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A Guideline for Occupational Health and Safety Considerations in Facilities Planning

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Abstract: *Facilities layout planning is fast becoming the compliance for the organizations. In the past two decades, researchers have developed simulation and mathematical programming models to estimate the performance measures of a production system. However, the considerations of occupational health and safety management have been overlooked.*

The objective of this work is to develop a comprehensive list of safety criteria which facility managers need to consider at the early stages of the plant design in order to improve occupational health and safety. These criteria, which are based on previous research as well as the safety guidelines and standards, provide a tool for anticipating hazardous situations and instructing the improvements to reduce the occupational accidents. Furthermore, a structured safety outline for facilities planning will prevent future potential layout modifications for safety reasons and consequently reduce costs.

Keywords: *Facilities layout planning, occupational health and safety, safety criteria*

1 Introduction

Industrial and manufacturing companies are facing many problems in today's competitive environment (Gupta et al., 2004). Customers expect excellent quality product, low-priced and creativity in response to their needs (Pine and Davis, 1999). To attain these objectives, companies have to focus on possible improvements, productivity, quality, resource, space, and reducing wasting-time (Wang, 2010). Selecting a good layout, which is defined as the physical arrangement of machines, personnel, raw materials and finished goods (Roslin and Seang, 2008), is a critical decision in facilities planning, since the layout selection will serve to establish the physical relationships between activities. A well-designed plant can minimize the amount of land occupied and the movements in a process while maintaining easy access to spaces around individual units and providing safety zones between them. It not only reduces investment costs but also avoids or minimizes safety and maintenance problems (Penteado and Ciric, 1996).

Efficient facilities layout is essential in any industrial sector in order to improve quality, productivity, and competitiveness of an industry (Russell and Taylor, 2000). The facilities layout's goal is to provide the best arrangement of process equipment in the plant. Therefore, the criteria for evaluating a good layout necessarily relates to personnel, materials, machines and their interactions. While the different design of a plant layout has generally been recognized as one of the most important solutions for the facilities layout problems, a company can reach its goals by emphasizing the layout design and creating a layout model (Rawabdeh and Tahboub, 2006).

On the other hand, a company contains a large number of systems which interact to achieve the business objectives (Waeyenbergh and Pintelon, 2002). Occupational health and safety (OHS) contributes more than ever to the achievement of these objectives. Indeed, proper OHS consideration ensures regulatory compliance, improves productivity and well being of personnel, keeps the cost down by avoiding stoppage time following accidents and investigation; OHS contributes posi-

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tively to the overall performance of the company (Jallon et al., 2011a,b).

Furthermore, safety is a cross-disciplinary area concerned with protecting the safety, health and welfare of people engaged in work environment or employment (Chang and Liang, 2009). There are some basic ways to improve the safety in a plant; inherent safe design aims at eliminating the hazards. If this approach is not possible, the risk associated with hazards can be reduced by engineering solutions, safe working methods, information and training. However, taking into consideration the safety concerns related to the working environment of the company as early as in the design stage of the facilities layout can be a preventive solution.

The majority of previous research in facilities layout planning has focused upon optimizing movement costs, site costs, and qualitative preferences (Tompkins et al., 2010). The relationship between facilities layout and occupational safety has not been researched extensively. Chang and Liang (2009) developed a model, based on a three level multi-attribute value model approach, in order to evaluate the performance of process safety management systems of paint manufacturing facilities. Fernandez-Muniz et al. (2007) developed a Safety Measurement System Scale based on the results of a questionnaire survey of 455 Spanish companies, to be used to guide the safety activities of organizations. Penteado and Ciric (1996) presented a new mixed-integer nonlinear optimization approach to process plant layout that integrates safety and economics. Their proposed approach identifies safe and economical layouts by minimizing overall costs for chemical plants. Broberg (2007) described the concept of workspace design as a potential new approach for ergonomists and other OHS consultants. Shikdar and Sawaqed (2003) identified factors that affected workers' productivity and OHS. Lack of skills in ergonomics and training, communication and resources are believed to be some of the factors contributing to the poor ergonomic conditions and consequent loss of worker productivity and reduced health and safety in these industries.

