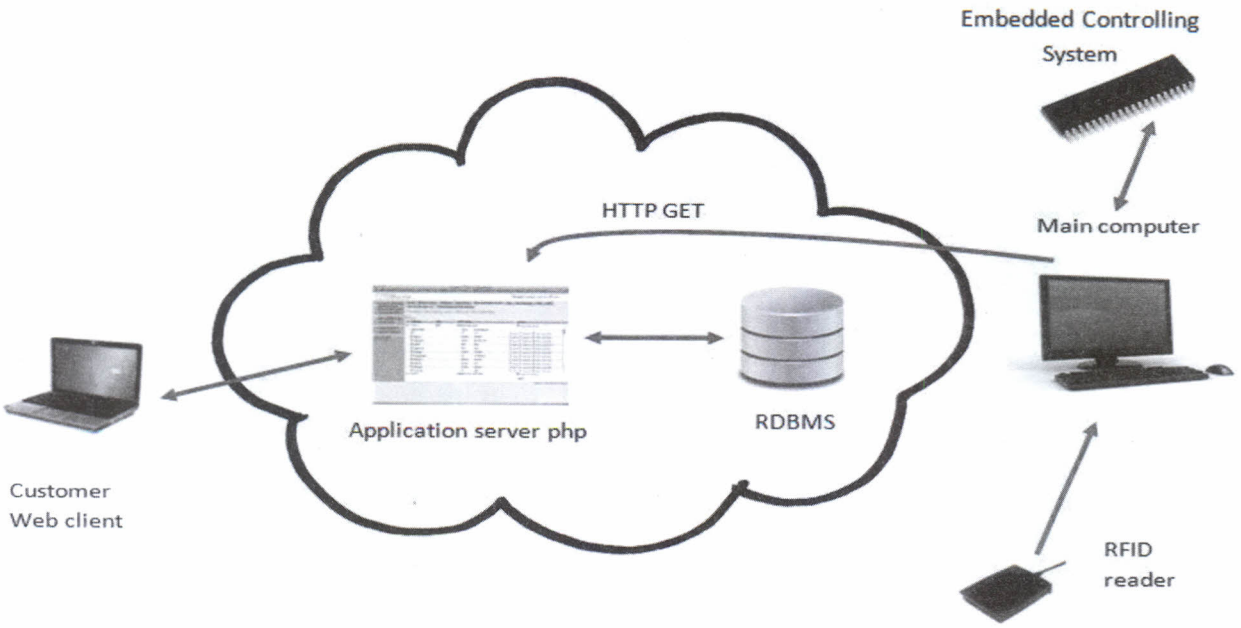


Figure 3.7: Communication methodology

The business logic is implemented in a php application. This application processes the http requests and the desired business logic is invoked and the database system is updated accordingly with the current status of the inventory stocks. The client application can request this data through the php server and display them. When the RFID reader reads a value, the embedded system activates the control logic for the controlling of the robot arm and the conveyor belts and sends a message to the php server. This message is again processed by the php application and updates the database system. The communication methodology within the main system is shown in Fig 3.7.

## 4. Results and Discussion

Adopting Radio Frequency Identification technology for a manufacturing industry promotes Flexible Manufacturing System (FMS). This enables a paperless working environment and real-time traceability of products within the shop-floor which improves the operational efficiency and reliability. In this paper a FMS is introduced with a smart conveyor system which adopts RFID technology for product identification and handling. In the system introduced, RFID technology assists a smart conveyor system, a 3-DOF robot hand and a real time updatable database with web based applications. The main advantages of using RFID technology could be identified as,

- Real-time updatable inventory with stock records

An accurate real-time updatable inventory is an important factor in managing a Just-in-time (JIT) production module. The RDBSM introduced in this prototype system provides up-to-date stock information on the components available in the inventory. This provides real-time visibility of the overview of stock levels which in turns reduces the possibility of running out-of-stock.

- Tracking the real-time consumption

The automated data capture using RFID and the real-time updatable inventory, enables tracking of real-time consumption and removes the human factor in track-and-trace operations. This improves the efficiency of the manufacturing environment.

- Demand forecasting

Using the statistics available in the system, the administration is able to forecast the demand for future production.

Though RFID technology, conveyor systems, robot hands and database management systems are already being used in the industry as individual systems, the overall system introduced in this paper which synchronizes the RFID technology, the SCS, the robot arm and the inventory system with web based applications is a novel concept of advanced manufacturing technology (AMT).

One of the main contributions from this project is the smart conveyor system linked with the robot arm, where the robot arm adjusts its movements using the feedback gained from the smart conveyors. The 'independent zone control concept' is introduced through the intelligent conveyor system equipped with RFID technology and optical sensors. This enables controlling of particular areas of the same conveyor along its length.

