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A Holistic Team Approach (HTA) Model to Curb Machinery Accidents in Power Plants

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Machinery accidents have been an important aspect that needs proper attention in all work places in recent years especially power plants. A large number of accident cases have been reported from the year 2018 to 2022. Accident report from DOSH (Department of Safety and Health Malaysia) indicates that a significant number of machinery accident cases occur in power plants while PERKESO (Social Security Organisation Malaysia)has investigated and tabulated accidents based on area of workplace and injury. Research shows that most statistical studies do not comprise of a preventive model to curb machinery accidents, which involves employees and management. A model that comprises of Machinery or Area of work (M) and the type of injury (I) is identified and summed in a form of a scientific equation which results in the possible accident type (α) which is the accident occurred. A Holistic Team Approach (HTA) model is designed that involves a team for each element M and I which comprises of engineers, technicians and operators working in the same area of equipment and a management representative. Each team is assigned to specific accidents according to the M and I element and classified as α-combinations. Teams are sent for incident investigation where preventive actions and reporting are discussed. A decision analysis is performed based on the model that emphasizes two Process Safety Management (PSM) elements which are accident investigation and employee participation. The HTA model is able to reduce machinery accidents by involving the elements of machinery and injury types, which is applicable to workplaces worldwide.

Keywords: Employee, Injury, Management, Occupational safety, Process safety

Introduction

The Malaysian Government drafted and initiated the Occupational Safety and Health Act (OSHA) 1994 to strengthen the safety and health laws of the country prior to major accidents that occurred i.e. the Sungai Buloh Incident.[1] The Factories and Machineries Act (FMA) 1967 was the main reference for safety in Malaysia before OSHA 1994 was enacted, which covers only mining, manufacturing, construction and quarrying industries. OSHA 1994 includes all sectors except armed forces and ship boards which are covered within their own rules and regulations.[2]

FMA 1967 and OSHA 1994 are the two major regulatory acts that are utilized till today, with improvements being made within the act to suit the ongoing safety and health issues, especially the replacement of Occupational Safety and Health (Classification, Packaging and Labelling of Hazardous Chemicals) CPL Regulations 1997 to The Occupational Safety and Health (Classification, Labelling and Safety Data Sheet of Hazardous Chemicals) CLASS Regulations 2013, which advances the chemical safety and health of hazardous substance usage in workplaces.[3] However, the accident rates in Malaysia are still on a substandard level which can be enhanced further. The number of industrial accidents and the accident rate per 1000 employees reported in Malaysia from the Year 2018 to 2022 are shown in Fig. 1.[(4)]

The number of accidents has mostly increased every year, ranging from 5000 cases to 7000 cases, with a total of 33031 cases from the year 2018 to 2022. The accident rate is also a perturbing factor despite the decrease in the year 2020, which involves machineries in industries as well. Machinery accidents affect the standards of machinery safety in a workplace, which reduces productivity and efficiency.[3] Machinery safety includes the equipment

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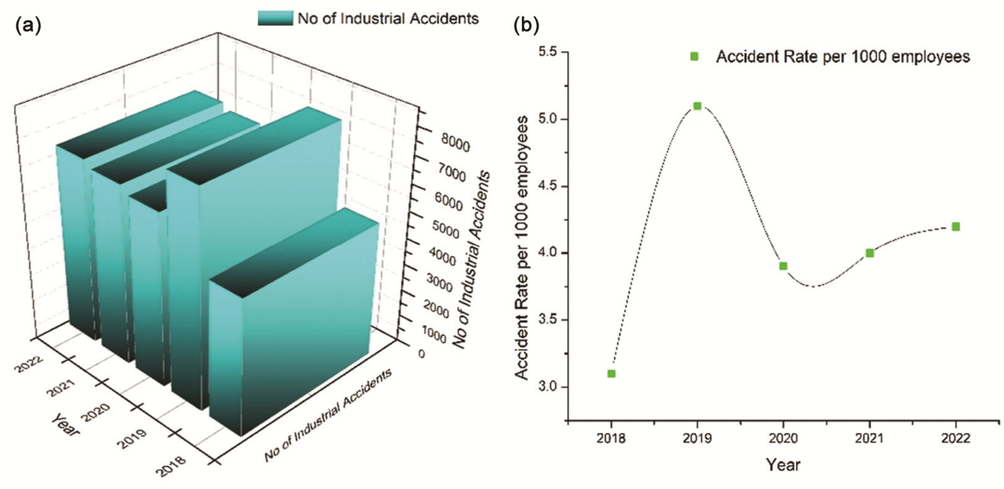

