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Study of Industrial Plant Layout Development and Associated Safety Standards

Dr. A. R Arvind[1], Niteesh Balaji. K[2], Hemanth Sivaganesh. S. P[3], Adithyan. A[4]
Deputy General Manager, Project Planning Department, Ashok Leyland, Ennore, India[1]
B.Tech Production Engineering, Department of Production Engineering, NIT-Trichy, India[2]
B.Tech Mechanical Engineering, Department of Mechanical Engineering,
Amrita School of Engineering, Chennai, India[3]
B.Tech Mechanical Engineering, Department of Mechanical Engineering,
SRM Easwari Engineering College, Ramapuram Chennai, India[4]
arvind.AR@ashokleyland.com, 114123059@nitt.edu
hemanthsivaganesh.sp@gmail.com, adithyanadithya72@gmail.com

Abstract: *A well-planned plant layout is essential for ensuring safety, efficiency, and environmental sustainability in industrial operations. This study presents key safety guidelines focusing on risk reduction, accident prevention, and worker well-being. It highlights critical factors such as fire protection, electrical safety, machine guarding, ergonomics, and hazardous material handling, along with environmental controls like ventilation, noise reduction, and waste management. Provisions for emergency readiness, first aid, and safety signage are also included, all aligned with ISO standards , and the Indian Factories Act, 1948. Integrating these measures from the design stage helps minimize risks, enhance productivity, and ensure compliance, while supporting sustainable development and operational excellence in modern industrial facilities.*

Keywords: *accident prevention*

I. INTRODUCTION

The design and layout of a manufacturing plant (Figure 1.0) significantly influence its efficiency, productivity, and overall safety. Beyond arranging machines and materials for smooth workflow, modern plant layouts must prioritize the health, safety, and well-being of workers while minimizing environmental risks. A poorly designed facility can result in workplace accidents, fire hazards, toxic emissions, and other safety incidents that disrupt operations and harm both people and the environment.

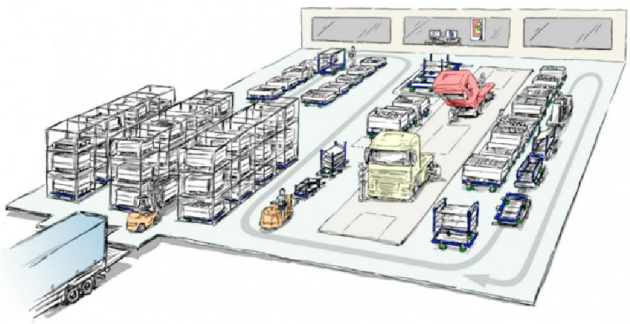

Figure 1.0: MANUFACTURING PLANT

This study emphasizes on integrating safety standards into the early stages of plant layout planning. Key considerations include proper equipment placement, clear emergency exits, safe pathways for material handling, designated zones for hazardous materials, and effective fire protection and ventilation systems. These guidelines are developed in line with

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global standards, and India's Factories Act, 1948 to ensure legal compliance and the creation of a secure, healthy working environment.

In addition to ensuring worker safety, the layout also supports environmental sustainability by incorporating waste management systems, pollution control measures, and energy-efficient solutions. By adopting these practices, industries can improve operational efficiency, reduce risks, and promote long-term environmental responsibility. This study aims to help plant designers, engineers, and safety managers create layouts that balance productivity with safety and sustainability (Figure 1.1)

Figure 1.1: Plant layout interaction diagram

Design for Safety:

Plant layout is concerned with the spatial arrangement of processing equipment, storage area, workplace and warehouse. It considers the design constraints arising from safety, environment, construction, maintenance, and operation with an economical balance. Access to the plant and supply of maintenance, construction and emergency services are all affected by the plant layout. Numerous accidents, occupational diseases, explosions, and fires are preventable if suitable measures and code of standards are taken into consideration right from the earliest planning, design, and the initial project stage. Efficiency and safety in industrial operations can be greatly increased by careful planning of the location, design, and layout (of a new plant or of an existing one) in which major alterations are to be made (Fig1.2: schematic diagram of plant).

Plant layout will be based on factors like:

1. New site development or addition to previously developed site.
2. Type and quantity of products to be produced,
3. Possible future expansion,
4. Operational convenience and accessibility,
5. Type of process and product control,
6. Economic distribution of utilities and services,
7. Type of building and building code requirements,
8. Guidelines related to health and safety,
9. Waste-disposable problems,
10. Space available and space requirement,
11. Auxiliary equipment,
12. Roads and utility

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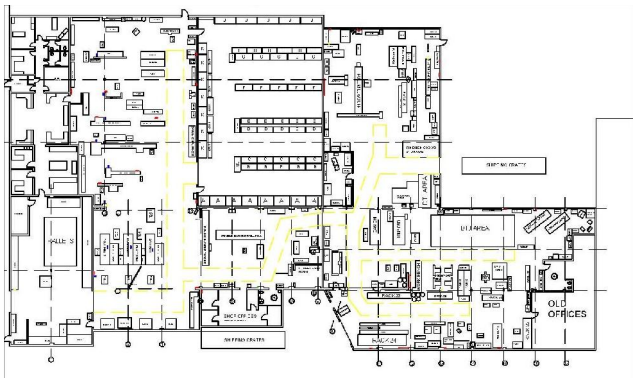