Nevertheless, in most literatures, health and safety issues are considered from the ergonomic aspect versus the facilities layout design. However, other factors such as: safety of material handling systems, machineries, environmental concerns, etc. are also important. The main objective of this paper is to explicit safety considerations related to facilities layout planning features. We provide recommendations for the following research question:

What are the relevant facilities planning factors that features OHS criteria?

In this concern, a comprehensive list of safety criteria is developed and discussed. Our recommendations are derived from information generated through literature reviews. This approach is used to identify, propose and discuss safety criteria that need to be considered when implementing a facilities layout. Thus, OHS needs to be considered during the early stages of the plant layout design. Facilities layouts are developed and modified several times during the design process. Using a structured methodology for facilities layout which incorporates OHS can minimize the number of trial and error revisions of layouts resulted from safety considerations; hence reduce costs attributed to modifications. Ultimately, the outcomes enrich the methodologies of facilities layout planning by incorporating OHS considerations.

2 Occupational Safety Management

In the last 20 years, safety management at industrial facilities have evolved from conventional safety audits and passive compliance to laws and regulations to a proactive approach such as the establishment and the execution of systematic safety management system (Chang and Liang, 2009). According to Kharbanda and Stallworthy (1988), safety is a concept covering hazard identification, risk assessment and accident prevention. Risk assessment is the process of systematically guiding risk reduction and management activities based on collecting and evaluating data on severity of a harmful event and probability of occurrence of that harm. Depending on function and operating mode, safety requirements can vary in different facilities layouts.

Previous research and literature reviews demonstrate different tools and methods for assessing risk while it is not easy choosing the tool best adapted to the needs of each company. Wassell (2008) presented a coherent and concise description of current methods for risk identification and describes their limitations. His research proposed identifying gaps and opportunities for improvement in risk identification through the literature search. Chinniah et al. (2011) researched to theoretically compare the performances of tools in estimating risks and to evaluate whether they estimate the risks uniformly. 31 qualitative tools used for estimation risks associated with industrial machines, following the ISO 14121-1:2007 guidelines, were analysed by comparing their risk estimation parameters as well as applying the different tools to estimate risks associated with 20 hazardous situations. Abrahamsson (2000) attempted to analyze various quantitative risk estimation tools particularly in the occupational exposure to hazardous substances. His research focused exclusively on the analysis of the various types of uncertainty associated with the tools. Above all, safety should always come first and remain so, despite of its costs. Good design and forethought can often bring increased safety at less cost (Heikkila, 1999).

3 Methodology and Results

This research is built upon a comprehensive list of safety criteria. These criteria were basically generated from literature reviews on the subject and were classified under six major facilities planning factors, introduced by the authors. These factors and their 20 safety criteria are listed in Table 1. A detailed description of each safety criteria is provided in the following sections.

Safety Criteria	
Machine	1. Placement and distance of machines according to each other
	2. Standardization in using machineries and equipments
	3. Degree of automation
	4. Storage space
Movement	5.Material handling load, method and equipment
	6. Movement of machinery, machine part and equipment
	7. Minimum aisle width
Workforce & Ergonomic	8. Training, education and labour experience
	9. Self-inspection and personal protection
	10. Job flexibility
	11. Safe Access to machineries
	12. Ergonomic hazards
Maintenance & Services	13. Access to machines for setting, maintenance or repair
	14. Machine safeguards flexibility and machine guard removal
Material	15. Characteristics of product
Environment	16. Noise disturbance
	17. Electricity or released of stored energy
	18. Temperature and pressure, radiation, fire and explosion
	19. Illumination
	20. Respiratory hazards

Table 1: Facilities planning factors and related safety criteria

3.1 Machine

Ever since machinery was first developed to help man with his labours, a heavy price in injuries and damage has been paid for the convenience. This safety factor deals with some of the principles involved in providing safety in oppose to the common hazards caused by machineries and equipments.