Fig. 1 — Total number of accidents and accident rate per 10,000 employees from Year 2018 to 2022

and machinery used in a workplace and the restrictions towards achieving the intended task. The effect of machinery usage on the output and the accident causation are also elements of machinery safety.[5] Besides, International Labour Organisation (ILO) reported that almost 2.3 million employees all over the world die from machinery accidents every year which associates to over six thousand fatality every day.[6]

One of the industries that involve major hazards in machineries are the power plant industries, which covers sixty-five power plants in Malaysia, ranging from coal-fired to biomass and hydroelectric.[7] Power plants comprise of a high number of safety critical machineries which can cause major hazards leading to major accidents. One of the major notable power plant accidents is the 1986 Chernobyl accident which caused multiple injuries and deaths.[8]

Multiple research ideas and models have been analysed and proposed to enhance machinery safety in workplaces and power plants. However, most of the models comprise of benefits and limitations as well. The earliest model is the step model by Heinrich[9] that explains the formation of an accident which starts from ancestry to the fault of a person through unsafe act that causes the accident and injures the individual. Frank Bird[10] later created the Loss Causation model which was an improvement of the step model. The model starts from the lack of control to basic and immediate causes that result in incident and loss of property or people. These chronological models are elementary and do not tackle the underlying issues of accidents, including the preventive measures that need to be taken to reduce the ongoing accidents.

Other models that involve software algorithms were proposed to reduce machinery accidents. Lu *et al.*[11] proposed a safety detection approach using adaptive parameter optimization algorithm to detect weak industrial safety practices involving machinery. Azadeh *et al.*[12] investigated the safety and health of a petrochemical plant using neuro-fuzzy algorithm to operators with the aid of Health, Safety, Security and Environment (HSSE) elements. Further algorithm studies[13–18] including Monte Carlo and Bayesian Network methods were proposed. However, the technicality and availability of software algorithms in small and medium enterprises and in low-and mid-income countries are not feasible to be applied which further involves budgeting issues.

Research that involves case studies and data formation has also been investigated in the literature. Okoh *et al.*[19] analysed major accidents in power plants and cause related maintenance to obtain the potential deficiencies of accidents. Kidam *et al.*[20] also investigated equipment design and machinery accidents through design errors and performed hazard analysis to identify the types of hazards that contributed to machine accidents. Additional research[21–26] was studied through data collection from past events and statistical departments for power plants to achieve the objective of the study. Nevertheless, most statistical study does not involve a model formation to improve the machinery safety level in a workplace.

Besides, employees are bound to work according to Standard Operating Procedure (SOP) given by the management for proper workflow. Management also plays a pivotal role to maintain the integrity of safety in a workplace. Therefore, a new approach is needed to overcome the high accidental rates in the country, especially in industrial sectors that work with hazardous equipment which includes employees and management participation. This paper analyses the elements of accident causation and aims to develop a scientific model to reduce machinery accidents in hazardous workplaces corresponding to power plants.

Materials and Methods

The statistical data is obtained from the Department of Safety and Health Malaysia (DOSH) and Social Security Organisation Malaysia (PERKESO) which are two government bodies that handle accident statistics. The data is readily available in the annual report published for public information. The DOSH report comprises of accidents in power plants. On the other hand, PERKESO handles details of accidents and has a more structural approach for wider database tabulations.

Materials

Department of Occupational Safety and Health Malaysia (DOSH) aims to reduce occupational accidents and occupational diseases by implementing proactive measures and campaigns to employer and employees in Malaysia.[27] The DOSH annual report covers the Quality Management System (QMS) of DOSH in workplaces, the effectiveness of regulatory implementations on workplaces in terms of safety and health as well as the strategic measures taken to limit accidents in workplaces.[28] The statistical data taken from DOSH Malaysia has the accident information of workplaces that occurred for each consecutive year, including the overall accidents, division of state, type of industrial accidents and the death toll. The statistical data are released to the public in the form of an annual report after eight months of filing and tabulation. The report contains more than 34000 accident records each year which are briefly tabulated and shown in graph form for quick data collection in the appendix section. The accidents that have occurred in power plants are classified in the utilities sector.

