FACILITY LAYOUT MODIFICATION OF EXISTING PRESSURE DIE CASTING MANUFACTURING PLANT USING CRAFT AND ACO ALGORITHMS

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Abstract
The optimization of facility layout is an important role of manufacturing system design since the layout of manufacturing departments directly effects on the material handling distance reduce, the flow of production and operational efficiency. An inefficient layout may result in unnecessary transportation, increased handling effort and poor utilization of available floor space. Here an existing pressure die-casting manufacturing plant at Tyche Cast Tech Pvt. Ltd. In order to assess the alternative department arrangements, the Load Distance method is adopted as the objective function. To explore possible enhancements in the current configuration, two optimization methods, such as Computerized Relative Allocation of Facilities Technique (CRAFT) and Ant Colony Optimization (ACO), are used. CRAFT solves the problem of arranging the department interchanges, while ACO solves the problem of assigning the departments to a specific position based on the pheromone and heuristic information. Material flow and inter-department distance are adopted as the common evaluation criteria to assess the performance of the resulted layouts. The suggested layouts will need to be further tested for actual department sizes, equipment requirements, aisles, safety clearances, or other operational considerations and conditions before being installed in practice.

Key words: Facility Layout Optimization, CRAFT, Ant Colony Optimization, Material Handling, Load–Distance, Rectilinear Distance, Die-Casting Manufacturing.

I. INTRODUCTION

The planning of the layout of a factory is an essential field of industrial engineering, because the layout of work departments, inspection facilities, storage areas and material handling routes have an immediate impact on the performance of the factory. A good layout of a facility facilitates easy movement of materials, minimizes waste of transportation and maximizes the use of space. On the other hand, an inefficient arrangement can result in more material handling, longer transportation distances, congestion and delays between successive production operations. Hence, the importance of systematic evaluation and optimization of facility layouts in order to increase the efficiency in manufacturing.

The facility layout problem is a problem that involves arranging departments in an available manufacturing area with regard to material-flow relationships, spatial requirements and operational constraints. The products flow that goes through several successive operations in a manufacturing process, department layout is a significant factor in the total travelled material-handling distance. Quantitative assessment techniques like the Load – Distance method are systematic methods that can be used to evaluate the current layout and to compare the different layout options.

The current study deals with the layout of the pressure die casting manufacturing plant namely Tyche Cast Tech Pvt. Ltd. Sullurupeta, Tirupati (Dist), AP, India. that manufactures aluminium components. The factory has 15 departments including raw material storage, chemical analysis, melting, die casting, inspection, finishing, machining, storage and dispatch. The materials flow between these departments along the manufacturing sequence and the current physical layout dictates the distance of material movement while manufacturing.

In this work, the current facility layout is analyzed by means of the department centroid coordinate information and material-flow information. The distance between department locations is calculated with rectilinear distance method and layout performance is analyzed in terms of Load Distance method. The Computerized Relative Allocation of Facilities Technique (CRAFT) is used to analyze the interchanges between departments and Ant Colony Optimization (ACO) is utilized to examine the allocation of departments' positions to other departments.

The purpose of this study is to determine if CRAFT and ACO algorithm can be used to determine better facility arrangements to reduce the calculated Load–Distance value. The resulting layouts are assessed in a standardized way. The study is meant to help with the planning of industrial facilities while simultaneously taking into account the practical aspects of implementation which need further verification of spatial, equipment, safety and operational requirements.

II. LITERATURE REVIEW

Facility layout optimization is an important approach for reducing material-handling distance and improving manufacturing efficiency.

Armour and Buffa (1963) developed a heuristic approach for determining the relative locations of facilities, providing a foundation for computer-aided layout planning. Pour and Nosraty (2006) investigated Ant Colony Optimization (ACO) for facility layout and location problems, demonstrating its potential for exploring alternative arrangements.