As further improvements, PDA with bar-code/RFID functions, handheld smart devices and GSM devices which can communicate with mobiles, etc. could be introduced to the manufacturing system. Real-time WIP inventory monitoring and production exceptions alert systems could be developed as well. In this paper passive RFID transponders were used for object identification. The overall system could be developed at a higher level by the adoption of active RFID tags. Also the system could be further developed with a real-time product traceable system for a supply chain industry where both the customer and the supplier are able receive the real-time location and status of the products in the supply chain, which benefits both the customer and the supplier.

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# A socio-cultural analysis of building and improving safety culture: A case of the marine industry in Sri Lanka

Prasad Manjula Hettiarachchie

## Abstract

*The aim of this study is to determine the influential power of some cultural and social factors which could uplift the safety culture in the Sri Lankan marine industry and to examine the underlying factors which contributed to evolve safety in the marine sector. Such a study is timely as far as current trends developing in this industry are concerned. The researcher used a questionnaire to collect data from 101 employees attached to three key organizations of the Sri Lankan marine industry. The quantitative data collected from the questionnaire were analyzed in order to identify the trends and their significance. The questionnaire consists of five key parameters which were widely used by previous researchers for their safety culture related studies. The analysis of the response to the above factors confirms that the marine industry in Sri Lanka had been able to establish a positive safety culture although there are some areas which need close attention and improvement. Top management commitment to safety is one key area which achieved a higher level of satisfaction while areas like risk communication, employee empowerment, risk perception of employees are some of the areas which are not at par with the required level. It is also noted that trade union support to make the working environment safe is relatively poor and employees' risk acceptance level is high. It is also noted that the peer-pressure against unsafe acts and legal framework against Industrial safety also are not in a satisfactory level.*

## 1. Introduction

Many organizations invest a considerable amount of money to improve their safety performance. But it is quite questionable whether they are getting the expected return for that investment. Similar kinds of accidents due to the same errors or mistakes are very common. "It is relatively unusual for new types of accidents to occur on board and many of those that continue to occur are due to unsafe acts by seafarers. These errors, or more often violations of good practice or established rules, can be readily avoided. Those who make them are often well aware of the errors of their ways. They may have taken short-cuts they should not have taken. Most will have received training aimed at preventing them but, through a culture that is tolerant to the 'calculated risk', they still occur." (IMO, Safety culture) [1]. This is very much applicable to the Sri Lankan marine organizations as well. So the aim of this study is to understand what socio-cultural factors drive this situation and how to improve the safety culture to improve the situation.

### *1.1 Background*

Sri Lanka is an island situated in close proximity to major shipping routes connecting South Asia, the far east and the Pacific with Europe and the Americas. It is also strategically very impo[1]rtant because it is very close to the fast growing economies of the Indian sub-continent and also close to Southeast Asia. With a view to leveraging this geographical advantage for the country, the Sri Lankan government has launched multidimensional development programs to fortify the marine industry in Sri Lanka. There are a few proposals to build new dry-docks and also to start ship breaking in Sri Lanka as well. Apart from all this, offshore oil drilling, which started in the year 2011, intensified the marine involvements of the nation to a great extent. Due to all these reasons engagement of people in marine related activities are expected to increase rapidly in the next few years.

Many researchers and scholars believed that 80% of accidents are due to human factors. It is interesting to see the trend in marine industry because the human error contribution for marine accidents is also 80% [2]. In a report on Deepwater Horizon, the author suggests that approximately 80% of the failures are rooted in Extrinsic Uncertainties (human and organizational performance, knowledge acquisition and utilization) and only the balance 20% of the failures are rooted in Intrinsic Uncertainties (Bea, 2010, pp.1) [3].

Therefore, it is fairly understandable that in order to uplift the safety performance in the marine industry, greater attention has to be given to the human factors for the reason that merely investing money to develop infrastructure or equipment itself may not achieve the desired outcome. Therefore, it is timely to study human factors in the Sri Lankan marine organizations.

According to the discussions we had so far, it is clear that Sri Lanka has been rapidly increasing its marine related activities. Given such a background the study of human factors is crucial to promote safety culture in marine organizations as the influence of the human factor in accidents is as high as 80%. With this background, this study attempts to understand the safety culture in Sri Lankan marine organizations and its underlying social and cultural factors which could help to uplift the safety performance. The outcome of this study may contribute to further studies in this discipline and help establish a strong safety culture in Sri Lankan organizations which could really benefit all stakeholders in the society because it may save human lives and prevent occupational hazards to employees, which is the most crucial production factor.

The objectives of this study are three fold, namely:

I. to examine the underlying factors which contribute to improving safety culture in marine industry in Sri Lanka.

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II. to determine the relative influence of some social and cultural factors which could uplift the safety culture in the Sri Lankan marine industry

III. to understand the barriers and lapses in creating a positive safety culture within marine organizations in Sri Lanka

*1.2 Literature review*

Immediately after most of the accidents, we often tend to claim that the root cause for that incident is a human error or a technical failure. Of course, the proximate cause for the failure might be one of the above two factors. But with a deeper insight into the facts, it may not be difficult to understand that the real cause for the accident was not merely a straight forward human error but instead a failure of the entire system itself. As pointed out the circumstances surrounding major accidents such as the Texas oil refinery accident, the loss of the shuttles Challenger and Columbia, and various civil engineering, transport and nuclear incidents have revealed issues beyond the immediate causes (Safety culture, 2010, pp.2) [4]. Yet for all, issues beyond the immediate causes could be connected to have been the lapses of human factors across the organization.