Figure 1.2: plant layout

II. LITERATURE REVIEW

The significance of incorporating safety standards into plant layout design has been consistently highlighted by researchers and industry experts. Studies by Gupta and Sharma (2018) emphasize that a well-planned layout not only improves operational efficiency but also reduces occupational hazards, thereby protecting worker safety and ensuring regulatory compliance. Similarly, Kumar et al. (2019) stress the importance of integrating emergency exits, fire protection systems, and hazardous material controls during the design stage to minimize potential risks and enhance workplace safety, as recommended by ISO 45001:2018 standards. Ergonomic and environmental factors are also crucial in modern plant layouts. Patel and Desai (2020) point out that improper workstation arrangements can lead to worker fatigue and musculoskeletal issues, while Singh and Verma (2021) discuss the integration of sustainable practices like waste segregation and energy-efficient systems in line with ISO 14001:2015. These measures not only support environmental responsibility but also contribute to cost-effective and healthy work environments. The role of smart technologies in ensuring industrial safety is gaining attention as well. Zhang and Chen (2023) highlight the use of Industry 4.0 solutions such as IoT-enabled hazard monitoring and predictive maintenance, which allow for real-time safety management and early fault detection. These advancements help industries shift from reactive to proactive safety approaches, enhancing overall plant reliability and operational control. Additionally, Yusuf and Adeleke (2020) emphasize that machine positioning and the provision of maintenance access points are essential for safe equipment handling and operational continuity. Inadequate space planning can lead to unsafe repair practices and increase the risk of accidents. Their research underlines the need for designated maintenance zones and strict isolation of hazardous machinery to prevent workplace injuries and ensure compliance with safety protocols.

III. SAFETY ASPECTS OF PLANT LAYOUT

General:

The overall design, size, and structure of buildings should support efficient handling of materials and processes while minimizing risks. Multistorey buildings may be preferable for gravity-based operations, but provisions like elevators must be made to prevent manual lifting hazards. In contrast, industries such as automobile manufacturing benefit from single-storey buildings due to heavy floor loads and easier equipment access(Figure 3.0).

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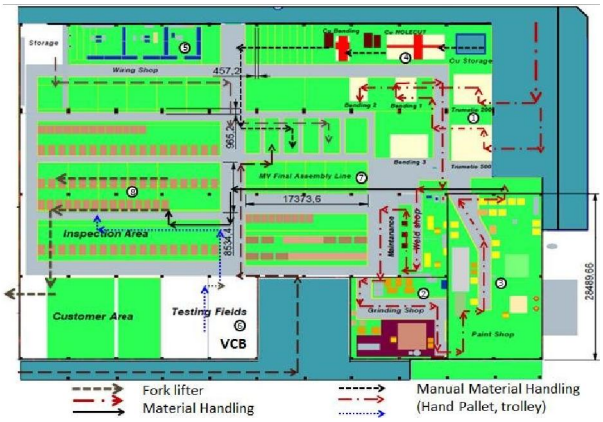

Figure 3.0: schematic diagram of plant

General Layout Safety:
1. Ensure clear separation between pedestrian pathways and vehicle routes to prevent accidents.
2. Provide sufficient working space around equipment for maintenance, repair, and emergency escape.
3. Avoid dead-end passages in critical work areas.
4. Allocate designated emergency exits, which are clearly marked and accessible.
5. Maintain an unobstructed flow of materials and personnel by following logical process sequencing.

Location of Buildings and Structures:
Proper segregation between storage areas for raw materials, process buildings, and finished goods is crucial to reduce fire and explosion hazards. Separate storage for volatile substances minimizes fire risk and simplifies emergency response. Sufficient spacing from roads and adjacent building ensures safety, while compliance with local and national codes regarding distance, materials, and fire resistance must be ensured, especially when handling flammable material.
a) Control facilities: Control buildings must safeguard occupants from fire, toxic releases, and explosions by being positioned away from high-risk areas and designed with robust, ductile materials. Ideally, they should be on the plant's edge with escape routes and not serve as emergency assembly points, as specialized emergency control centers are needed for incident management.
b) Escape: Sufficient escape routes should be provided for every workspace, with exits located within reasonable distances based on risk. Solid flooring and proper stairway design are essential for safe evacuation. Escape paths should remain clear and adequately sized to allow quick personnel movement during emergencies.
c) Fire fighting: Effective fire control requires plant layouts that ensure fire-fighting equipment can reach all areas easily. Hydrants must be appropriately spaced, and fire protection systems designed to prevent equipment from becoming unusable during fires. Building spacing and road access should support quick response to any fire outbreak.

Space Requirements:
The layout must accommodate present operations and future expansion without overcrowding. Utility services like air compressor, power stations, and pumps should be placed in locations that prevent them from becoming hazards themselves. Site design must also consider environmental aspects such as drainage, effluent handling, and waste disposal to avoid pollution or flooding.

Ergonomic Safety:
1. Design workstations with adjustable features to suit operator height and posture.
2. Place controls, tools, and materials within the operator's easy reach zone.
3. Provide anti-fatigue mats, seating arrangements, and adequate lighting to reduce physical strain.

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Electrical Equipment :
Substations and electrical panels should be located away from flammable materials and clearly marked for safety. Non-flammable transformers are preferable, and equipment must meet national standards for grounding, pressure relief, and containment. Proper separation from high-risk zones is essential to prevent electrical incidents.

Electrical Safety:
1. Use proper earthing systems and circuit breakers to prevent electrical hazards.
2. Isolate electrical control panels in dedicated safe zones away from water lines or flammable materials.
3. Provide insulation and shielding for live parts as per IEC 60204-1.
4. Clearly label all electrical equipment and restrict access to authorized personnel only.