1. Placement and distance of machines according to each other

In order to plan for machineries placements, machine specifications, space size and safety requirements must be considered. Space and equipment considerations include machine dimensions, power, dedicated circuits, etc. Regarding the aspects of space limits, one should:

- Consider the range of movement. Sufficient spaces have to be allocated in order to avoid hazardous zones, e.g., entrapment between moving part of equipment and fixed fixtures of the plant or adjacent equipment;
- Consider space requirements for the person interacting with the machine, such as during operation and maintenance. Postures for operators and mechanics are linked to availability of space;
- Consider the human interactions such as the operator-machine interface. The control panels need to be allowing clear view of the equipment in order to avoid blind spots and create potential hazardous zones;
- Consider the machine-power supply interface. The equipment need to have its own power supply and energy isolating devices in order to isolate the equipment without affecting the adjacent one if needed. The use of local isolating devices makes it more convenient and more prone to the application of lockout procedures. The isolating devices have to be easily accessible and machine layout need to take this into consideration.

2. Standardization in using machineries and equipments

Many dangerous accidents are caused by the incorrect use of machinery, equipment and tools. The following guidelines are to be followed (MIT, 2004):

- Use of machinery, equipment and tools must be restricted to authorized personnel who have the proper training on safe working methods;
- Use proper and safe tools for the job and use it in accordance with the manufacturer's instructions, ensuring that guards and safety devices found on equipment are used;
- Before undertaking maintenance or repair on any plant, equipment or tools, apply lockout procedures (i.e. turn off equipment, switch off the power and disconnect the drives, apply locks and or tags to isolating devices, dissipate residual energies, verify absence of energies);
- Switch off electric tools and allow them to stop revolving before laying them down or making any adjustments;
- Ensure that equipment, machinery or tools are in good condition before using;
- Before using power tools check that an electrician has inspected and tested the tools quarterly;
- Check that cables, plugs and insulation are undamaged;
- Wear protective clothing and equipment provided such as goggles and face masks.

3. Degree of automation

In addition to advantages such as greater productivity, reduced production costs, improved product quality and greater manufacturing flexibility, automated systems often eliminate the need for repetitive, tedious and hazardous tasks. Under normal operating conditions, workers do not access danger zones and are kept away from many hazards since the automated machines, often controlled by programmable logic controllers are designed to operate without human intervention. These automated systems should inherently improve safety by eliminating the need for workers to reach into danger zones. Furthermore, since fewer workers are needed in automated factories, it could be argued that potentially fewer workers are at risk (Goetsch, 2008; Chinniah et al., 2007).

Despite this, every new tool developed to enhance the ability of humans to work efficiently and effectively has brought with it a new safety and health hazard (Goetsch, 2008):

- Pay special attention to the numerous hazards which are not always easy to identify and coming from the use of multiple technologies (hydraulic, electric, pneumatic and mechanical) working simultaneously;
- Pay attention to potentially dangerous tasks, including maintenance, setting, commissioning, training, material loading/unloading, tool changes or adjustments during production, removal of jammed materials, and repairs or interventions following malfunctions;
- Consider the human errors such as miscommunication between workers who mistakenly energize or start a machine when a co-worker is in the danger zone;
- Consider common and unsafe workplace practices such as incorrect use of safeguards, bypassing of protective devices, removal of guards, or changes in the program of electronic programmable safety devices.

4. Storage space

Storage space around machinery can create hazardous situations. When large pile of material is placed next to the machine, this can create blind spots and result in accidents such as collision between forklifts and pedestrian. The material itself can be hazardous; e.g. a pile of metal sheets next to a hydraulic power press brake. Sheets have sharp corners, they are heavy and can harm personnel; i.e. harm to lower limbs and back pains when manually feeding or inserting sheets to machine. Moreover, feeding machine manually can create hazardous situations (Brauer, 2006):

- Analyse the type and quantities of materials that may be present;
- Plan storage location for each type of item;
- Allow for the separation of incompatible materials, such as oxidizers and fuels;
- Provide adequate storage equipment and racks to keep materials organized;
- Clearly mark all areas.