The Social Security Organisation (PERKESO) functions to manage and impose the Employees' Social Security Regulations (General) 1971 and the Employees' Social Security Act 1969.[(29)] The principal capacity of PERKESO is to give social security safety for workers and their dependants through two schemes, namely Employment Injury Scheme and the Invalidity Scheme. The Employment Injury Scheme delivers shields to personnel from work-related injuries with travel related accidents connected to work. The Invalidity Scheme gives full day protection to staff in contradiction of invalidity or fatality by reason of causes happening after working periods. PERKESO compensates the accident victims by offering cash which is claimable upon approval and application, including medical treatment and awareness programmes. The accident data in the PERKESO Annual Report comprises of accident statistics based on employees' range, relative frequency of accidents, industry type, cause of accident, location of injury and type of injury. The accidents tabulated on the type of equipment and types of injury are chosen for this study from the report.

Over the past five years, machinery accidents have covered more than 1000 accident cases per year in Malaysia. The Annual Report from DOSH Malaysia has analyzed the accidents and numbered the accidents based on actual statistics reported to the department. Accident and death rates in all power plants in Malaysia from the year 2018 to 2021 is shown in Table 1.

Based on Table 1, there is a constant increase of accidents every year, with the highest number of accidents reported in the year 2021. Note that for the Year 2019, there is an inclined increase of accidents with an increased percentage rate of 23.21% from year 2018. In the death toll section, the number of deaths is not decreasing despite multiple safety measures. Overall, the accident and death rates from the year 2018 till year 2021 demands attention for reduction and preventive measures.

PERKESO has also released the accident rates based on their annual report.[30] Accidents are all classified based on the area of workplace and injuries, which is shown in Table 2 and 3 respectively.

As shown in Table 2, the accident cases are classified based on the equipment used in the workplace. The top six equipments utilized in power

Table 1 — Number of accidents and deaths in power plants[4]

No	Year	No of accidents in power plants	No of death
1	2018	168	6
2	2019	207	9
3	2020	210	9
4	2021	220	9
Total: NA		805	33

Table 2 — Number of accidents based on equipment[30]

No	Year	No of Accidents based on equipment						
		Pressure vessels	Mechanical conveyors	Prime movers	Transmission machinery	Furnaces	Electrical installations	Lifting machines
1	2015	13	8	14	50	17	15	1
2	2016	69	3	32	96	16	27	1
3	2017	51	15	9	32	8	16	204
4	2018	31	12	8	52	10	14	188
5	2019	33	16	7	50	17	10	198
Total: NA		197	54	70	280	68	82	592

Table 3 — Number of accidents based on injury reported[30]

No	Year	No of Accidents based on Injury					
		Falling object	Struck by object	Caught in between object	Over-exertion	Due to high temperature	Due to electrical current
1	2015	3943	20803	4298	5462	387	49
2	2016	3848	19620	5431	7047	436	48
3	2017	4421	22410	2801	7192	451	23
4	2018	4210	23051	3582	7285	509	25
5	2019	4325	24120	3785	7299	501	27
Total: NA		20747	110004	19897	34285	2284	172

plants are chosen from the statistics. The year 2016 is an important aspect to be focused on due to the increase in the number of accidents reported. Note that there is an increase of 430.77% in pressure vessel cases, 128.57% in prime movers, 92.00% in transmission machinery and 80.00% in electrical installation cases. The data for lifting machines from the year 2017 until 2018 has a major increase because the tabulation and method of data collected has been changed and improvised to suit the statistical structure of the report. However, the accidents reported in these two years are still high and show no major reduction to prove a safe level of accidents. As for the year 2019, there are no improvements in pressure vessels, mechanical conveyors, furnaces and lifting machines. The number of incidents based on injuries reported is shown in Table 3.

The top six injuries connected to power plant accidents from the statistics were chosen and taken from the PERKESO annual report. Struck by object accidents were reported to be the highest among the other five accidents with a percentage of 27.81% from the total number of accidents. Accidents caused by over-exertion or intense movements fall on the second highest injury with a percentage of 8.67% from the overall accidents reported. The year 2019 records an increase in all sections excluding high temperature, which demands major attention. This information led to the formation of a proper prevention plan for this study.

As the study focuses on machinery accidents in power plants, the following elements are selected based on the accidents reported in Table 2 and 3 or the analysis of this study:

A) Machinery and area of work
- M_1 – Pressure vessels
- M_2 – Mechanical conveyors
- M_3 – Prime movers
- M_4 –Transmission machinery
- M_5 – Furnaces
- M_6 –Electrical installations
- M_7– Lifting machines

B) Type of accident
- I_1 – Falling object injury
- I_2– Struck by object injury
- I_3– Caught in between object injury
- I_4 – Over exertion injury
- I_5 – High temperature injury
- I_6– Electrical current injury

These elements are selected based on the reported accidents in the power plant. Accidents that do not involve these elements are not selected for this research study.