Ventilation, Heating and Air Conditioning:
Heating, ventilation, and air conditioning (HVAC) systems are essential for ensuring both the comfort of personnel and meeting specific process requirements within a facility. Comfortable working conditions are crucial as they directly influence employee efficiency and help minimize fatigue or discomfort caused by unfavorable environments. Areas where machines generate heat or release harmful fumes require additional ventilation to maintain air quality, with the ventilation rate typically based on the need to remove contaminants effectively, measured by air changes per unit time. Equipment like boilers, fans, and air conditioning units are usually positioned away from main work areas due to the precision needed in their operation. Boilers must have adequate airflow to ensure safe combustion and proper exhaust of by-products. Similarly, incinerators should be installed carefully to avoid issues from negative pressure gradients that could reverse airflow. Maintenance access is also vital; sufficient space should be provided around machinery for easy part replacement and tube removal if necessary. Moreover, control rooms and critical workspaces must maintain positive air pressure to prevent the infiltration of dust and fumes from the surrounding environment.

Chemical and Hazardous Material Safety :
a) Allocate separate storage zones for flammable, toxic, or reactive materials.
b) Equip storage areas with leak detection and spill containment systems.
c) Provide Material Safety Data Sheets (MSDS) for all chemicals used in the plant.
d) Follow ISO 45001 guidelines for Occupational Health and Safety Management Systems.

Environmental Safety :
a) Design for proper ventilation and exhaust systems to handle fumes, dust, and heat.
b) Include noise control measures such as barriers and enclosures around noisy machinery.
c) Provide waste disposal and recycling zones that comply with local environmental regulations.
d) Ensure that effluent treatment plants (ETPs) are properly integrated into the layout for wastewater management.

Emergency Preparedness and First Aid:
a) Provide first aid stations at easily accessible locations across the plant.
b) Ensure clear visibility and accessibility of emergency assembly points.
c) Train employees on emergency response procedures including fire, electrical, chemical, and mechanical emergencies.
d) Include automated defibrillators (AEDs) and stretchers at designated points

Site Planning:
Plant location should be chosen considering hazards, environmental impact, space needs, transport availability, and water sources. Safety professionals must influence the design to reduce risks early in the planning phase. Proper siting prevents accidents from spreading and ensures that hazardous operations do not endanger nearby communities or ecosystems.

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Storage :

Industrial facilities often face limitations in storage space, making efficient planning essential for accommodating raw materials, finished products, and equipment. Storage requirements should consider peak production demands, seasonal variations, and bulk purchasing needs. Modern handling systems, such as double or triple decking, can optimize vertical space, provided the building design allows for potential floor load increases. Effective storage layouts must ensure accessibility, safe stacking, and proper sprinkler system function, especially when materials are stacked over 3.5 meters. Items like tools, ladders, and machine parts should have designated storage areas to prevent hazards, with racks, bins, and drip pans used for oily components. Provisions for sanitary supplies and waste storage, including safe disposal methods for sharp materials, are also necessary to maintain a clean and organized workspace.

Receiving and Dispatching :

Receiving and dispatching houses should be compatible with overall material flow of the company or facility, and should support efficient material flow into and out of manufacturing areas. Individual material gate should be provided, such as liquid movement, solid logistic movement, which shall cater to all entries pertaining to excise and taxation. Receiving and dispatching spaces should be configured to minimize building heating and cooling losses.

Self-leveling dock boards, truck levelers, and cranes may be used for loading and unloading. Stores/ Load office may be located close to the gate of the material to enable inward receipt of the goods.

Truck siding separate should be given close to the material gate for truck parking after their movement of finishing goods or raw material unloading. Parking facility must also be given for tankers, which are waiting in the queue for loading/unloading. In such scenario, good communication (such as pubic address system, walky-talky, hot lines) between the parking facility and the load office must be there with security posts to manage vehicular movement. Toilet facilities and canteen should be available so that drivers' movement in the work area could be averted. Dispatch of all finished goods must be from an isolated place in the factory without disrupting the movement in work premises. A good barricade, with security gate must be made to prevent any unauthorized entry of vehicle in the plant premises.

Roads and Footpaths

A safety-focused approach in plant road and footpath design is essential to minimize accidents. Roads should be properly planned, well-constructed, and maintained with sufficient width, gentle gradients, proper drainage, and safe distances from buildings, especially at loading docks and entrances. Traffic control measures like signs, signals, mirrors at blind spots, speed breakers, and barricades must align with local regulations, with reflective signs for night use. Separate gates for shift buses and other vehicles help manage flow efficiently. Safe, direct footpaths made of concrete or gravel with clear markings should connect buildings, avoiding rough ground or railway tracks unless properly fenced and signed. Regular maintenance ensures paths remain safe, especially at crossings or during adverse weather.

Parking Areas

Parking lots in industrial plants should be ideally located between the entrance and locker rooms to reduce unnecessary movement. They must be fully fenced, well-drained, and surfaced smoothly to prevent slips and falls. Clear markings with white lines help organize parking spaces and reduce accidents, while standard stall sizes and proper aisle widths ensure ease of movement without obstruction. Both angle and straight parking have their advantages, but the layout must prevent blocking of approaches, loading zones, and clearances. Separate entry and exit points, along with proper signage, enhance traffic flow and safety. Sufficient lighting, especially at night, ensures visibility and security, and traffic at busy street exits must be managed with signals or merging lanes to avoid congestion.