The Swiss cheese model of Reason [5] provides a clear insight into the above discussed situation. According to the model, injuries or incidents do not occur just because of the failure of the last level of defence. Every system has latent failures (or pathogens). Due to the imperfections in individual safeguards or defences these pathogens sneak through all defences and trigger the active failure. According to Reason [5] causes for both active and latent failures are introduced by organizational or managerial factors (top management decision making) but individuals (psychological or behavioral precursors) trigger the active failure [6]. Therefore, it is quite clear that accidents are not just because of a single failure of defence or a human error, but rather it has a much broader and wide-spread perspective. Therefore, in the recent past, most accident investigation reports have made use of term "safety culture" to describe the big picture of the failure instead of individuals.

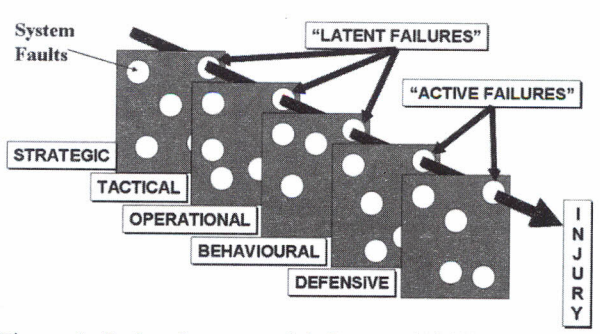


Figure 1: Swiss cheese model, Reason (1990)

The term "safety culture" was introduced by the International Atomic Energy Agency (IAEA) as a result of their first analysis into the nuclear reactor accident at Chernobyl [7].Since then, this term and concept has become more popular in society as many accident review reports after Chernobyl have used this term to discuss a broader range of shortcomings in organizational climates which could lead to final failure. However, still there is no universally accepted single definition for the term "safety culture". The definition given by the Advisory Committee on the Safety of Nuclear Installations (ACSNI) is the most accepted one and it says that: "Safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management". It further says that "Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of preventive measures" [8].

As indicative in the definition, safety culture necessarily should have a shared perception of importance throughout the organization. This has been clearly explained by Cooper [9] in his business process model of safety culture.

According to this model the inputs (different attributes such as safety values...etc) to any system are processed by a combination of the company's goals and management practices and transformed into the safety culture, the product or output. By proposing this model Cooper [9] emphasizes that, it is clear to organizations how they should have best managed their inputs to the system in view of achieving the desired outcome or level of safety culture[9]. The most important implication of Cooper's [10] model to this study is that, it says outcome is "observable degree of effort which all organizational members direct their attention and action towards improving safety on a daily basis." As such safety culture can be measured via "observable degree of effort" of employees in that organization.

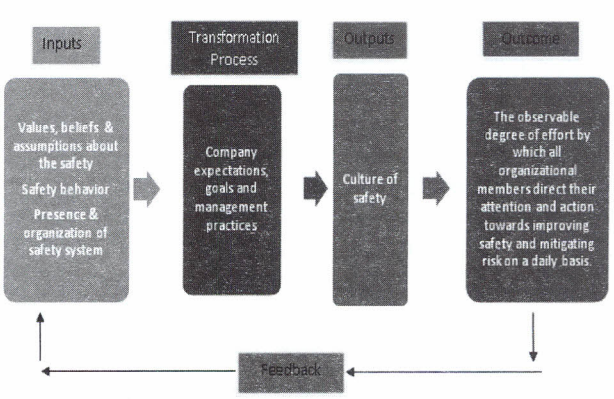


Figure 2: Business process model of safety culture [9]

According to the Bandura's model [11] of reciprocal determinism derived from social cognitive theory, an individual's behavior both influences and is influenced by personal factors as well as the social environment (Figure.3). Therefore, the social environment and personal factors play an important role in determining safety culture in an organization.

Bandura's [11] model was later used by Cooper [10] to develop a concept for measuring and quantifying safety culture in organizations in his study of "Surfing your safety culture". He termed it a reciprocal safety culture model and he redefined "Person" in Bandura's model as

Safety climate (perceptual audit) and "behaviors" as Safety behavior (Behavioral safety). He replaced the word "environment" in Bandura's model with "Organization" and considered how the safety system is organized [6]. Therefore, the concept developed by Cooper simplifying Bandura's model had facilitated safety culture related studies.