Methods

In this research study, equipment in a place of work and an injury is connected as a step to form the Holistic Team Approach (HTA) model. The equipment, classified as M_a and the injury as I_b are co-related to form a scientific equation that indicates the relationship of an accident. The basic equation is written as below:

$$M_a + I_b = \alpha_c \quad ... (1)$$

where, α represents an accident that has occurred in the power plant based on two of the elements involved.

The equation formed can be estimated to have a minimum of 42 combinations based on the elements chosen for the study. The combination for M_1 for α-type accidents are shown in Eqs (2−7).

$$M_1 + I_1 = \alpha_1 \quad ... (2)$$

$$M_1 + I_2 = \alpha_2 \quad ... (3)$$

$$M_1 + I_3 = \alpha_3 \quad ... (4)$$

$$M_1 + I_4 = \alpha_4 \quad ... (5)$$

$$M_1 + I_5 = \alpha_5 \quad ... (6)$$

$$M_1 + I_6 = \alpha_6 \quad ... (7)$$

The equation above is then applied to M_2 till M_7 to form the appropriate combinations needed for this study.

Moreover, the equation can also be applied if the accident involves more than one equipment or more than one injury, which will lead to a combination of maximum 117469 combinations as 7^6 (M^I). The examples of these specific accidents−can be written as shown in Eqs (8) – (10).

$$M_1 + I_a + I_b = \alpha_x \quad ... (8)$$

$$M_1 + I_a + I_b + I_c = \alpha_y \quad ... (9)$$

$$M_a + M_b + I_a = \alpha_z \quad ... (10)$$

Provided that $1 \leq \alpha \leq \infty$

Results and Discussion

Due to the increased number of accidents involving machinery accidents, a new approach is needed to curb the accidents to sustain machinery safety. The model that represents the overall process of curbing machinery accidents that involves the participation and both the management and the employee which is classified as Holistic Team Approach (HTA) Model is shown in Fig. 2.

The Elements for machinery are taken from the elements studied in the methods in this study. Seven