IV. PLANT LAYOUT PARAMETERS

Product & Process Definition :

1. Product Types: Covers various vehicle categories and components (LCVs, HCVs, axles, engines, etc.).
2. Process Types: Assembly (manual/automated), machining (turning, milling, grinding), welding (MIG, TIG, laser, etc.).

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3. Complexity: Determined by part count, customization levels, material types (steel, aluminum).
4. Volume & Mix: Mass, batch, job-shop production with model flexibility and line balancing needs.
5. Sequence Planning: Logical part assembly/machining/welding order, including subassemblies and torque sequence.(Figure 4.0)

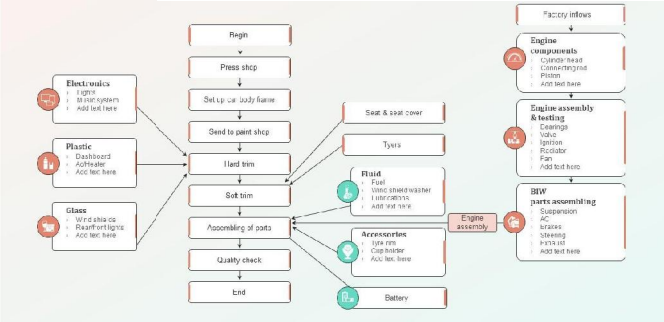

Figure 4.0: Process flow

Layout & Space Utilization :

1. Workstation Design: Ergonomic layouts with proper tool access and rework stations.
2. Line Configuration: Straight, U-shaped, or S-shaped based on plant space and flow efficiency.
3. Machine Placement: Ensures safety, maintenance access, and logical flow.
4. Clearances: For operator movement, equipment servicing, and safety zones.

Utilities & Infrastructure :

1. Power & Air Supply: Adequate electrical panels, compressed air, coolant and lubrication systems.
2. Ventilation & Safety: Fume extraction, noise control, fire safety, PPE zones.
3. Environmental Controls: Lighting, temperature, humidity, dust/fume management.

Material Handling & Logistics:

1. Flow Pattern: Lean, unidirectional, minimal backtracking.
2. Conveyance Systems: Trolleys, conveyors, AGVs for part delivery. (Figure 4.1)
3. Storage Solutions: FIFO bins, gravity shelves, tool cabinets, chip collectors.
4. Inventory & Tool Management: Barcode/RFID systems, tool libraries, presetting, SMED.

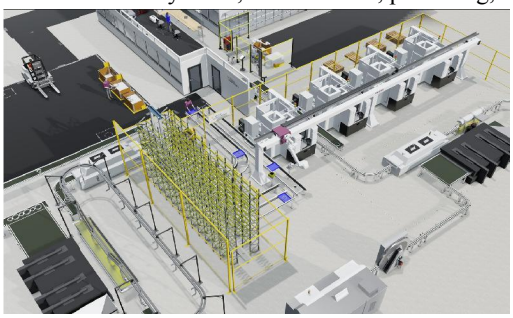

Figure 4.1: Material handling

Quality Control Integration :

1. Inspection Points: In-line and end-of-line checks for fitment, torque, surface finish, joint quality.
2. Testing Equipment: CMMs, NDT tools, real-time dashboards.
3. Error-Proofing: Poka-yoke systems, feedback loops for rework and defect prevention.
4. Documentation: Quality logs, traceability records, rework reports.

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Performance & Time Metrics :

1. Takt Time & Cycle Time: Aligned with customer demand.
2. Changeover Time: Optimized through quick-change tooling.
3. OEE & Downtime Tracking: Real-time data on availability, quality, and machine utilization.

Human Factors & Workforce :

1. Operator Requirements: Skill levels for CNC, welding, inspection.
2. Training & Flexibility: Multi-skilled workforce with ergonomic stations and welfare areas.
3. Safety Zones: Emergency stops, fences, light curtains, supervision areas.

Digital & Automation Integration :

1. MES, SCADA, IoT: Real-time process monitoring and control.
2. Automation Tools: Pick-and-place arms, vision systems, robotic welders.
3. Digital Twin & Instructions: Virtual layout simulation and screen-based SOPs.

Environmental & Sustainability Aspects :

1. Energy Consumption: Profiling per shift/product; efficient machine use.
2. Waste & Emissions: Coolant recycling, scrap handling, emission controls.
3. Noise & Air Quality: Within occupational safety norms.

Flexibility & Scalability :

1. Modular Layouts: Easily expandable zones for future capacity.
2. Adjustable Workstations: Ergonomic, multi-purpose setups.
3. Multi-Use Zones: Shared infrastructure with reconfigurable flow.

Departmental Integration :

1. Stores Interface: Timely part delivery and stock management.
2. Rework & QC Zones: Isolated from the main line to maintain flow.
3. Dispatch: Integrated with logistics and customer delivery plans.

V. SELECTION OF PLANT LAYOUT BASED ON PRODUCT VARIETY AND PRODUCTION VOLUME(FIGURE 5.0).

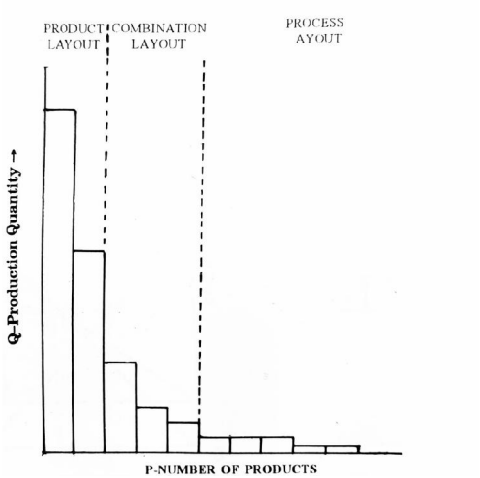

Figure 5.0: P-Q Graph

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Product Layout (Left Zone):

1) Best for low variety and high-volume production.
2) Example: Assembly lines for the same model vehicle.
3) Layout: Linear, fixed-sequence workstations.
4) Benefit: High efficiency and low unit cost.