Hani et al. (2007) applied ACO combined with Guided Local Search to an industrial layout problem, highlighting the benefits of metaheuristic optimization. Komarudin and Wong (2010) studied Ant System techniques for unequal-area facility layout problems, considering alternative arrangements and local-search procedures. Kulturel-Konak and Konak (2011) investigated ACO for unequal-area flexible-bay layouts, emphasizing the importance of spatial constraints. Pérez-Gosende et al. (2021) reviewed facility layout planning research and discussed different optimization methods and their industrial applications.

The reviewed studies demonstrate the importance of heuristic and metaheuristic methods in improving facility layouts. However, the effectiveness of an optimization method depends on material flow, department positions, and layout constraints. In the present study, CRAFT and ACO are applied to a die-casting manufacturing plant at Tyche Cast Tech Pvt. Ltd. The 15 departments are evaluated using material-movement data, rectilinear distances, and the Load Distance objective. The two methods are compared to identify the layout that achieves a lower Load Distance value and improves material-handling efficiency.

OBJECTIVES

The main purpose of this study is to assess the current plant layout and optimize it for a pressure die-casting manufacturing plant for minimizing material handling distance and improving material flow.

Specific objectives are:

I. To assess the current configuration with the Load–Distance approach.
II. To conduct a CRAFT algorithm to explore other department interchanges.
III. To develop Ant Colony Optimization to find alternative assignments of departments.
IV. To compare the existing and optimized layouts using a common objective function.
V. To determine an alternative facility configuration for the additional practical validation.

III. METHODOLOGY

This work used the methodology of analyzing the existing facility layout, determining material-flow relationships, calculating inter-department distances, formulation of the Load Distance objective function and conducting the CRAFT and ACO tasks to investigate the different layouts. The resulting optimal solutions should be compared with each other on the same validated material-flow information and base configuration.

A. Production Flow

The work takes into account 15 departments related to the production of aluminium die-cast parts. The production process starts with Raw Material Store and the Spectro Laboratory, then to the Furnace and Die Casting departments. The parts then go through X-Ray Inspection, Fettling, Shot Blasting, R3 Storage, Machining Storage, Machining, Co-ordinate Measuring Mmachine Inspection, Final Inspection, Pre-Dispatch Inspection, Finished Goods Storage and Dispatch.

Based on the production sequence, the material-flow relationships between successive departments can be established.

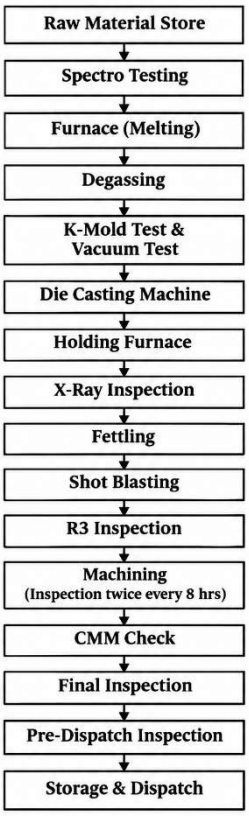


Fig. 1. Production Flow of the Die-Casting Manufacturing Plant

B. Existing Facility Layout

Existing Plant configuration is used for the baseline configuration for the optimization study. The 15 departments are shown by their centroid coordinates, which will be used as reference points to calculate distances between departments. The current arrangement is reviewed to calculate the role that inter-department distances play in the material handling requirement. The same layout data are used as the starting point for the CRAFT and ACO algorithm.

The 15 departments are represented by their centroid co-ordinates these give a reference point to calculate the distance between departments.