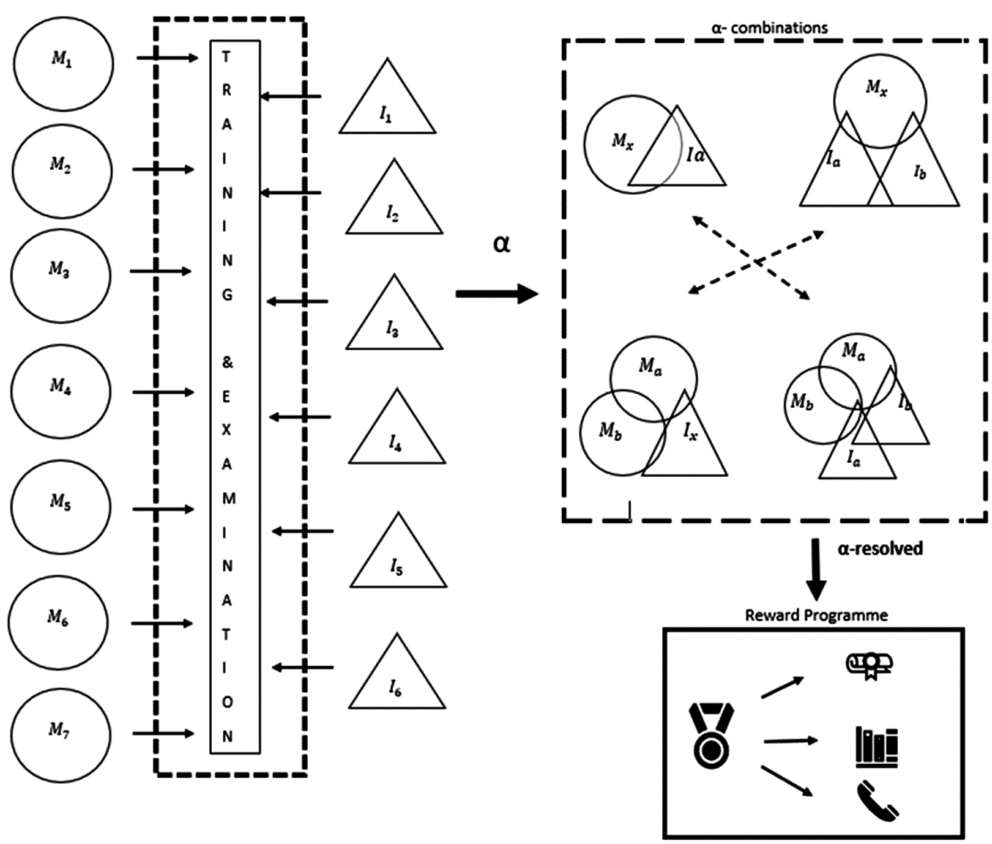

Fig. 2 — Holistic team approach (HTA) model

major safety critical equipments were chosen, which varies from M_1 to M_7. A dedicated number of participants are added into each element as team members, to fulfill the needs of a holistic background for optimum safety performance. The word "Holistic" was chosen for the model as the combination of team members are interconnected within a team to execute their tasks in a cooperative manner. The participants in the team consists of five members, with two engineers, a technician and an operator from the same area of work connected to the chosen element to ensure accuracy and relevance to the respective equipment for the study. Five members are selected for the HTA plan process to move smoothly, as the members of the team would cover the staff directory department representatives. Two engineers are allocated in order to provide engineering feedback and knowledge to the team during the entire HTA plan process. The remaining team member is a representative from the management department.

Teams are also chosen for elements varying from I_1 to I_6. The participants in the team follow the same ordeal as the M element teams, provided that the members of the I element are not the same as the M element. This is important to avoid discrepancy and to strengthen the safety knowledge and specificity of technical safety measures, which will later aid in the accident investigation process. Once the teams are formed, approval requests would be sent to the manager to verify the process and participants. The manager is tasked to evaluate the participation selection and accommodate the participants based on the allocated budget for this project model. Upon approval, teams are sent for specific training based on their allocated groups. For example, M_1 teams would undergo training to know the characteristics and the specifications of pressure vessels, the safety measures currently being taken, the law enforcements involving pressure vessel installations, repair and maintenance, common pressure vessel incidents and etc. The I_1 teams would undergo training to identify and understand the specifics of falling object injuries, the common accident types and the range of falling object accidents which can cause temporary or permanent disability to the affected employee. Training would be conducted by experts from the chosen field and recorded for reference and management review attributes.

Authentication on knowledge learning is essential to validate the objective of training. Assessment sessions would be set up for the participants which would consist of objective and subjective responses prior to the allocated group elements. Once a minimum score of 75% has been reached, the participants are given a certificate from the trainer as a landmark to start the HTA model project. Participants who did not pass the assessment are advised to re-sit for the examination after revision. Participants who could not pass the assessment after two trials are deemed ineligible for the HTA model project.

Accidents that occur in the company are classified as α, provided that $1 \leq \alpha \leq \infty$. The value of α is directly proportional to the safety performance of a company, excluding the off-range incidents that do not involve the M and I elements. As the first step of the HTA model to function, α has to be identified in the company. The α element can be a repetitive or a major impact influencer that involves the chosen safety critical equipment in the power plant. The α element can comprise of different element involvement, which can range from MI combination, MMI combination or MMII if the α is of a major accident in the company. For example, If the α comprises of one M element and one I element, the combination is defined as MI combination. Next, if the α is a combination of more than one element such as two M elements and two I elements, the combination is defined as MMII combination. The combinations can vary from $1 \leq \alpha - combinations \leq 117649$, as $7^6\ (M^I)$ is the estimated maximum combinational range for this HTA model. Team members connected to the α combination is first brought into the pre-investigation for briefing on the accident that occurred, followed by team pre-meeting on the accident details and occurrences.

The respective M and I team would collaborate with the investigation team to fork out root causes based on experience, evidence provided and through interviews with the affected employees. A report of pre-investigation is written and directed to the manager and Human Resource (HR) for record keeping. After the accident is investigated and the root cause is identified, the involved team members would be invited for a post-investigation meeting to discuss on the Preventive Actions (PA) taken to curb the accident from re-occurring. The discussed PA is then approved within the team after unanimous voting based on experience, relevance and effectiveness of the proposed PA. The investigation then ends with a post-investigation report that is written and given to the HR team and Manager for reference and recordkeeping. The employees involved in the M and I team are then advised to share the outcome of the accident investigation to the employees in the area of work. The report will be then taken into full consideration during the monthly management review. The management then introduces a reward programme after three months of revision in terms of accident rates and effectiveness of the team's approach for accident rate reduction in their respective area of work. The reward programme consists of a certificate of excellence by the company, and an option to redeem company merchandise or electronics devices that are of equal value. The total duration of the HTA plan covers a minimum of five months for the whole process to take place from the team member selection until the reward programme finalisation.