Combination Layout (Middle Zone):

1) Suitable for moderate variety and medium production volumes.
2) Hybrid of product and process layout.
3) Often used in plants with flexible assembly lines or modular setups.
4) Balances standardization with flexibility.

Process Layout (Right Zone):

1) Ideal for high variety and low production volumes.
2) Equipment is grouped by function (e.g., all welding in one area, all machining in another).
3) Example: Job shops or custom fabrication units.
4) Focus: Customization and adaptability.

VI. MODERN TRENDS AND CASE STUDY IN PLANT LAYOUT DESIGN

One of the notable industry implementations of modern plant layout principles is observed at major commercial vehicle manufacturer in India. The company successfully transitioned from a traditional fixed assembly line to a modular U-shaped layout in several of its plants. This transformation enhanced layout flexibility, reduced material handling time, and improved safety by clearly segregating pedestrian zones and heavy equipment movement paths.Key benefits realized include:

a) 30% reduction in intra-plant logistics time.
b) Introduction of AGVs (Automated Guided Vehicles) for part delivery.
c) Enhanced visibility and supervision with U-shaped cells.
d) Digital work instructions implemented at each workstation, improving accuracy and reducing errors.

Emerging Trends in Layout Design:

Industry 4.0 Integration:

Modern plants are embedding IoT sensors, real-time monitoring, and predictive maintenance tools into their layout planning. These technologies enable smarter decisions related to space usage, machine health, and energy consumption.As the manufacturing landscape evolves with the rise of automation and digital transformation, plant layout design is also undergoing a significant shift. Traditional layouts focused on fixed, linear workflows are increasingly being replaced by modular and adaptive layouts that support flexibility, real-time responsiveness, and integration with smart technologies.

One emerging concept is the Reconfigurable Manufacturing System (RMS), which allows industries to adapt their layout to changing market demands. Unlike static layouts, RMS supports plug-and-play workstations, mobile tooling units, and scalable infrastructure, making it easier to introduce new product lines without major downtime.

Another key trend is the adoption of digital twins—virtual replicas of the physical plant layout that allow engineers to simulate operations, test layout changes, and optimize performance before physical implementation. This minimizes costly trial-and-error adjustments and improves space utilization and safety compliance.

Additionally, collaborative robots (cobots) are influencing layout planning. Since cobots work safely alongside humans, layouts now must consider shared workspaces that are ergonomically optimized and equipped with integrated safety systems such as proximity sensors and emergency stop zones., real-time data analytics is shaping dynamic layouts where bottlenecks, tool usage, and operator performance are monitored continuously. These insights lead to proactive adjustments in material flow and workload distribution, resulting in higher efficiency and lower error rates.

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Green Layout Planning:

a) Environmental sustainability is becoming central. Plants are being designed with:Natural lighting and ventilation integration.

b) Waste flow optimization and circular logistics.

c) ETPs (Effluent Treatment Plants) and solar panels incorporated into the layout design stage. Sustainability-driven layouts are also gaining traction. New plant designs increasingly incorporate solar power integration, rainwater harvesting, energy-efficient lighting, and green roofs. Environmental control systems are being designed not just for compliance, but to reduce the plant's carbon footprint and enhance the working conditions for employees.

VII. SAFETY STANDARDS APPLIED IN A MANUFACTURING PLANT

Factor	Aspect	Description of Aspect	ISO/Standard
MEN	Ergonomic tool access	Position frequently used tools within 500mm reach	ISO 14738
	Chip-protective gear	Face shields for grinding; anti-static aprons for composites	ISO 13694
	Shift rotation zones	Quiet rooms (<55 dB) for mental recovery	ISO 45003
	Skills training bays	Disabled machines for hands-on practice	ISO 9001 (Cl. 7.2)
	PPE storage near workstations	Labeled cabinets for gloves, goggles, respirators	ISO 45001 (Cl. 8.2)
	Fatigue mats at standing stations	12mm thick rubber mats with anti-slip backing	ISO 11226
	Emergency shower/eyewash	<10 sec access from grinding/EDM areas	ANSI Z358.1
MACHINE	Chip conveyor access	600mm clearance for maintenance	ISO 16090-1
	Coolant drain pans	Sloped floors (1:100) to central trenches	ISO 14001 (Cl. 8.1)
	Vibration isolation	Epoxy granite bases for high-precision grinders	ISO 10816-3
	Tramming clearance	360° access around mills/lathes	ISO 230-1
	Guard interlocks	Pressure-sensitive strips for lathe chucks	ISO 14119
	Thermal radiation barriers	Ceramic shields near furnaces/heat treatment	ISO 13732-1
	Robot maintenance aisles	≥0.8m clearance behind cells	ISO 10218-2
MATERIAL	Raw stock humidity control	40–60% RH for aluminum/steel	IATF 16949 §7.1.3.1
	Swarf vacuum ports	Centralized within 10m of machines	ISO 14122-1
	Cutting fluid bunded tanks	110% capacity + spill kits	ISO 12944-8
	FIFO rack labeling	Color-coded by material grade	ISO 9001 (Cl. 7.5)
	Hazardous waste segregation	Red bins for oily rags/solvents	ISO 14001 (Cl. 8.2)
	Scrap metal sorting lines	Ferrous/non-ferrous conveyors to balers	ISO 14021
METHODS	Tool presetting climate control	20°C ±1°C near CNC cells	ISO 13399
	CAM programming booths	Soundproofed with 300 lux lighting	ISO 6983
	Cutting parameter displays	Digital screens at each station	ISO 9001 (Cl. 8.5.1)