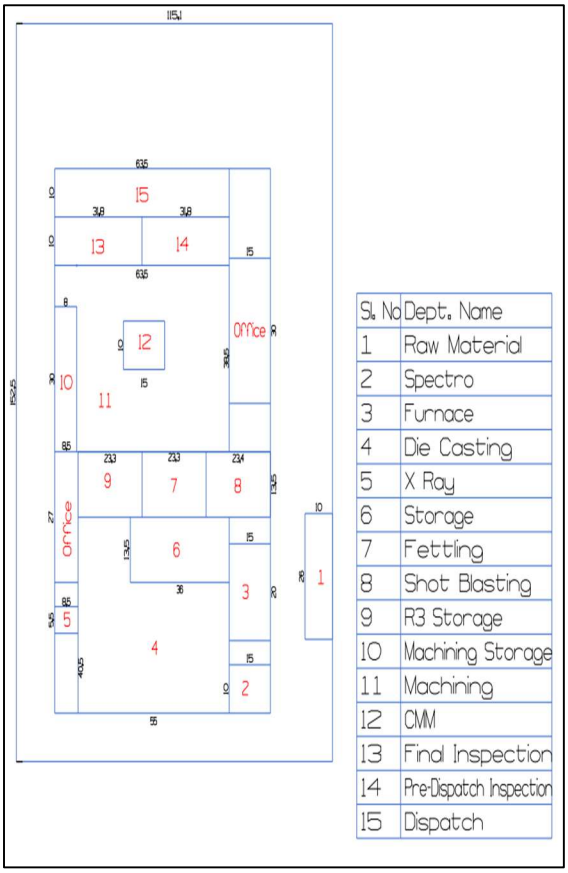


Fig. 2. Existing Facility Layout of the Die-Casting Manufacturing Plant

C. Material Flow Analysis

The sequence of production in the manufacturing plant is used to establish material flow. The project data indicated that the plant has three shifts per day and two production batches in each shift. So, it is assumed there are six material-movement trips per day for each consecutive department relationship.

The Movement Frequency is then multiplied by the corresponding IDD to get the Load–Distance value. This is carried over on every layout alternative scenario that are considered. Assume the material flows from the source.

Check the number of trips with production data prior to submission.

Table 1. Material Flow Between Departments

No.	From department	To department	Trips/day
1	Raw Material Store	Spectro Laboratory	6
2	Spectro Laboratory	Furnace	6
3	Furnace	Die Casting	6
4	Die Casting	X-Ray Inspection	6
5	X-Ray Inspection	Fettling	6
6	Fettling	Shot Blasting	6
7	Shot Blasting	R3 Storage	6
8	R3 Storage	Machining Storage	6
9	Machining Storage	Machining	6
10	Machining	CMM Inspection	6
11	CMM Inspection	Final Inspection	6
12	Final Inspection	Pre-Dispatch Inspection	6
13	Pre-Dispatch Inspection	Finished Goods Storage	6
14	Finished Goods Storage	Dispatch	6

Source: Project material-flow assumptions. Verify the trip frequency against actual production records before submission.

D. Department Centroid Coordinates

Each department has its centroid coordinate (x, y) in the units of the plant layout. These are the coordinates used for calculating the distance between departments.

Data from Department Co-ordinate Table in project report. Check the coordinates with the final drawing and decide if all the coordinates are given in meters.

The names and coordinates of the department must be the same as the layout version. Specifically, verify the meaning of the department field "Storage" and make sure that it matches the location of the finished goods at the point of storage used in the production flow.

Table 2. Department Centroid Coordinates

No.	Department	X-coordinate(m)	Y-coordinate(m)
1	Raw Material Store	57.55	132.50
2	Spectro Laboratory	71.00	5.00
3	Furnace	71.00	20.00
4	Die Casting	36.00	20.25
5	X-Ray Inspection	4.25	2.75
6	Storage	45.50	47.25
7	Fettling	66.80	60.75
8	Shot Blasting	43.45	60.75
9	R3 Storage	20.15	60.75
10	Machining Storage	4.25	74.00
11	Machining	36.00	73.25
12	CMM Inspection	36.00	73.15
13	Final Inspection	15.90	97.50
14	Pre-Dispatch Inspection	47.65	97.50
15	Dispatch	31.75	107.50

E. Rectilinear Distance Calculation

The distance between two departments is computed using the rectilinear distance method which is also called Manhattan distance method. This method is the horizontal and vertical translation of the centroids of the departments. The distance from these two department centroids, by the straight line, is therefore 15.00 coordinate units (assuming meter is the unit of size used).

