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Dynamic Facility Layout on Small and Medium Industries

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Abstract: Small and medium industries (SMIs) face frequent production changes, demand variability, and resource constraints. Traditional static facility layout planning methods often struggle to adapt efficiently. Dynamic Facility Layout Planning (DFLP) offers a responsive, data-driven approach. This paper reviews DFLP methods, especially metaheuristic and simulation-based optimization, and explores applications in SMIs. Two case examples are analyzed. We propose a hybrid methodology combining Systematic Layout Planning (SLP), digital twins, simulation, and metaheuristics tailored to SMIs. Finally, guidelines for practical industry deployment are given.

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I. INTRODUCTION

Facility layout design critically influences manufacturing efficiency and material flow. While Systematic Layout Planning (SLP) is widely used for static layouts, SMIs frequently require frequent layout adjustments due to changes in product mix, order volume, and space constraints. Dynamic Facility Layout Problems (DFLPs) address this by enabling reconfiguration over time while optimizing objectives like material handling, space utilization, and cost.

➢ *Industry Context*

In SMIs, limited budgets and frequent customization demand agile layout solutions. Unlike large-scale plants, SMIs must minimize downtime and avoid costly reconfiguration. Thus, dynamics must be baked into the layout planning process itself.

➢ *Objectives*

- Review DFLP methods, especially for SMIs.
- Examine case studies and academic findings.
- Propose a practical methodology synthesizing literature insights and industry constraints.

II. LITERATURE REVIEW

➢ *Static vs. Dynamic FLP*

A recent comprehensive survey distinguishes between Static Facility Layout Problem (SFLP) and Dynamic Facility Layout Problem (DFLP), highlighting that most traditional methods assume static demand and product mix. However, DFLP addresses changing conditions, making it more suitable for modern manufacturing settings.

➢ *Classical and Systematic Techniques*

SLP, proposed by Muther (1961), arranges areas hierarchically based on closeness ratings and workflow relationships to minimize material handling distance and cost. Though effective, SLP is static and often subjective.

➢ *Metaheuristics and Multi-Objective Optimization*

Recent research integrates SLP with advanced heuristics:

- Multi-objective genetic algorithms, simulated annealing, and particle swarm optimization balancing objectives such as handling cost, adjacency rating, space utilization, and even carbon emissions.
- A specialized model for unequal-area DFLP with a flexible-bay structure solved using simulated annealing delivered robust layouts under dynamic constraints without frequent rearrangements.

➢ *Simulation-Based and Digital-Twin Approaches*

Simulation-based optimization (SBO) is an emerging paradigm, integrating production and logistics constraints within planning. It creates digital-twin models to evaluate layouts under future scenarios, enabling data-driven decision-making.

A cutting-edge case study combines reinforcement learning with plant simulation to dynamically adapt layout in a modular panel assembly facility. KPIs included

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throughput, AGV utilization, handling distance, and equipment utilization, where multi-objective RL produced layouts with lower logistics distances and improved operational efficiency.

- *Literature Review on Industrial Perspectives*

A 2025 systematic literature review identified criteria such as planning approach, material handling configuration, area, generation method, metaheuristic, and evaluation approach—specifically calling for alignment with industry needs for practical re-layout strategies.

III. CASE STUDIES IN SMI

- *Triangular Flow Diagram in an Indonesian MSME*

Researchers applied the Triangle Flow Diagram and Rectilinear measurement to re-layout a hybrid corn seed plant in Indonesia. They achieved a 48.5% reduction in material movement distance, reorganized the flow into a U-shape pattern, and improved space utilization dramatically—all while respecting social distancing protocols during the pandemic.

- *PP-Bag Manufacturing SME in India*

A medium-scale plant producing polypropylene bags used modified SLP with historical production data to optimize the layout. The method reduced material handling distance, four-waste generation, improved manpower utilization, and lowered energy consumption.

IV. PROPOSED METHODOLOGY FOR DYNAMIC LAYOUT IN SMIS

- *Stage 1: Baseline Analysis via SLP*

* Conduct material flow analysis (from–to charts), closeness relationships, and space constraints.
* Use modified SLP tailored to historical flow data to generate an initial layout.
* Simple digital drawing tools (e.g. CAD, floor grid) for visualization.

- *Stage 2: Digital-Twin–Based Simulation*

* Create a lightweight digital twin (e.g. Excel-Python or simple plant simulator) to model material flows and handling equipment.
* Simulate future scenarios: demand shifts, process changes, product variants.

- *Stage 3: Metaheuristic Optimization*

* Define multiple objectives: material handling cost/distance, space utilization, adjacency relationships, possible environmental cost.
* Initialize population using SLP-derived layouts; then apply NSGA-II, simulated annealing, or PSO. Metaheuristics tailored to unequal areas and flexible bays if needed.
* Incorporate Pareto-front optimization to provide decision-makers with trade-off layouts.

- *Stage 4: Decision Support and Implementation*

* Analyze Pareto-optimal layout options with stakeholders, considering reconfiguration cost, downtime, ease of change.
* Choose layout and plan incremental deployment.

- *Stage 5: Monitoring and Continuous Re-Evaluation*

* Use low-cost tracking (e.g., infrared sensors, simple 3D mapping, IPS/MoCap) to capture live flow data.
* Periodically re-simulate and adjust layout as needed.

V. DISCUSSION

- *Cost vs. Benefit:*

While metaheuristics and simulation demand upfront investment, SMIs benefit from reduced material handling cost, improved throughput, and agility. Modified SLP combined with prior data reduces time demand.

- *Scalability:*

The hybrid method is scalable: start small with SLP + Excel simulation, then progressively add optimization modules.

- *Reconfiguration Disruption:*

Robust approaches like the simulated annealing model for unequal-area DFLP reduce the need for frequent relocations.

- *Sustainability Factors:*

Incorporating environmental criteria like carbon emissions is increasingly relevant; multi-objective models can incorporate that dimension.

VI. CONCLUSION

Dynamic facility layout planning offers SMIs the agility to respond to changing production demands without excessive cost or disruption. By combining SLP, lightweight simulation, metaheuristic optimization, and zone-based modular planning, SMIs can build robust and adaptable layouts. Continuous real-time flow monitoring enhances this adaptability further. Future work could implement a live pilot in a specific SME and evaluate performance over time.

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