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Simulation based layout design of large sized multi-row Flexible Manufacturing Systems

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Abstract

The layout of workstations in a Flexible Manufacturing System (FMS) plays a very important role as it critically affects the operating efficiency, system capacity and system flexibility. An effective layout of workstations can significantly cut down manufacturing lead times. The layout of workstations is an inevitable problem in all industrial plants and the decisions regarding the layout of workstations receive intense attention in production and operations management. The layout should be expandable and adaptable, should be easily maintainable and should promote high employee morale. In the present work the optimum and near optimum layouts for a 15-workstation FMS are obtained using Ant Colony Optimisation (ACO) approach. To evaluate the system performance in a more realistic way, simulation models have to be connected to evolutionary methods to evaluate the candidate solutions.

In the present work the results obtained from ACO approach for various FMS layout alternatives have been validated using the discrete event simulation software, Flexsim Version 3.01, which is a versatile tool for modelling and simulation of manufacturing systems. Thus the most favorable number of rows and the sequence of work stations in the individual rows are established.

Keywords: Layout Design, Flexible Manufacturing Systems, ACO, Simulation, Optimization

Introduction

Layout problems are encountered in several types of manufacturing systems. Typically, layout problems are related to the location of facilities (e.g., workstations, departments) in a plant. They are known to greatly influence the system performance.

The placement of the facilities in the plant area, often referred to as ‘‘facility layout problem’’, is known to have a significant impact upon manufacturing costs, work in process, lead times and productivity.

The significant problem of facility layout is about the decision on which pairs of facilities should be located next to each other [1]. The most related machines are located adjacent to each other as possible to minimize transfer time, waiting time in queue, product cycle time, and maximize total production and machine utilization. The machine layout affects the material handling cost and time, throughput and productivity of the facility and some factors namely, material handling system used, available space, the similarity of the sequences of operations of the parts, the capability of meeting system’s requirements [2].

Unfortunately, layout problems are known to be complex and are generally NP-Hard [3]. As a consequence, a tremendous amount of research has been carried out in this area during the last few decades. The layout of the FMS, that is, arrangement of the various workstations into rows, has a definite impact on the production time and cost, especially in case of large FMSs [4]. Minimization of the total material handling costs is the most frequently considered objective in layout problems. 20–50% of the total operating expenses are composed of material handling cost, and an effective layout can reduce these costs by 10–30% [5]. Therefore, it is necessary to decide upon the optimum layout of FMSs with the most up-to-date tools much before the actual installation of the FMS, since huge installation and operational costs are involved.

Ant Colony Optimization (ACO) algorithms, or simply ant algorithms, are population-based optimization approaches that have been successfully applied to solve different combinatorial optimization problems such as Travelling Salesman Problem (TSP) [6], Quadratic Assignment Problem (QAP) [7], job-shop scheduling problem [8,9] etc. ACO algorithms are inspired by the foraging behavior of real-life ant colonies in which individual ants deposit a pheromone on the path while moving from the nest to the food sources and vice versa.

Thereby, a pheromone trail is formed, through which individual ants are aided to smell and select their routes. The paths with a higher amount of pheromone would be more likely to be selected by other ants, thus resulting in further amplification of the current pheromone trails. Because of this interesting behaviour of ants, it has been observed that after some time, a colony of ants would select the shortest path from the nest to the food source and vice versa [11].

Modeling and simulation is a problem-solving methodology for analyzing complex systems [12]. Simulation is widely used in manufacturing field because it can observe different operational patterns quickly and choose the appropriate plan to solve problems [12]. The results of simulation help in exploring the problem clearly [13]. Simulation studies are often used to measure the benefits and performance of given layouts [14]. Discrete-event modelling and simulation is used for comparing alternatives in analysing, testing and design of FMSs [15].

Gelenbe and Guennouni [16] described a simulation tool called Flexsim for modelling and analysing FMSs. Flexsim is designed to separate the specific FMS data from the simulation model to enhance the portability of the modeling tool. Flexibility of the modelling approach is important, especially for comparison of various arrangements of workstations. Hence the same simulation tool, Flexsim is used in the present work. Flexsim is used for the design, analysis, testing and comparison of FMS layout alternatives.