Equation (1): Rectilinear Distance

$$d_{ij} = |x_i - x_j| + |y_i - y_j| \qquad Eq - (1)$$

Where:

- d_{ij} = Rectilinear distance between departments i and j.
- x_i, y_i = X- and Y-coordinates of the centroid of department i.
- x_j, y_j = X- and Y-coordinates of the centroid of department j.

Example calculation:

Using the reported coordinates of the Spectro Laboratory and Furnace:

$$d_{2,3} = |71.00 - 71.00| + |5.00 - 20.00|$$
$$d_{2,3} = 0 + 15.00 = 15.00 \text{ m}$$

Thus, the rectilinear distance between these two department centroids is 15.00 coordinate units, assuming the coordinate units are metres.

F. Load–Distance Objective Function

The method used to estimate the material-handling requirement of a facility layout is called the Load–Distance method. It takes into account the frequency of material flow between departments and the distance between the departments.

Equation (2): Total Load–Distance

$$LD = \Sigma_i \Sigma_j F_{ij} \times d_{ij} \qquad Eq - (2)$$

Where:

- LD = Total Load–Distance value.
- F_{ij} = Material-movement frequency or load from department i to department j.
- d_{ij} = Distance between departments i and j.

The objective of the optimization process is:

$$Minimize\ LD = \Sigma_i \Sigma_j F_{ij} \times d_{ij}$$

The smaller the Load–Distance value, the smaller the material-movement requirement in the calculation is for the given flow data and distance assumptions.

The units of movement frequency should be applied in the same way. The units of the objective are meter-trips per day if the flow values are trips per day and distances are measured in meters.

G. CRAFT Algorithm

Improvement-based facility layout optimization method – Computerized Relative Allocation of Facilities Technique (CRAFT). It starts from a given layout and considers alternative layouts by swapping department positions.

The distances between the departments and the Load–Distance value are recalculated for every candidate interchange. The result of this operation is compared to the current configuration, and a better configuration is stored if it meets the acceptance criteria of the method. This process is repeated for the viable interchanges studied.

The CRAFT procedure can be summarized as follows and is the procedure used in this study:

I. Determine the current facilities layout and departments.
II. Create material flow matrix for departments.
III. Find distances between centroids.
IV. Find the initial Load – Distance value.
V. Produce reasonable department interchanges.
VI. For each candidate arrangement, recalculate the Load – Distance value.
VII. Choose the preferred interchange and modify the layout.
VIII. Repeat the process until the stopping criterion is met.
IX. Write the layout chosen and its corresponding Load–Distance.

The alternatives evaluated will be used in the CRAFT algorithm to determine an improved layout. The solution may not be the optimal solution globally.

H. Ant Colony Algorithm

Ant Colony Optimization (ACO) is one of the metaheuristic optimization methods based on the foraging behavior of ants. The algorithm is applied in the current research to investigate alternative department / position assignments.

Each artificial ant constructs a candidate layout. The objective function is the Load–Distance function that is used in the evaluation of the candidate and the solution quality affects the pheromone update. Pheromone evaporation diminishes the impact of previous assignments and pheromone deposition promotes viable solutions.

1. Pheromone update equation

$$\tau_{ij(t+1)} = (1 - \rho)\tau_{ij(t)} + \Delta\tau_{ij(t)} \qquad Eq - (3)$$

Where:

- $\tau_{ij}(t)$ = Pheromone value at iteration t.
- $\tau_{ij}(t+1)$ = Updated pheromone value.
- ρ = Pheromone evaporation rate.
- $\Delta\tau_{ij}(t)$ = Pheromone deposited during iteration t.