The HTA model is designed for an effective safety management tool to curb machinery accidents, which involves a decision analysis that investigates the effectiveness of the model. The decision analysis based on the designed HTA model is shown in Fig. 3.

This model starts from indicating an incident, performing accident investigation and mitigating accidents in the workplace. The process of HTA covers two essential elements from the Process Safety Management (PSM) approach which are incident investigation and employee participation. Focusing on incident investigation, HTA model is able to reduce accident rates in the workplace. As the model inculcates the root cause of an accident and performs investigation to generate appropriate PA, the accidents that have occurred would have a lower percentage of reforming.[31] The model also promotes better safety performance as ideas and steps are shared and taken in a group of different experience and expertise. This delivers the objective and Key Performance Indicator (KPI) of the safety team in the company and achieves the goal of maintaining safety levels in the company. As per employee participation, loss prevention in terms of budgeting can be obtained due to effective accident investigation in a team manner.

As the members from the I and M element are mostly from the same area of work and equipment, the ideas and points given by the team members help the investigation team to rule out misconceptions and identify common and repetitive root causes which can later be listed as major issues for further analysis. If the α is a major accident that has prior connection to other α-combinations or has a history of the same root cause with previous α, both α-combination team members can associate with each other for further knowledge and ideas sharing sessions to prompt for effective accident solving methods. This creates a

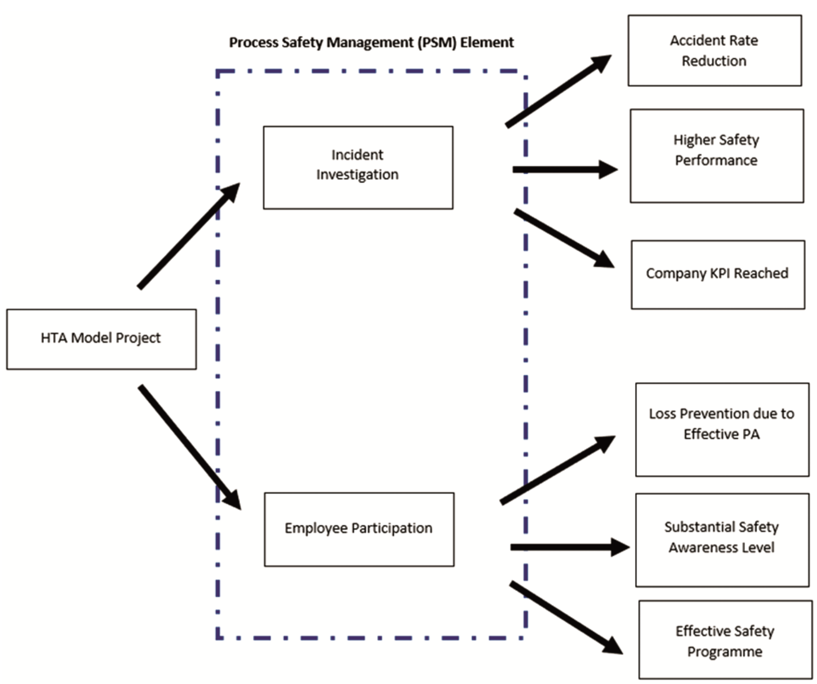

Fig. 3 — Decision analysis based on HTA model

substantial safety awareness level among employees in the workplace. An effective safety programme is created through this model as part of the aims and functionality of the safety committee in the workplace. This model is applicable to all types of power plants involving coal-fired, biomass and nuclear that comprises of safety critical equipment.

Conclusions

The data analysis obtained from the statistical data of DOSH and PERKESO indicate that the number of accidents in Malaysia generally increases every year, especially in power plants. The Holistic Team Approach (HTA) model is able to reduce the α value by involving the elements of machinery and injury types. The $\alpha - combinations$ can be formed from the diversity of the α reported in the workplace, which includes the elements from Process Safety Management (PSM) principle. However, the research is limited to the following:

A) Power Plant Equipment – Only the safety critical equipment used in power plants are included in this study, which covers most of the major hazardous workplaces.

B) Government Annual Report – The data obtained from the statistical data is used as the background of this study.

Although this study focuses mainly from the data collected from the Malaysian Government Statistical Body, the HTA model can be utilized in other countries as well due to the effectiveness and the versatility of the proposed model.

Conflict of Interest (COI)

The author declares no conflict of interest.

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