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	Lean kanban replenishment	Visual min/max markers at WIP zones	ISO 22468
	Poka-yoke device zones	Error-proofing stations near assembly	IATF 16949 §10.2.4
MEASUREMENT	CMM room specs	20°C ±0.5°C; vibration-isolated tables	ISO/IEC 17025
	Surface finish labs	Cleanroom (ISO Class 7)	ISO 4288
	Gauge calibration humidity	30–50% RH for precision tools	ISO 10012
	In-line inspection stations	Real-time measurement setups during production	IATF 16949 §8.6.1
	Metrology lab access restrictions	Controlled entry to ensure traceability and cleanliness	ISO 17034
	Light-controlled measurement booths	Uniform lighting conditions for accurate readings	ISO 8995-1
	Sample retention areas	Designated zones for storing tested parts	ISO 9001 (Clause 8.5.1)
	Drop prevention for instruments	Cushioned surfaces, tethering tools to avoid damage	ISO 45001 (Clause 8.1.2)
CIVIL	Floor load capacity markings	Labels indicating safe load limits on floors	ISO 12100
	Trench/drain covers	Anti-slip, load-bearing covers for floor openings	ISO 14122-1
	Seismic bracing for structures	Structural reinforcement for earthquake resistance	ISO 3010
	Column impact protection	Guarding for structural columns against forklift strikes	ISO 14122-2
	Slip-resistant flooring	Textured surfaces to prevent slips in wet/oily areas	ISO 45001 (Clause 8.1.2)
	Fire-rated partitions	Fire-resistant barriers between zones	ISO 834-1
	Dock leveler safety zones	Marked and protected zones around loading docks	ISO 16369
	Roof access restrictions	Guardrails, signage, and locks to limit roof entry	ISO 14122-3
ELECTRICAL	CNC power stability	Voltage regulators (±2%)	IEC 61000-3-12
	Coolant-proof outlets	Elevated 1.2m above floor	IP66/NEMA 4X
	Harmonic filtering	Mitigate distortion in sensitive CNC controls	IEEE 519
	Grounding	<5Ω resistance, periodic testing	IEC 60364-4-41
	Harmonics	THD (Total Harmonic Distortion) <5%	IEEE 519
	Insulation	Megger testing, arc flash labels	IEC 60204-1 / NFPA 70E
	Static Control	Ionizing bars, conductive flooring	IEC 61340-5-1

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	Cable Management	Tray fill ratios, bend radius	IEC 61537
	Short-Circuit Protection	SCCR (Short-Circuit Current Rating)	IEC 60947-1 / UL 508A
LIGHTING	General illumination (200 lux)	Basic ambient lighting level for general work areas	ISO 8995-1
	Task lighting (500+ lux)	Focused lighting for detailed operations like machining	ISO 8995-2
	Emergency lighting duration	Backup lighting with sufficient runtime during power outages	ISO 30061
	Hazard area strobes	Flashing lights to indicate danger zones	ISO 16069
	Glare control for screens	Anti-glare lighting setup to reduce eye strain at displays	ISO 9241-307
	Photoluminescent exit path markers	Glow-in-the-dark signage for safe evacuation	ISO 17398
	Lighting uniformity (0.7 ratio)	Even light distribution to minimize visual strain	CIE S 008/E
AMBIENCE	Temperature control (18–24°C)	Maintain thermal comfort in occupied zones	ISO 7726
	Humidity monitoring (30–60%)	Control moisture levels for equipment and material stability	ISO 7726
	Noise reduction barriers	Acoustic panels to isolate high-noise machines	ISO 11690-1
	Vibration-damped zones	Floors or mounts designed to absorb mechanical vibrations	ISO 2631-1
	Dust extraction at source	Capture fine particulates during cutting/grinding	ISO 15012-1
	Fume monitoring points	Sampling locations for air quality testing	ISO 15202-1
	Odor control systems	Filtration units to neutralize chemical smells	ISO 16890
	Air velocity (<0.3 m/s)	Maintain low airflow to prevent drafts and protect measurements	ISO 7730
ERGONOMICS	Adjustable workbenches	Height-adjustable benches to suit different operator needs	ISO 14738
	Anti-fatigue matting	Cushioned flooring to reduce strain from prolonged standing	ISO 45001 (Clause 8.1.2)
	Lift-assist device paths	Clear pathways for hoists, arms, and manipulators	ISO 3691-1
	Manual handling zones	Defined areas with ergonomic layout for lifting/carrying	ISO 11228-1
	Sightline clearances	Visual access zones for controls and displays	ISO 11064-3
	Footrests at standing stations	Platforms to support posture and reduce fatigue	ISO 11226
	Tool reach envelopes	Range of safe arm movements for accessing tools	ISO 14738
	Seated task legroom	Minimum clear space under benches for seated operators	ISO 9241-5
MECHANICAL	Rotating equipment guards	Fixed or removable guards for shafts,	ISO 14120