3.2 Movement

Safety should not be an afterthought when designing the material handling, machinery and equipment movement. Discussions on machineries and material handling safety from the perspective such as load, equipment, gangway spaces and unnecessary movements are discussed under this dimension.

5. Material handling load, method and equipment

Statistics showed that lifting or handling operations result in a vast number of injuries to employees (University College London, 2000). Good lifting techniques save employees from back problems and should be used to ensure no unnecessary pain is suffered.

Cranes, pulleys, blocks, chain and wire or rope slings are used to handle heavy materials and equipment, which must not be used by untrained employees (University College London, 2000). Safe working loads will be clearly marked on equipments that regularly inspected and tested. Rules for picking up a load include (Goetsch, 2008):

- Make sure the load is within the capacity of the material handling machine;
- Make sure the load is properly balanced;
- Make sure the load is secure;
- Raise the load to the proper height.

Powered industrial truck or forklift safety can cause injuries which often result from impact or acceleration hazards. Forklifts are different from cars and trucks in several ways and employees should consider these differences (Goetsch, 2008).

- Consider that forklifts are typically steered by the rear wheels and an empty forklift can be more difficult to steer than one with a load;
- Consider that forklifts are frequently driven in reverse;
- Consider that forklifts have tree-point suspension so that the centre of gravity can move from the rear of the vehicle closer to the front when it is loaded.
- Consider that forklift overturn is frequent and that speed, loads, driving and loading techniques are causal agents for these accidents.

Because of these differences, it is important to ensure that only trained employees drive forklifts and they follow rules of lifting, travelling, and speed to prevent accidents.

6. Movement of machinery, machine part and equipment

In reviewing mechanical hazards of machinery and equipment, one should consider movements in machines which may have sufficient force to cause injuries (WorkSafe, 2007):

- Be aware of machinery and equipment with moving parts that can be reached by people;
- Be aware of machinery and equipment which can eject objects (parts, components, products or waste items) that may strike a person with sufficient force to cause harm;

- Be aware of machinery and equipment with moving parts that can reach people such as booms or mechanical appendages (arms);
- Be aware of mobile machinery and equipment such as forklifts, pallet jacks, earth moving equipment, operated in areas where people may gain access.

7. Minimum aisle width

Determining optimal aisle width is a critical part of an overall storage/material-handling strategy. Aisle width decisions must attempt to achieve the best combination of productivity, space utilization, flexibility, safety, and equipment costs for the specific application.

- Where mechanical handling equipment is used, sufficient clearances for the type and size of the equipment should be maintained, including sufficient aisle clearances;
- The powered industrial trucks require sufficient overhead clearance from pipes, lights, overhead installations, sprinklers, etc. This fact is based on the size and manoeuvrability of the material handling equipment.

3.3 Workforce & Ergonomics

Labour experience, training and flexibility of jobs could greatly impact the safety of workers. Furthermore, ergonomics approach will provide a better condition for workers to perform the tasks well.

8. Training, education and labour experience

Only qualified and certified personnel are permitted to undertake any hazardous duties or operations such as handling toxic, explosive or highly flammable materials in order to maintain, service, or repair any dangerous equipment or in order to transport and operate any vehicle, mobile equipment or its component assemblies (Goetsch, 2008).

Programs are instituted to qualify and certify workers for their duties. Qualified personnel are indicated as certified by suitable identification issued after proficiency examination and demonstration. Certification programs include training and testing on safety subjects such as hazard involve in the operation for which the worker is being certified, practices and procedures required to protect themselves and others, remedial actions to be taken in any contingency, safety devices, possible malfunction and marking of wiring, piping, and equipment, meaning of warnings, sound alerts or any other emergency signal, and any other information the safety manager considers advisable (Goetsch, 2008).