Application of Ace to the Layout Problem

An ant algorithm is a recently developed, population-based approach which has been successfully applied to several NP-hard combinatorial optimization problems [17].

As the name suggests, ant algorithms have been inspired by the behavior of real ant colonies, in particular by their foraging behavior. One of the main ideas of ant algorithms is the indirect communication of a colony of agents, called (artificial) ants, based on pheromone trails. The (artificial) pheromone trails are a kind of distributed numeric information which is modified by the ants to reflect their experience while solving a particular problem.

Recently, the Ant-Colony Optimization (ACO) meta-heuristic has been proposed which provides a unifying framework for most applications of ant algorithms to combinatorial optimization problems.In the present work, an FMS consisting of fifteen workstations is considered for analysis. The flow matrix and adjacency matrix are taken from the test problem given by Nugent et al [18]. The required dimensions of the workstations and the cost matrix are assumed since they are not given in the test problem. Table 1 gives the dimensions of the workstations. The flow matrix, adjacency matrix and cost matrix are shown below

Table 1 Dimensions of the workstations

Workstation Number	Dimensions of the workstations	
	Length (m)	Breadth (m)
1	5.0	3.0
2	2.0	2.0
3	2.5	2.0
4	6.0	3.5
5	3.0	1.5
6	4.0	4.0
7	2.0	2.0
8	6.0	3.5
9	3.5	3.0
10	4.5	4.0
11	2.5	2.0
12	5.5	3.0
13	3.0	2.5
14	2.0	1.5
15	4.0	3.0

$$f_{ij} = \begin{pmatrix}
0 & 20 & 20 & 40 & 70 & 20 & 10 & 0 & 10 & 30 & 0 & 0 & 10 & 0 & 20 \\
20 & 0 & 10 & 60 & 140 & 40 & 0 & 20 & 20 & 0 & 40 & 20 & 0 & 30 & 0 \\
20 & 10 & 0 & 20 & 30 & 30 & 50 & 40 & 0 & 10 & 0 & 10 & 30 & 20 & 0 \\
40 & 60 & 20 & 0 & 50 & 60 & 40 & 40 & 30 & 0 & 0 & 20 & 0 & 0 & 30 \\
70 & 140 & 30 & 50 & 0 & 80 & 70 & 30 & 20 & 30 & 10 & 0 & 20 & 30 & 0 \\
20 & 40 & 30 & 60 & 80 & 0 & 60 & 30 & 30 & 0 & 30 & 20 & 40 & 0 & 20 \\
10 & 0 & 50 & 40 & 70 & 60 & 0 & 20 & 120 & 10 & 0 & 30 & 10 & 40 & 0 \\
0 & 20 & 40 & 40 & 30 & 30 & 20 & 0 & 10 & 70 & 40 & 30 & 0 & 30 & 0 \\
10 & 20 & 0 & 30 & 20 & 30 & 120 & 10 & 0 & 30 & 100 & 60 & 20 & 10 & 20 \\
30 & 0 & 10 & 0 & 30 & 0 & 10 & 70 & 30 & 0 & 60 & 50 & 30 & 30 & 10 \\
0 & 40 & 0 & 0 & 10 & 30 & 0 & 40 & 100 & 60 & 0 & 20 & 100 & 50 & 70 \\
0 & 20 & 10 & 20 & 0 & 20 & 30 & 30 & 60 & 50 & 20 & 0 & 20 & 90 & 50 \\
10 & 0 & 30 & 0 & 20 & 40 & 10 & 0 & 20 & 30 & 100 & 20 & 0 & 10 & 90 \\
0 & 30 & 20 & 0 & 30 & 0 & 40 & 30 & 10 & 30 & 50 & 90 & 10 & 0 & 80 \\
20 & 0 & 0 & 30 & 0 & 20 & 0 & 0 & 20 & 10 & 70 & 40 & 90 & 80 & 0
\end{pmatrix}$$