2. ACO parameter settings

Table 3. Parameters Used in the ACO Algorithm

Parameter	Symbol	Value
Number of ants	m	30
Number of iterations	N	100
Initial pheromone	τ_0	1.0
Pheromone influence	α	1.0

Heuristic influence	β	2.0
Evaporation rate	ρ	0.5
Deposit constant	Q	100

3. ACO algorithm procedure

It is a general optimization work-flow that is described in the diagram. Precise procedures of generating candidates, updating the pheromone and stopping should correspond to the algorithm implemented.

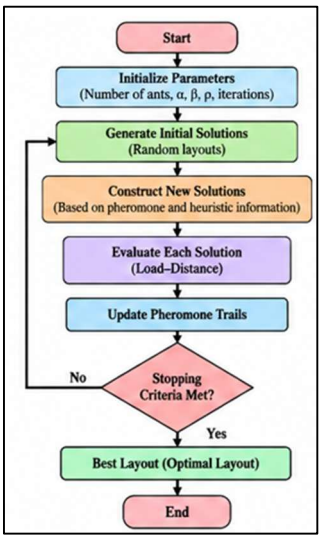


Fig. 3. ACO-Based Facility Layout Optimization

I. Performance Measures

Each layout is tested for performance according to the Load-Distance reduction and percentage improvement compared with the existing layout.

Equation (4): Absolute reduction

$$Reduction = LD_{existing} - LD_{optimized} \qquad Eq - (4)$$

Equation (5): Percentage improvement

$$Improvement\ (\%) = \left[\frac{(LD_{existing} - LD_{optimized})}{LD_{existing}}\right] \times 100 \qquad Eq - (5)$$

Where:

- $LD_{existing}$ = Load–Distance value of the existing layout.
- $LD_{optimized}$ = Load–Distance value of the optimized layout.

These measures provide a consistent basis for comparing the alternative arrangements.

IV. RESULTS AND DISCUSSION

A. Existing Layout Evaluation

Performing a layout evaluation on an existing layout. Evaluating an existing layout. The current facility configuration is analyzed based on the centroid coordinates of the departments and material-flow relationships and rectilinear distance.

To determine the baseline performance, the Load–Distance method is used for the optimized layouts. The value of 4044.00 m-trip/day is the existing-layout load-distance value verified from this study. This value is used as a benchmark as to how much is being cut under the CRAFT and ACO algorithm.

Table 4. Existing Layout Evaluation

Parameter	Value
Number of departments	15
Existing layout Load–Distance	4044.00 m-trip/day
Optimization objective	Minimize Load–Distance
Distance method	Rectilinear distance

B. CRAFT-Optimized Layout

The CRAFT algorithm compares a number of department interchanges and determines if there is an improved interchange. A Load–Distance objective function is used to evaluate each candidate arrangement and the most successful arrangement is remembered by the procedure.

The selected CRAFT layout from the main project report has a reported load distance product of 3896.00 m-trip/day. The absolute reduction is defined as: The absolute reduction is calculated as:

$$Reduction = 4044.00 - 3896.00 = 148.00\ m - \frac{trip}{day}$$

The percentage improvement is:

$$Improvement\ (\%) = \left[\frac{(4044.00 - 3896.00)}{4044.00}\right] \times 100 = 3.66\%$$

Table 5. Existing and CRAFT-Optimized Layout Comparison

Layout	Load–Distance(m-trip/day)	Reduction (m-trip/day)	Improvement (%)
Existing layout	4044.00	—	—
Selected CRAFT layout	3896.00	148.00	3.66

Note: These are the reported project values. Verify the CRAFT result using the final calculation sheet before submission.

C. ACO-Optimized Layout

The heuristic information and the pheromone are used to find the alternative department-position assignments by using the ACO algorithm. The best solution is selected during the search using the Load–Distance objective function and is kept. that the ACO Load–Distance value is reported as 3801.90 m-trip/day.