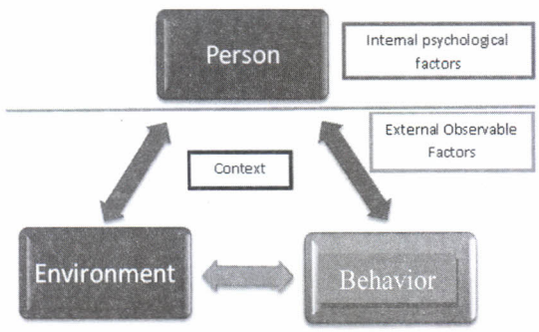


Figure 3: Bandura's (1986) model [11] of reciprocal determinism

So, as it is clear that safety culture can be measured by external observable factors, let us try to identify, what those factors are and how effectively they have been used by previous researchers.

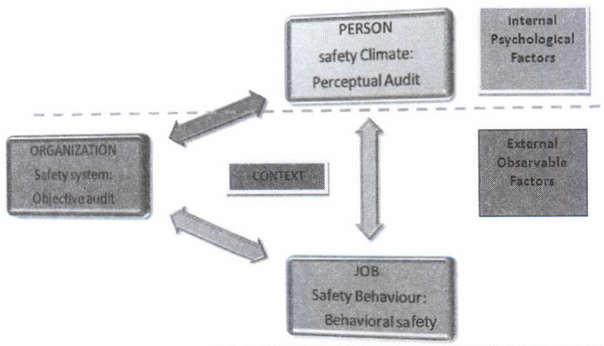


Figure 4: Cooper's (1993) [10] Reciprocal safety culture model

Same as the definition of the term "safety culture", different researchers and scholars used different combination of factors to measure safety culture. Currently, there are no standardized or "off the shelf" tools that can be used across domains or even within a single domain to measure safety culture. However, a variety of methods or tools have been proposed (Wiegmann et al., 2007, pp.8) [12]. In the next few paragraphs we have discussed some of the parameters used by different researchers for their studies which are considered in preparing the questionnaire in this research.

Pidgeon and O'Leary [13] argued that, "good" safety culture may reflect and promote four factors namely: senior management commitment to safety, realistic and flexible customs and practices, continuous organizational learning and care and concern for hazards which are shared across the workforce.

In a very recent study on safety culture evaluation in the metal products industry of Iran, the research group used five variables to measure safety culture, namely, organizational commitment, management involvement, employee empowerment, reporting system (that can prevent many occupational accidents) and finally the rewarding system which reflects how safe behaviors are appreciated (Ooshaksaraie et al, 2009a, pp.162/163) [14].

In a review of safety culture theory, Wiegmann [12] and his fellow researchers proposed four indicators to measure safety culture. The first indicator is organizational commitment. This is the level of top management's commitment to the safety in strategic level decision making and allocation of resources to ensure safety. It consists of three components (i) Safety Values—attitudes and values expressed in both words and actions by upper management regarding safety, (ii) Safety Fundamentals—compliance with regulated aspects of safety, such as training requirements, manuals and procedures, and equipment maintenance, and (iii) Going Beyond Compliance—priority given to safety in the allocation of company resources (e.g., equipment, personnel, time) even though they may not be required by regulations. The second indicator is operational personnel, which refers to the people who are directly engaged in supervising employees' behavior, and how best they reinforce the safety values created by the top management. The third indicator is the formal safety system which denotes how well the reporting mechanism of the organization on occupational safety and process safety hazards are functioning and how well the reported issues are addressed. This includes the status of the formal safety system and status of the personnel in the safety system such as a Safety Officer. The last indicator is the informal safety system which considers about unwritten rules of the organization and how the organization responds to safe and unsafe actions of individuals by means of rewards and punishments (Wiegmann et al, 2007, pp.6/7) [12].

In their study of "Exploratory Study of Obstacles in Safety Culture Development in the Construction Industry", Kulchartchai and Hadikusumo had considered seven factors which restrict the implementation of a strong safety culture in the construction industry. We are not discussing the first two factors as they are specific to construction industry but starting with the 3rd factor: (iii).Problems related to the use of subcontractors: just as in the construction industry, in Sri Lankan marine organizations there are a significant number of subcontractors working due to fluctuation in the work-load. (iv).Problems related to supervisors and workers: they are the people who are really involved in the production process. (V).Problems related to communication: communication plays a vital role in safety culture because communication gaps often lead to accidents. (vi).Problems related to reporting: a strong reporting culture is a must to create a safe working environment. Instead of accepting minor incidents as "just part of day's work" those incidents have to be promptly reported. (vii).Problems related to a blame culture: blame culture affects most of the other factors of the safety culture. Due to the existence of a blame culture people tend not to report what they observed as hazardous [15].

In a separate study on safety-culture in a Norwegian shipping company, Håvold used a different scale with the following factors: management and employee commitment to safety, safety norms and compliance to

rules and occupational risk behavior, workload and work pressure/stress, fatalism, knowledge/competence, espoused safety values, degree of conflict between safety and work/priorities, reporting culture, work appreciation, officers' awareness of risk , learning culture/learning from accidents/organizational learning, safety communication, actions based on accidents, perception of safety instructions, work itself, and safety behavior [16].