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		pulleys, and spindles	
	Pressurized system relief valves	Safety valves to release excess pressure in hydraulic/pneumatic lines	ISO 4126-1
	Alignment access for shafts	Clearance zones for shaft alignment and maintenance	ISO 7919-1
	Lubrication service points	Marked and easily accessible lube points	ISO 21469
	Thermal expansion allowances	Design clearance for heat-induced dimensional changes	ISO 14713
	Vibration sensor mounting pads	Flat, accessible areas for accelerometer or sensor attachment	ISO 10816
	Drive belt tensioning space	Room to adjust or replace belts safely	ISO 4184
	Coupling guard clearances	Guarding around mechanical couplings with proper access	ISO 14120
VENTILATION	Dust collector explosion vents	Safety vents to relieve pressure from combustible dust events	NFPA 68
	Duct access doors	Inspection and maintenance ports along duct systems	ISO 16890
	Make-up air heating	Temperature control for incoming replacement air	ISO 7730
	Local exhaust hood placements	Effective positioning of extraction hoods near emission sources	ACGIH IV Manual
	Filter change platforms	Safe, elevated areas to access and replace air filters	ISO 14122-1
	Noise dampened fans	Sound-insulated fan units to reduce HVAC noise levels	ISO 11690-2
HYDRAULIC	Fluid reservoir containment	Secondary containment to prevent fluid spills	ISO 4413
	Hose burst guards	Protective sheathing to contain fluid spray during hose failure	ISO 4413
	Pressure test ports	Safe access points for pressure measurements	ISO 10763
	Heat exchanger clearances	Space allowance for servicing and avoiding heat exposure	ISO 13732-1
	Filter service aisles	Clear access zones for replacing hydraulic/pneumatic filters	ISO 4413
	Leak detection sensors	Monitoring systems to detect fluid leaks	ISO 19879
	Fire-resistant fluid zones	Use of certified fluids and containment in high-heat areas	ISO 12922
	Accumulator safety caps	Pressure-rated covers to protect from sudden release	ISO 4413
PNEUMATIC	Air receiver drain access	Clear access to manually or automatically drain stored condensate	ISO 4414
	Silencer installations	Devices to reduce exhaust noise from pneumatic valves and actuators	ISO 11820
	Condensate collection	Systems to capture and dispose of moisture from compressed air	ISO 8573-4

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	Quick-disconnect safety locks	Safety mechanisms to prevent accidental hose disconnection	ISO 4414
	Lubricator refill stations	Accessible points for topping up pneumatic oil reservoirs	ISO 8573-5
	Pressure regulator access	Unobstructed access to adjust system pressure safely	ISO 4414
	Hose whip restraints	Restraints to prevent injury from whipping hoses under pressure loss	ISO 4414
	Dryer regeneration vents	Controlled exhaust paths for desiccant dryer regeneration cycles	ISO 12500-1
SIGNS & MARKINGS	Safety pictograms	Standardized visual symbols for mandatory, warning, and emergency signs	ISO 7010
	Pipe identification bands	Color-coded and lettered markers for pipe contents and flow direction	ANSI/ASME A13.1
	Floor traffic arrows	Directional markings to control pedestrian and vehicle movement	ISO 16069
	Chemical hazard labels	GHS-compliant signs for hazardous substances	GHS/ISO 3864-2
	Machine status indicators	Visual alerts for emergency stop, running, or fault states	ISO 13850
	Overhead clearance warnings	Signage indicating low-hanging obstructions	ISO 14122-1
	Fire equipment signs	Labels identifying extinguishers, alarms, and hydrants	ISO 7010
	Electrical voltage markings	Hazard labeling for high-voltage or arc-flash zones	NFPA 70E
FACTORY IN-SPACE	Future expansion buffers	Reserved areas for future machinery or layout flexibility	ISO 9001 (Clause 7.1.3)
	Vertical storage mezzanines	Elevated platforms for inventory or tools to maximize floor space	ISO 14122-1
	Modular utility corridors	Structured routing paths for power, water, and data lines	ISO 11064-4
	Lean aisle widths	Optimized walking and forklift lanes to minimize waste	IATF 16949 §7.1.3.1
	Overhead crane coverage	Area span and load handling capacity of bridge cranes	ISO 12480-1
	AGV charging bays	Designated, safe charging zones for Automated Guided Vehicles	ISO 3691-4
	Office visibility lines	Clear lines of sight from control offices to production areas	ISO 11064-3
	Flexible partition systems	Mobile or modular dividers to reconfigure spaces easily	ISO 17966
HYGIENE	Non-porous flooring joints	Seamless, easy-to-clean floor joints to prevent bacterial buildup	ISO 22000 (Clause 7.2.3)
	Sanitizing stations	Hand or equipment sanitization points at key locations	ISO 45001 (Clause