9. Self-inspection and personal protection

No person is required to perform an operation that could result in injury to himself or to any other person because of close proximity or incompatibility of their tasks. In order to (1) avoid injurious effects on the body and (2) safeguard workers in the event of accidents, managers must ensure that certain rules are observed (Goetsch, 2008):

- For normal operations, first choice is eliminating the hazard in the environment rather than using personal protective equipment;
- Approved protective equipment and devices must be made available and used to guard against specific hazards that cannot be eliminated but should be controlled when encountered during the operation;
- No supervisor should permit conducting an operation unless such equipment and devices are in proper working order and used as stipulated by the safety engineer;
- Only protective and rescue equipment approved for the purpose by responsible agencies and in accordance with OSHA or other mandatory standards should be used;
- Location of personal protective, emergency, and first aid equipment must be easily accessible and readily distinguishable;
- Equipment should be stored as close as practicable to the possible point of use. Operating procedures should identify the equipment stored and its location. Inspections are to be made periodically to ensure that stipulated items are present;
- No person should enter a hazardous environment without the prescribed protective equipment, remove it while in the hazardous environment, or use it if it is faulty or damaged. Tests to demonstrate the equipment is operating properly are required before a worker enters a questionable environment;
- All workers must be familiar with the capabilities, limitations, and proper method of fitting, testing, using, and caring for protective equipment. Managers will require and ensure that courses of instruction are provided to familiarized personnel with safety equipment. Safety engineers and supervisors will schedule practice sessions or have training units conduct sessions to maintain user proficiency;
- Devices are available to detect, warn, and protect against an impending or existing adverse environmental condition. Such equipment should be used to evaluate atmospheres that might be toxic, flammable, or explosive or in which excessive levels of radiation, heat, pressure, noise, or other hazard might exit. Devices will be provided to apprise personnel of the status of such conditions that might be hazardous or of the loss of control of a hazard. Equipment provided should be adequate for detecting the presence of the hazard under conditions other than normal for the operating environment;
- Detection and warning equipment should be maintained in a state in which operations and readings are dependable and accurate; which should be tested and calibrated periodically;
- Detection and warning equipment should be installed, maintained, adjusted, and repaired only by trained personnel.

10. Job flexibility

Flexible work arrangements are alternate arrangements from the traditional working day/week. Employees may choose a different work schedule to meet personal or family needs. Alternatively, employers may initiate various schedules to meet their customer needs. Job flexibility is a critical resource for maintaining job satisfaction and quality of life among employees. Many benefits are reported by various studies (CCOHS, 2002):

- Increased ability to attract, retain and motivate high-performing and experienced employees;
- Reduced absenteeism;
- Helps employees manage their responsibilities outside of work;
- Increased job satisfaction, energy, creativity and ability to handle stress.

Flexible job can be distinct as:

Flex-time: A work schedule with variable starting and ending times, within limits set by one's supervisor/manager. Employees still work the same number of scheduled hours as they would under a traditional arrangement (MIT, 2004).

Job-sharing: An arrangement in which two or more part-time employees share the responsibilities of one full-time job (MIT, 2004). This way, the tasks performed by employees would be more variable; as well as the increase in the number of machines operated by a workforce. However confusions might be caused from several operations carried out simultaneously.

11. Safe Access to machineries

People may continually or occasionally access machinery and equipment for tasks such as operation, maintenance, repair, installation, service or cleaning. Therefore, safe access must be provided suitable for the work performed in, on and around them. A stable work platform suited to the nature of the work, allowing good posture relative to the work performed, sure footing, safe environment and fall prevention are basic requirements. Access needs can be predicted and planned in advance. Access may vary during each stage of machinery and equipment life cycle (WorkSafe, 2007):

- *Installation or removal:* complete access from every area is required and involves disconnection or connection of services such water, air, pipes, installation of electrical cable to switch board, etc.;
- *Operation:* access for set-up, operation and adjustment;
- *Maintenance, repair, cleaning, alteration or adaptation:* access to remote areas is required.