The important observation of the above research which is related to this study is that the study confirms that different nationalities have different perceptions towards safety and quality themes. Further, it is pointed out that in situations where national and organizational culture are in harmony there are no stress factors that can influence safety, but in situations where the values in the national and the organizational culture are in conflict, this might lead to stress and influence safety [16].

According to the study of Helmreich and Merritt[17], culture forms a complex framework of national, organizational and professional attitudes and values within which groups and individuals function. The focus groups of this study are professions in aviation and medicine. In these two environments, they have shown the effects of professional, national and organizational cultures on individual attitudes, values and team interactions.

Considering all factors/indicators discussed so far to measure safety culture, that is 4 factors of Pidgeon and O'Leary's [13], 5 variables considered by Ooshaksaraie et al. [14], 4 indicators of Wiegmann [12], and 7 factors of Kulchartchai et al. [15] the researcher has developed a questionnaire under six main topics considering the applicability and importance of each factor to the marine industry of Sri Lanka. This will be further discussed under the methodology section of this paper.

## 2. Methodology

This study was carried out based on three major marine institutions in Sri Lanaka, namely Colombo Dockyard Plc (CDPLC), Sri Lanka Ports Authority (Colombo port) (SLPA) and South Asia Gateway Terminals (Pvt) Ltd (SAGT).

For this study the researcher has adopted a mixed methodology, which is a combination of both qualitative and quantitative approaches. Safety culture in the marine industry is an area where there are no previous research been done in the Sri Lankan context. Therefore, the underlying factors are not clear and hard to predict. As such a questionnaire was administered to collect data.

### *2.1. Why is a questionnaire appropriate?*

As indicated, in most cases employees are reluctant to give their genuine comments in face to face interviews. The Sri Lankan culture usually does not encourage people to be outspoken. Especially, they do not criticize their superiors and prefer instead to be rather polite and obedient. Therefore, the possibility of getting their genuine ideas via face to face interviews is very remote. This is one of the reasons for administering a questionnaire to collect data for this study.

Secondly, most of the time, these organizations have many hierarchical levels (up to 7 from MD/CEO to shop floor employee). Therefore, shop-floor-level people may not be able to perceive the top management involvement and attitudes at once. Asking questions or interviewing will make this perceptional error more significant than providing questionnaire where respondents have sufficient time to think deeply and freely before answering.

The third reason for using the questionnaire is that in most of the Sri Lankan organizations the blame culture still exists. Therefore employees are reluctant to express their real experiences due to the fact that accepting or disclosing their own mistakes could affect them adversely. This is quite evident when going through the previous accident cases, where top management was always trying to trace the one who was responsible for the last level of defence or the one who triggered the active failure, instead of identifying latent failures of the system as a whole.

So far we have discussed practical reasons for selecting the questionnaire option for this research. From a theoretical view point, many scholars accept questionnaires as a better tool for research work. Gillham [18] gives a list of nine advantages of administering a questionnaire for research work, which include some of the points mentioned above. Those nine advantages are: Low cost in time and the money, easy to get information from a lot of people very quickly, respondents can complete the questionnaire when it suits them, analysis of answers to close questions is straightforward, less pressure for an immediate response, respondents anonymity, lack of interviewer bias, standardization of questions (but also true for structured interview), can provide suggestive data for testing an hypothesis [18].

He also says that "...but it is nevertheless uncommon for social psychologists to use behavioral or even behavioroid data. Instead, they rely very heavily on the rating or scale. Occasionally, it may be impossible to get anything more, but we feel that it is seldom the case. All too often, it appears that the questionnaire is chosen because it is simpler to concoct and easier to administer" ) [19].

In addition to that there are many previous researchers who have used questionnaires for their studies, a few of which we have discussed under the literature of this paper. Therefore considering all the above facts we decided to use questionnaire as the tool to collect data for this research work.

### *2.2. A mixed mode methodology*

Due to the fact that this research is dealing with a broad scope, the researcher used a mixed methodology approach for this study. Both quantitative and qualitative methods are used as appropriate to achieve the highest possible success in the study. This decision has been influenced by some of the previous studies and literature.

Citing the previous research work of Wreathall [20], Wiegmann and Thaden [12] made the following statements in their research to emphasize the appropriateness of utilizing mixed method for safety culture researches. "There is a general consensus among

researchers that both qualitative and quantitative methods have unique potential for assessment and theory testing. There is a benefit to combining methods to gain a comprehensive understanding of safety culture. Nonetheless, quantitative approaches, especially surveys of individuals' responses, are often more practical, in terms of time and cost-effectiveness" [12].

### *2.3. The questionnaire*

As discussed under literature review, the questionnaire development has been done mainly based on the questionnaire which had been used by the previous researchers discussed under the literature review. The researcher has selected the above studies and factors considering the relatedness of those factors to the marine sector and measurability in local context. In addition, 25 different definitions for safety culture summarized by Wiegmann and Thaden [12] is also considered.

The questionnaire was developed under 6 main topics namely; Safety culture evolution, Socio-cultural dimensions, top management commitment, employee empowerment, risk communication, employees' attitudes and behaviors.