The verified baseline reduction is the absolute reduction from the baseline, which is calculated as:

$$Reduction = 4044.00 - 3801.90$$
$$= 242.10\, m - trip/day$$

The percentage improvement is:

$$Improvement\ (\%) = \left[\frac{(4044.00 - 3801.90)}{4044.00}\right] \times 100$$

$$= 5.99\%$$

Table 6. Existing and ACO-Optimized Layout Comparison

Layout	Load–Distance (m-trip/day)	Reduction (m-trip/day)	Improvement (%)
Existing layout	4044.00	—	—
Reported ACO layout	3801.90	242.10	5.99

Note: The ACO value and the associated calculations should be verified against the original program output before publication.

D. Comparative Evaluation of CRAFT and ACO Layouts

The chosen CRAFT and reported ACO arrangements are compared to the current facility layout on the same Load–Distance baseline.

Table 7. Comparative Performance of Existing, CRAFT and ACO Layouts

Layout	Load–Distance (m-trip/day)	Reduction (m-trip/day)	Improvement (%)
Existing layout	4044.00	—	—
Selected CRAFT layout	3896.00	148.00	3.66
Reported ACO layout	3801.90	242.10	5.99

The ACO value reported is 94.10 m-trip/day less than the selected CRAFT value. Based on this comparison, it seems that ACO gives the minimum objective value among the layouts given in the report on the above assumptions.

But the lower the Load–Distance value, the better is not necessarily the best answer to ACO's universal superiority over CRAFT. The results of the conclusion do not apply to any other input data, constraints, algorithm implementations or solutions different from those evaluated and examined in this study.

Table 8. Comparison of Load–Distance Values

Layout	Load–Distance (m-trip/day)
Existing layout	4044.00
Selected CRAFT layout	3896.00
Reported ACO layout	3801.90

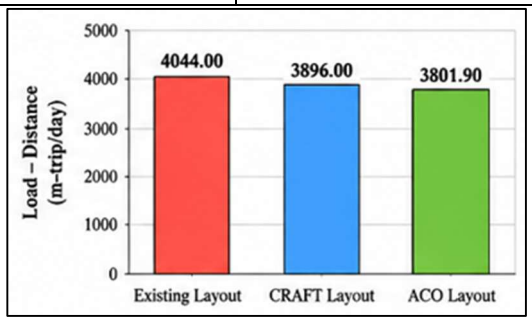


Fig. 4. Comparison of Load–Distance Values

E. Convergence Analysis of ACO

The convergence analysis looks at the changes of best objective value as the ACO algorithm is run for each of the iterations. The graph of a convergence curve usually has the iteration number on the x axis and the best value of the Load–Distance at that iteration on the y axis.

According to the project paper, the optimal value of ACO is around 3801.90 m-trip/day and the solution locks in around the seventh iteration. The reported observation should be verified with the original iteration log before it is used as a verified computational finding.

Table 9. ACO Convergence Analysis

Iteration	Best Load–Distance	Status
1	Obtain from program output	Initial search
2	Obtain from program output	Search update
3	Obtain from program output	Search update
4	Obtain from program output	Search update
5	Obtain from program output	Search update
6	Obtain from program output	Search update
7	Verify from program output	Reported convergence point
8–100	Obtain from program output	Verify stability