12. Ergonomic hazards

Ergonomic hazard is a physical factor that harms the musculoskeletal system. It includes uncomfortable workstation height and poor body positioning. Ergonomic injuries include strains, sprains, and other problems. These injuries can be caused by: performing the same motion over and over again (such as vacuuming); using physical force (lifting heavy objects); or being in an awkward position (twisting the body to reach a light bulb). The four main ergonomic hazard factors are force, posture, repetition and duration (OFSWA, 2007):

- Force is generated by muscles to lift, lower, push, pull or hold objects. There is the risk of injury when the amount of force required for a job is more than the muscles can handle;
- Posture is the position of the different parts of the body related to one another. The more extreme, awkward or unnatural the posture, the greater the risk of injury to the muscles, ligaments, tendons and nerves;
- Repetition is the number of times an action or body motion is performed over a given time period. Jobs that require repetitive motion increase the stress to the muscles and tendons because of fatigue;
- Duration is the length of time an activity or movement is performed, a posture is held or a worker is exposed to other ergonomic hazards such as force or repetition. Even though a movement or activity may be fairly comfortable, the duration of job over a long period can lead to injury.

Other ergonomic hazard factors include: contact stress, vibration, temperature, work organization and methods.

3.4 Maintenance & Services

Accessibility and distances among machines, as well as the maintenance services concerned this safety factor.

13. Access to machines for setting, maintenance or repair

Employees can safely service or maintain machines with a guard in place. For example, polycarbonate and wire-mesh guards provide great visibility and can be used to allow maintenance employees to safely observe system components. In other instances, employees may safely access machine areas, without locking or tagging out, to perform maintenance work (such as machine cleaning or oiling tasks) because the hazardous machine components remain effectively guarded (OSHA, 2007); whereas the followings need to be taken into account:

- When considering the suitability of distance guarding, also should be considered the safe access requirements of maintenance people who gain access by ladder, scaffold or elevated work platform;
- Consider the sufficient space for maintenance or emergency operation;

- Consider adequate space area for critical maintenance and auxiliary services during the operation;
- Maintenance workers should lock out the machine from its power sources before beginning the repair;
- When several maintenance persons work on the same machine, multiple lockout devices should be used;
- The maintenance equipment itself should be properly guarded;
- The use of plant rooms, electrical switch rooms and other service areas such as service ducts, roof spaces and flat roofs, should be strictly limited to the purpose for which they were designed. Entrances to such areas must be kept locked and notices displayed indicating that unauthorised persons shall not enter.

14. Machine safeguards flexibility and machine-guard removal

A guard can perform several functions: it can deny bodily access, contain ejected parts, tools, off-cuts or swath, prevent emissions escaping or form part of a safe working platform. An effective guard or safety device must have certain features and meet certain criteria (Goetsch, 2008):

- Machines must be safe under all conditions. If it fails, causes to operate, or is opened, the machine should immediately and automatically stop;
- Access to the danger zone must be prevented while the equipment is operating;
- It must impose no restriction, discomforts, or difficulties for the worker;
- It must automatically move into or be fixed into place;
- It must be designed for the hazard, the machine, and type of operation;
- It must not require delicate adjustment for use or move out of alignment easily;
- It must be difficult for an operator to bypass or inactivate it without simultaneously inactivating the equipment on which it is mounted;
- It should require minimum maintenance;
- It should not itself constitute a hazard.

Guarding is commonly used with machinery and equipment to prevent access to (WorkSafe, 2007):

- Rotating end drums of belt conveyors;
- Moving augers of auger conveyors;
- Rotating shafts;
- Moving parts that do not require regular adjustment;
- Machine transmissions, such as pulley and belt drives, chain drives, exposed drive gears;
- Any dangerous moving parts, machines or equipment.

3.5 Material

The type and characteristics of the products and material used in the manufacturing process is an important dimension of safety to be considered.