Each topic starts with a yes/no question and then the questions move to 5-point Likert-type response scale to capture the level of agreement of respondents to certain areas. Finally it moves to open-ended questions enabling respondents to give their own views.

### *2.4 Field work*

The first step in data gathering was distributing the questionnaire to respondents and explaining the content in a face to face dialogue. After explaining the questionnaire, the respondents are allowed to complete it of their own, without any interference from other including the researcher. Finally feedback was collected from 35 employees from CDL, 33 employees from SLPA and another 33 form SAGT. This group of respondents in each organization consists of senior managers, engineers, foremen/supervisors and grassroots-level employees.

The quantitatively collected data were summarized and their mean values calculated. The summary of the questions with Yes/No answers were presented as percentages.

## 3. Data analysis

The following tables and graphs show the summary of quantitative data collected through the questionnaire.

### *3.1 Q1: Evolution of Safety in last 20 years*

The objective of the first question (Q1) is to examine the underlying factors which contributed to evolve a safety culture in the marine industry in Sri Lanka.

Responding to the question "Do you think that the safety of your organization had been improved during the last 20 years?" 100 respondents (that is 99%) answered "yes" giving strong evidence that they believe that safety has improved in their organizations during the last 20 years.

The following bar charts (Figure 5) show some of the areas developed during the past in working environments. Usage of personal Protective Equipments (PPE's) and knowledge of employees on safety are the two key areas improved representing 96% and 91% respectively while trade union support was the area where improvement was minimum, only 47%.

Answers to the next part of the question, "what are the factors that influenced these changes" are presented in Figure 6. According to the feedback, employees' knowledge and understanding about the importance of safety is the most significant factor for improving safety in the industry (78%), followed by the changes in top management (76%). The changes in national laws made the least contribution (54%) to the above mentioned development. Trade union impact on improving safety is the second from the last (59%).

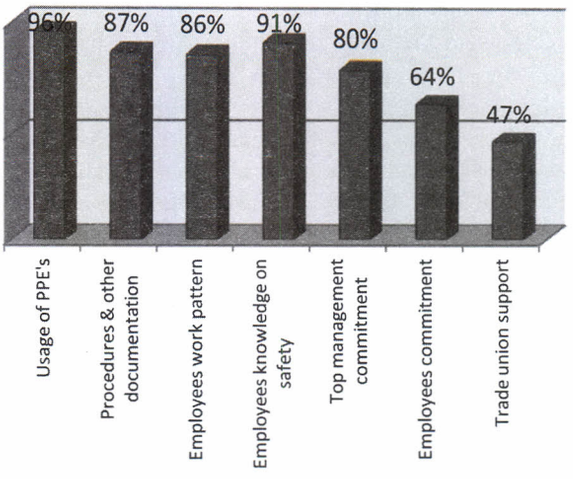


Figure 5: Areas improved in last 20 years

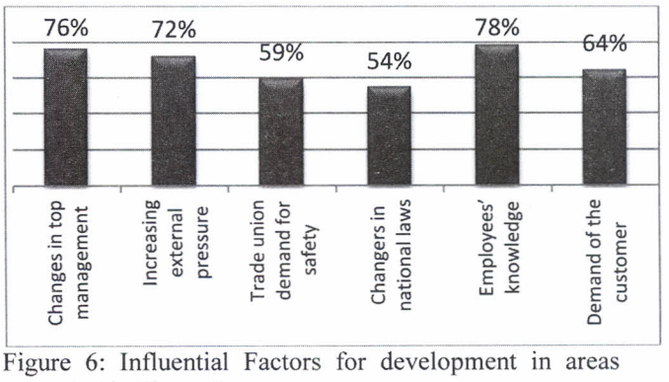


Figure 6: Influential Factors for development in areas presented in Figure 5

The Figure 7 illustrates the summary of the last part of the first question. The questionnaire provided a five point Likert scale as shown in the table below to record the response of the employees.

| Extremely poor | Poor | Moderate | Good | Excellent |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

***Table: 1, Likert scale provided for questionnaire***

According to Figure 7, all three factors were exceeding the midpoint of the Likert scale that is 3, but none of them reached the next level to be considered as "good". The chart also suggests that, increase of employees' competency level is more significant than the other two factors. It is also interesting to note that respondents

believed that evolution of top management's attitude towards safety is more significant than that of other employees.

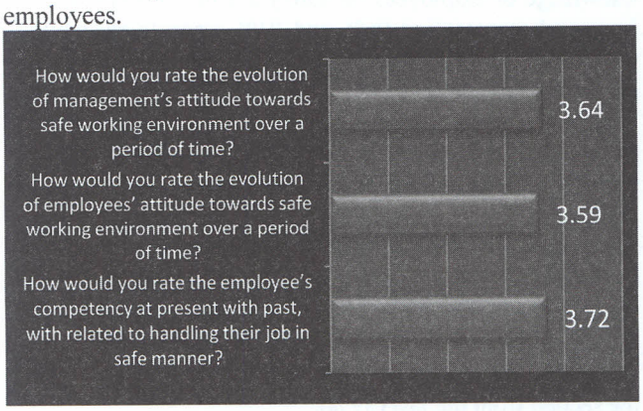


Figure 7: Rating of Management attitude, employees' attitude and competency level

*3.2 Q2: social and cultural dimensions*

The aim of this question is to understand the social and cultural dimensions which could affect the safety culture of the working environment. The outcome of the response is summarized and presented in Figure 8.