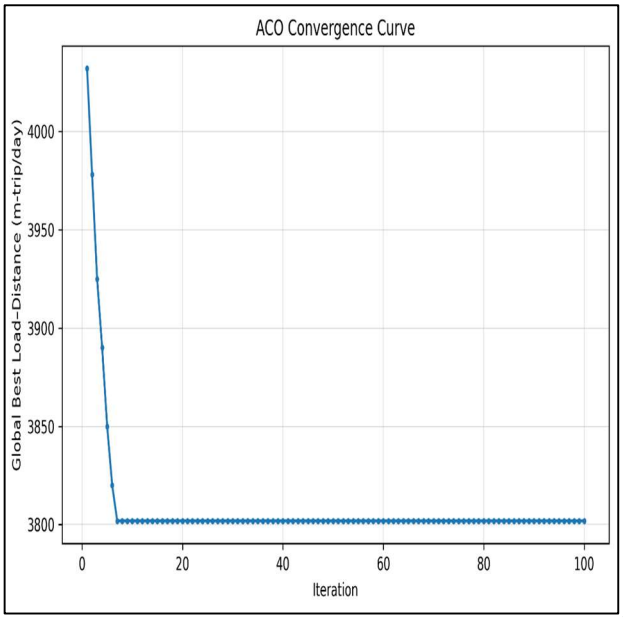
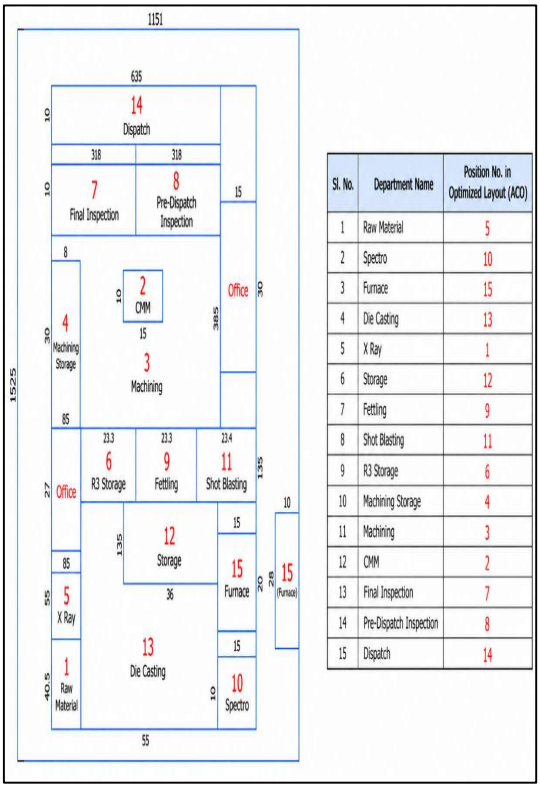


Fig. 5. Convergence Curve of the ACO Algorithm

F. Optimized Facility Layout

The optimized facility layout selected is the arrangement of the departments with the selected objective value. The plan for the new arrangement should be compared to the current one to see the effect of the location of departments on material movement.



Sl. No.	Department Name	Position No. in Optimized Layout (ACO)
1	Raw Material	5
2	Spectro	10
3	Furnace	15
4	Die Casting	13
5	X Ray	1
6	Storage	12
7	Fettling	9
8	Shot Blasting	11
9	R3 Storage	6
10	Machining Storage	4
11	Machining	3
12	CMM	2
13	Final Inspection	7
14	Pre-Dispatch Inspection	8
15	Dispatch	14

Fig. 6. ACO-Optimized Facility Layout

- All 15 departments with clearly readable names.
- The boundaries and dimensions, if available, of the department.
- Another well-defined location reference or centroid position.
- A departmental numbering system.
- Material-flow arrows that indicate the production sequence.
- Scale and orientation and relevant information for aisles, if available.

The optimized layout should maintain production relationships, and verify the space requirements, access, safety clearances, and actual building constraints. If the algorithm does not assign departments to specific positions, you must clearly state this limitation clearly.

V. CONCLUSIONS

This works deals with the layout design of a pressure die casting factory with 15 departments. Existing arrangement is assessed based on department centroid coordinates, material-flow relationships, rectilinear distance and the Load-Distance method. CRAFT and Ant Colony Optimization are viewed as techniques to determine other department configurations that have reduced calculated material-handling requirements.

The value of 4044 m-trip/day the total departments estimated CRAFT and ACO algorithms of 3896 and 3801 m-trip/day, respectively. Based on these reported values, the chosen CRAFT arrangement is a reduction of 3.66% compared to the baseline against a reported 5.99% reduction for the ACO arrangement.

Actual dimensions of the departments, equipment constraints, aisle widths, safety clearances and material handling costs should be incorporated into future work. Further computational simulations and engineering testing would enhance the credibility and commercial viability of the suggested design.

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