15. Characteristics of product

Factors such as size, shape, volume, weight, etc. of the materials and products can influence the safety considerations. The material/product and its components, including physical, chemical and environmental characteristics, and toxicity information, should be evaluated and assessed to determine the potential physical (fire and reactivity), health and environmental hazards associated with the material. Using professional judgement, the product should be classified according to the hazard criteria specified in legislation of the country where the product will be used; e.g., classify chemical products as flammable versus combustible or toxic versus very toxic.

3.6 Environment

Work environment is an important issue to consider. The environment should provide proper illumination, noise control, ventilation and temperature in order to accommodate the employees. Thus, work environment determination has to be carried and considered during the facilities planning process in order to achieve a higher production performance.

16. Noise disturbance

Legislation makes loss of hearing linked to the workplace compensable. Both employers and employees are therefore obliged to observe existing noise standards. Engineering solutions range from the use of component parts generating less noise, use of enclosures around machines to reduce noise level, to personal protective equipment (PPE) (e.g. ear plugs). High noise level can interfere with communication among workers, induce stress and result in accidents. Employees need to be trained to (Goetsch, 2008):

- Understand the danger to hearing that comes from prolonged and high level of noise exposure;
- Recognize noise exposures which are harmful;
- Evaluate noise levels of exposure in a practical way;
- Take action to protect from harm of noise.

17. Electricity or released of stored energy

The use of electricity and electrical equipments are so common that most persons fail to appreciate the hazards involved. These hazards can be divided into five categories: (1) shock to personnel, (2) ignition of combustible or explosive materials, (3) overheating and damage to equipment or burns to personnel, (4) electrical explosions, and (5) inadvertent activation of equipment (Goetsch, 2008).

Interlocks: Where an enclosure is breached, the circuit will be broken automatically and the system will be de-energized. Because enclosures are frequently opened for maintenance purposes, during which circuits must be checked, interlock switches must be operable deliberately when the access panel is open. Such switches should be of a type which reinstitutes the safety function when the enclosure is closed again (Goetsch, 2008).

Insulation: Insulation parts of electrical equipment which a person will contact routinely or accidentally during operation of the system are advisable. Insulated knobs, dials, handles and buttons on controls, switches, drawers, and meters are such items. Rheostats and potentiometer control shafts can be coupled to nonconductive rods and knobs (Goetsch, 2008).

Isolation: Electrical equipment, especially high-voltage type, should be isolated to keep unauthorized personnel from approaching too close. Large transformers with exposed terminals can be located in vaults or fenced enclosures to which only authorized persons have access. Panel boards, generators, large motors, batteries, bus bars, and other electrical equipment which might be hazardous should be enclosed or provided with guards to prevent accidental contacts (Goetsch, 2008).

Marking device: A suitable warning device may be connected to electrical equipment to indicate when it is energized. This may be a light, steady or flashing; a suitably coloured indicator; an on-off sign; or an audible signal (Goetsch, 2008).

18. Temperature and pressure, radiation, fire and explosion

High and low temperatures, heat, cold, and the variations can be directly injurious to personnel and damaging to equipment. Effects can be generated, e.g., by thermal changes in the environment which lead to accidents and therefore indirectly to injuries/damage. Numerous investigators have studied the effects of temperature on performance. In almost all instances, there is agreement that stresses generated by high temperatures degrade performance. The effects of heat will depend on the following factors: intensity of the heat, duration of the exposure period, tasks involved, persons performing the tasks, presence of other stresses (Goetsch, 2008).

One of the worst effects of elevated temperatures is the increased susceptibility to fire. If the temperature is high enough or the volatiles in the organic material are reactive, a fire may start spontaneously. Thermal radiation from flames, molten metal, or other high-temperature source can cause charring of materials such as wood, paper, and cloth. Charring can also occur when such material is in contact with a high temperature source such as a steam line, hot electronic equipment, or an overheated bearing (Goetsch, 2008).