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			8.1.2)
	Mold-resistant walls	Wall coatings and materials that resist fungal growth	ISO 846
	Food-grade lubricant zones	Areas using lubricants certified for incidental food contact	ISO 21469
	Pest control access points	Designated areas for traps and inspection points	ISO 22000 (Clause 7.2.4)
	Locker room drainage	Sloped flooring and drains to prevent water pooling	ISO 24516-2
	Dishwashing facilities	Areas for cleaning utensils or containers under hygiene protocols	ISO 22000 (Clause 7.2.3)
	Airborne contaminant sensors	Monitoring systems for particulates and microbial content in the air	ISO 14644-1
HAZARD PROTECTION	Interlocked access doors	Doors with sensors or switches to disable machinery when opened	ISO 14119
	Light curtain positioning	Sensor placement to detect entry into hazardous zones	ISO 13855
	Fixed guard thickness	Minimum material thickness for static protective barriers	ISO 14120
	Safety distance calculations	Required spacing between hazard and guard based on human body dimensions	ISO 13857
	Robot fencing rigidity	Structural strength of enclosures around robotic work cells	ISO 10218-2
	Conveyor nip point covers	Guards to prevent hand or finger entry into pinch points	ISO 14120
	Adjustable barrier rails	Movable physical barriers to protect against machine hazards	ISO 13857
	Thermal guard materials	Heat-resistant materials for shielding near hot surfaces or equipment	ISO 13732-1
	Chemical spill berms	Containment barriers to control and isolate chemical spills	ISO 14001 (Clause 8.2)
	Laser enclosure integrity	Structural and material compliance of laser-safe barriers	IEC 60825-1
	Radiation shielding	Protective barriers against ionizing radiation exposure	ISO 15382
	Noise attenuation booths	Enclosures designed to reduce high-decibel noise from machines	ISO 11957
	Explosion relief panels	Pressure-relieving panels to protect structures from internal explosions	ISO 26873
	Arc flash barriers	Shields to prevent injury from electrical arc flash events	NFPA 70E
	Fall protection anchors	Certified anchorage points for harness-based fall protection systems	ISO 45001 (Clause 8.1.2)

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	UV exposure shielding	Protective measures against harmful ultraviolet radiation	ISO 15004-2
MEDICAL	First aid room accessibility	Easy access to medical rooms from all plant zones	ISO 45001 (Clause 8.2)
	AED locations	Placement of defibrillators at strategic points	AHA / ISO 13485
	Eyewash station flow rate	Minimum flow rate for emergency eye flushing	ANSI Z358.1
	Stretcher access routes	Clear and wide paths suitable for stretchers	ISO 21542
	Biohazard waste containers	Specialized containers for contaminated medical waste	ISO 23907
	Emergency shower tepid water	Water temperature control for safety showers	ANSI Z358.1
	Defibrillator signage	Visible and standardized signs for AED locations	ISO 7010
	Burn treatment kits	Availability of supplies for treating thermal burns	ISO 11612
WASTE COLLECTION AND CONTROL	Hazardous waste labeling	Clear labels for toxic or dangerous materials	ISO 14001 (Clause 8.2)
	Recyclable sorting stations	Separate bins for different recyclable materials	ISO 14021
	Scrap metal bins	Dedicated collection for metal offcuts and waste	ISO 14001 (Clause 8.2)
	Oil-absorbent dispensers	Stations with pads or granules for oil spill cleanup	ISO 21018-3
	Battery collection containers	Safe receptacles for spent industrial batteries	IEC 62902
	Compactor fire suppression	Explosion relief or suppression in compactor areas	NFPA 68
	Solvent recycling points	Designated areas for collection and processing of used solvents	ISO 14001 (Clause 8.2)
	Chip conveyor drainage	Proper disposal of residual coolant or chips via trenching	ISO 9905-2
AUDITORY AND VISUAL DANGER ALERT SYSTEMS	Strobe light intensity	Brightness level for visual emergency alerts	ISO 16069
	Siren decibel levels	Audible signal levels for evacuation or warnings	ISO 7731
	Exit route photoluminescence	Glow-in-the-dark path markings for emergency escape	ISO 17398
	Gas leak alarms	Detectors for hazardous gas release	ISO 7240-7
	PA system speaker coverage	Coverage area of emergency announcements	ISO 7240-19
	Machine-specific emergency stops	Emergency shutdown mechanisms at individual machines	ISO 13850
	Fire alarm pull stations	Manual fire activation devices located throughout the facility	ISO 7240-11

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	Vibration alerts for hearing impaired	Tactile feedback devices for alerts	ISO 21542
AUTOMATIONS AND ROBOTS	Collaborative robot zones	Designated spaces for human-robot interaction	ISO/TS 15066
	AGV safety scanners	Area detection sensors to stop AGVs in unsafe proximity	ISO 3691-4
	Conveyor emergency cords	Pull cords to instantly stop conveyors	ISO 13850
	Robot maintenance clearance	Minimum space behind robots for safe servicing	ISO 10218-2
	Vision system lighting	Illumination required for optical or camera-guided systems	ISO 12179
	Control panel ergonomics	Design of control stations for comfort and reach	ISO 9355-2
	Safety-rated monitored stops	Control system function to safely stop robotic movements	ISO 13849-1
	Cable management for EOAT	Routing and securing of cables on end-effectors	ISO 9409-1

VIII. CONCLUSION

In this project, a comprehensive study on safety standards in plant layout has been undertaken to emphasize the critical role of layout planning in ensuring workplace safety, operational efficiency, and environmental sustainability. A well-designed plant layout minimizes risks, prevents accidents, and enhances productivity by ensuring smooth workflow, proper equipment placement, clear emergency escape routes, and effective fire protection systems. The guidelines framed in this study integrate important aspects such as ergonomic considerations, environmental control measures, and adherence to national and international standards like ISO 45001:2018, ISO 14001:2015, and the Indian Factories Act, 1948. The project also highlights the importance of adopting modern technologies, including real-time hazard monitoring and automation, to further enhance safety and sustainability in industrial operations. Overall, this study concludes that embedding safety measures into plant layout design is not only essential for legal compliance but also serves as a strategic advantage that contributes to reduced operational risks, improved employee well-being, and long-term organizational success.

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