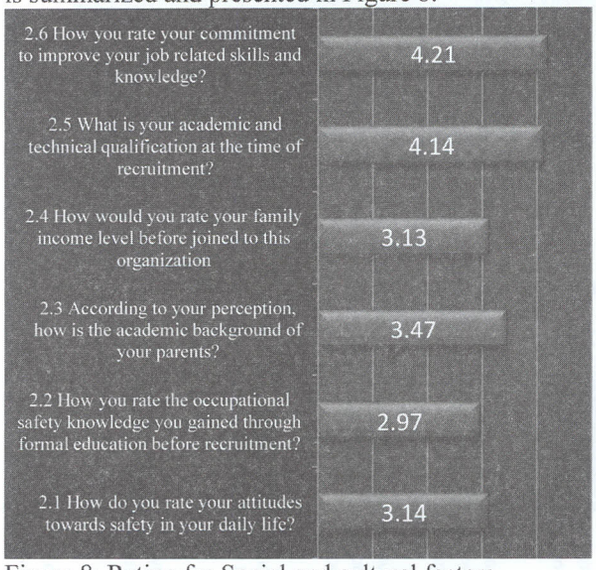


Figure 8: Rating for Social and cultural factors

According to the graphs, individuals are highly motivated to improve their job related skills and knowledge. Also it is important to notice that their academic and technical qualifications are higher. The value 4.14 means that the average qualification of an employee is equal to GCE A/L (as per the scale given in questionnaire) which can be considered a high academic standard and it implies that, as far as formal education is concerned the new generation is ahead of their parents as they rated their parents level of education as 3.47. The family income of an average employee is just above the average value before they joined the industry, which can be explained as most employees are from middle class families as far as the family income is concerned.

The formal education system of the country has not given much emphasis on safety because the overall rating for question 2.2 is 2.97, which is below the midpoint of the scale, and close to "poor". The respondents' attitude towards safety in day to day life is also around the midpoint which means they are not much concerned about safety in their everyday life, which could have influenced their organizational performance.

*3.3 Q3: Top management commitment*

It is interesting to note that 80% of respondents believe that top management is committed enough to create a safe working environment in their organizations, which is quite a high percentage with compared to employees' commitment (64%) and trade union support (47%).

The second part of the questionnaire enquired about some key responsibilities of the top management to confirm the above response of the respondents. Figure 9 represents the summary of the responses for those 4 questions, which suggest that other than the Safety Committee, the rest of the functions are around 3.5 which can be considered as reasonably good. However Safety committees are a key requirement in many safety Management Systems including OHSAS18001. According to the feedback, the effectiveness of safety committees in marine organizations in Sri Lanka is significantly low. This outcome is quite comparable for all three organizations.

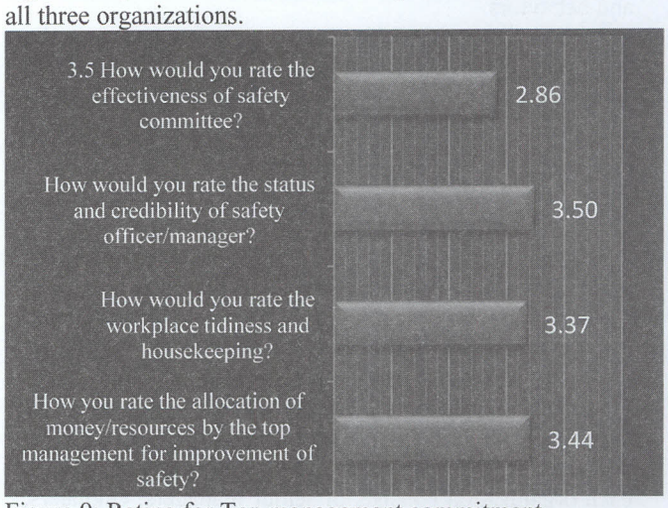


Figure 9: Rating for Top management commitment

*3.4 Q4: Employee involvement and Empowerment*

The next parameter used to measure the safety culture is employee empowerment/involvement. 65% of the sample group believes that the employees are empowered and they are involved in important safety related decision making.

Figure 10 illustrates the responses for 3 questions by the sample group. As per the first graph employees are quite confident about their level of knowledge, which scored 4. Compared to the employees' competency level, job pre planning, which is the second bar chart with value 3.49, is of a lower standard. The last bar chart which represents the employees' empowerment is the lowest one with 3.34 on Likert scale.

While 65% of respondents agreed that employees are involved in safety related decision making, this graph indicates that the level of empowerment of employees is very limited and may not be sufficient to make a significant impact on the decision.