Radiation may be either a direct or indirect source of fire ignition. Sunlight can be concentrated intentionally or accidentally by a lens or curved reflectors to cause ignition of combustible materials. Solar reflectors provide some of the highest temperatures available without the use of nuclear devices. Less efficient concentration of solar energy may still constitute sources strong enough to cause fires. Flames, industrial heating furnaces, highly incandescent metals, and glowing solid combustibles can also radiate energy to ignite flammable materials. Lasers can generate beams whose intensities may cause combustibles to ignite (Goetsch, 2008).

19. Illumination

Lack of lighting can contribute to accidents. People need to see what they are doing and where they are going. Some aspects of lighting are distracting or interfere with tasks. The major hazards associated with lighting involve illumination levels, changes in illumination levels, qualitative aspects of lighting and flicker of some light sources (Brauer, 2006).
Confined spaces generally have poor lighting, where temporary lighting is often needed. In potentially explosive atmospheres, lighting designed for such situations should be used.

20. Respiratory hazards

Respiratory hazards can be present as: gases, vapours, fumes, mist, and dusts. A variety of equipment can be used to protect workers from respiratory hazards. Devices range from simple, inexpensive dust masks to sophisticated self-contained breathing apparatus; i.e., air-purifying respirators and supplied-air respirators.

Ventilation is an effective method of controlling respiratory hazards. The space can be purged of dangerous atmospheres by blowing enough fresh air in, and/or by removing (or suction venting) the bad air and allowing clean air in. The best results are obtained by blowing fresh air into a space close to the bottom. Check the efficiency of ventilation by re-testing the atmosphere with the gas detection equipment before entry.

When ventilation is used to improve the air in a confined space, ensure that the toxic or flammable gases or vapours removed from the space do not pose a risk to other workers. Exhaust air should not be discharged into another work area.

4 Conclusion

Over the years it has been found that numerous problems can be avoided in designing or modifying plants if facilities plans are reviewed for safety aspects before initiating any construction or change. Furthermore, facility managers are the most responsible professionals for integrating people with their physical environment. As such, they often find themselves facing a myriad of complexities and challenges. Each of these challenges requires greater effort on the part of employers in identifying, correcting and preventing safety and health hazards. The key to reducing safety and health hazards is an effective safety management program.

However, the injury frequency or severity rates which are extensively used by government agencies for measuring occupational injuries/death, only reflects the status of the occupational safety and neither provide the management of any information for improvement. To effectively manage the safety management system, a composite performance evaluation system consisting of measurable and achievable indicators in many facets of safety management is definitely required.

Nevertheless, there is no general outline for an inherently safer process. One problem is how to minimize simultaneously the risk associated with all of the process hazards. In the real world, the various hazards are not independent of each other, but are inextricably linked together (Hendershot, 1995). A process modification, which reduces one hazard, might impact on the risk resulting from another hazard.

On the basis of previous research on safety management and the guidelines developed by international bodies and empirical studies on the safety features, as well as the importance of reviewing the safety aspects in the early stages of facilities planning, the authors considered that the safety management system is a multi-dimensional construct made up of the following factors: (1) safety policies reflecting the hazards caused by machineries and equipments; (2) safety in designing the material handling system, machinery and equipment movement; (3) employees training, experience and flexibility of jobs; (4) safety in maintenance and services; (5) type and characteristics of the products and material used in the manufacturing process; and (6) environmental aspects of safety.

A comprehensive list of safety criteria was developed, discussing different aspects of the six above mentioned factors. Facilities planners can use these criteria to evaluate their situation in regards to safety management, and to guide them about which areas they must improve if they wish to reduce their accident rates and losses.

Future research will focus on appraising the specific safety criteria and their importance for different type of plant layouts. While the presented guideline can be presented as a safety audit checklist for the facilities planners, different facilities layout planning tools can be modified to acknowledge a more detailed consideration of safety.
Moreover, the research can be enriched by quantitative information, such as performance indicators (related to the given criteria) which will be optimized by the best practices listed in this paper.

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