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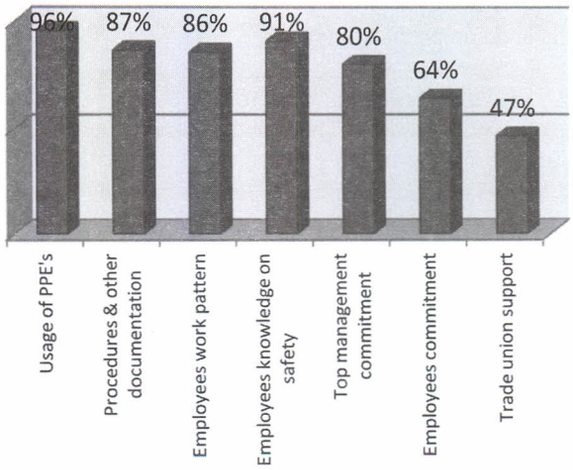


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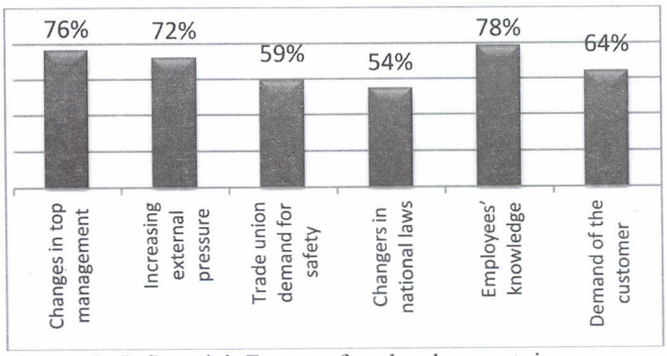


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contribute to improving safety culture in the marine industry in Sri Lanka". It is quite clear that most of the safety performance indicators in the Sri Lankan marine industry have improved significantly during the last 20 years. However, it is understood that the trade union support and employees' commitment has not developed when compared to other areas like top management commitment, usage of PPEs, documentation... etc. It was found that the improvement of employees' knowledge, changes in top management, customer demand and increasing external pressures on organizations for safety are the key underlying factors for the above mentioned developments. Here also the trade union role is not significant.

The second objective of the study was "to determine the relative influential power of some social and cultural factors which could uplift the safety culture in the Sri Lankan marine industry". It was understood that people are not very safety conscious in their day to day life and it was also noted that their level of risk acceptance is high. Therefore it is reasonable to conclude that employees are ready to take a high level of risk in their jobs. It is also noted that peer-pressure to prevent their colleagues from performing unsafe acts are not strong. Respondents rated them as reluctant to change and the flexibility of working customs is limited. This gives an indication that people are reluctant to give up their way of doing things although it is not very safe.

However a majority of employees are from middle class families with a higher educational background and they still have the willingness to continue their education. This is one key factor for the historical evolution of safety in this industry. Marine being an industry which is highly globalized, social pressure to achieve higher safety standards are obvious.

The third objective of the study is "to understand the barriers to and lapses in creating a positive safety culture within marine organizations in Sri Lanka". Unavailability of sound and updated regulatory infrastructure for industrial safety standards is identified as one key barrier to the development of safety culture in Sri Lankan organizations. It is also noted that safety is not included in the formal education system and safety education has not been promoted in the past. External pressures to uplift the safety performances, like customers and factory inspecting engineers are basically directed to the top management. But the impact of that pressure does not pass to the shop floor level employees and hence their commitment to improve the safety of their working environment is minimal.

There is enough evidence to prove that top management commitment to create a safe working environment exists, but that commitment is not reflected in the middle level management of these organizations as the mechanisms like safety committees are not properly functioning. Therefore the top management should have a holistic approach to overcome this hurdle, which is a big barrier to developing a safety culture. We also noted that trade unions are not providing enough support to the development of a safety culture.

Bottom up communication in these organizations are significantly poor due to the non-existence of a no-blame culture in their organizations. This is a big barrier to improving safety because most of the important information does not reach the top level decision makers. High level of risk acceptance of employees is also making a negative impact on safety culture.

The researcher used five main safety-culture parameters which have been used by various researchers to measure the same in organizations for many years. According to the data analysis the overall rating (mean) of socio-cultural dimensions is 3.5. Although the effectiveness of safety committees is not very sound, 87% of respondents believe the present top managements are committed to safety. 65 % of the participants are satisfied with the level of empowerment of employees. However it is highlighted that the trade union support for improving the safety culture is not sufficient. Level of risk communication is accepted by 61% of participants which is one of the areas to concentrate on for improvements. The final key point, attitude to risk, is one area which is assessed significantly low. The results proved that employees are taking risks due to various factors. However considering the overall result the researcher would like to conclude this discussion by proposing that the safety culture of the marine industry has significantly improved in the recent past and at the moment it is well established. However there are a few areas to concentrate and improve with a view to making it stronger.

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