$$d_{ij} = \begin{pmatrix}
0&1&2&3&4&1&2&3&4&5&2&3&4&5&6 \\
1&0&1&2&3&2&1&2&3&4&3&2&3&4&5 \\
2&1&0&1&2&3&2&1&2&3&4&3&2&3&4 \\
3&2&1&0&1&4&3&2&1&2&5&4&3&2&3 \\
4&3&2&1&0&5&4&3&2&1&6&5&4&3&2 \\
1&2&3&4&5&0&1&2&3&4&1&2&3&4&5 \\
2&1&2&3&4&1&0&1&2&3&2&1&2&3&4 \\
3&2&1&2&3&2&1&0&1&2&3&2&2&2&3 \\
4&3&2&1&2&3&2&1&0&1&4&3&2&1&2 \\
5&4&3&2&1&4&3&2&1&0&5&4&3&2&1 \\
2&3&4&5&6&1&2&3&4&5&0&1&2&3&4 \\
3&2&3&4&5&2&1&2&3&4&1&0&1&2&3 \\
4&3&2&3&4&3&2&2&2&3&2&1&0&1&2 \\
5&4&3&2&3&4&3&2&1&2&3&2&1&0&1 \\
6&5&4&3&2&5&4&3&2&1&4&3&2&1&0
\end{pmatrix}$$

$$C_{ij} = \begin{pmatrix}
0&4&4&6&4&5&3&3&2&2&4&5&6&3&2 \\
4&0&7&2&3&4&3&6&8&4&3&6&5&3&2 \\
4&7&0&5&4&2&2&3&6&4&5&3&2&6&8 \\
6&2&5&0&6&8&4&5&4&7&6&4&3&4&2 \\
4&3&4&6&0&6&4&3&6&5&8&2&5&3&4 \\
5&4&2&8&6&0&2&4&7&3&2&5&4&6&5 \\
3&3&2&4&4&2&0&8&3&6&7&8&5&2&3 \\
3&6&3&5&3&4&8&0&2&8&6&4&7&7&7 \\
2&8&6&4&6&7&3&2&0&2&4&6&8&5&6 \\
2&4&4&7&5&3&6&8&2&0&5&7&3&4&4 \\
4&3&5&6&8&2&7&6&4&5&0&2&6&6&5 \\
5&6&3&4&2&5&8&4&6&7&2&0&2&5&3 \\
6&5&2&3&5&4&5&7&8&3&6&2&0&7&8 \\
3&3&6&4&3&6&2&7&5&4&6&5&7&0&7 \\
2&2&8&2&4&5&3&7&6&4&5&3&8&7&0
\end{pmatrix}$$

By applying ACO to the problem, the optimum layout and two other near optimum solutions which minimize the total transportation cost are found out and shown in Table 2. These ACO results are for the multi-row 15-workstation FMS problem with a maximum length of row of 31m, row width of 4m and the distance between rows as 4m.

Table 2 Results for multi row 15 w/s FMS
(a = 31m; r = 4m; w = 4m)

S.No	Sequence of workstations	Total Transportation Cost from ACO
1	12-8-10-9-14-15-13-11-6-7-2-5-3-4-1	257928
2	11-8-10-9-13-14-15-12-7-2-5-4-6-3-1	278688
3	12-8-10-6-7-14-3-5-4-1-2-9-13-15-11	323452

Modeling and Simulation Using Flextime

The results obtained by ACO are to be validated by building a model and performing simulation on it using Flexsim to check the accuracy of the results. In order to build the model of the 15-workstation FMS in Flexsim and perform simulation on it, the flow matrix given in section 2 has to be converted into a network model as shown in Fig. 1.

The flow matrix is divided into 44 part types which consist of 970 parts (250+360+210+150). Parts enter the system at workstations 1, 2, 3 and 4. 13 part types (250 parts) enter the system at workstation-1, 14 part types (360 parts) enter the system at work station-2, 10 part types (210 parts) enter the system at work station-3 and 7 part types (150 parts) enter the system at work station-4. Parts after following the sequences which are shown in Table 3 leave the system at workstations 11, 12, 13, 14 and 15. 40, 110, 180, 260 and 360 parts leave the system at workstations 11, 12, 13, 14 and 15 respectively. The details of the part types, their flow through various workstations of the FMS and their quantities are shown in Tables 3, 4, 5 and 6.

Table 3 Details of parts entering at workstation-1

Part Type	Sequence of flow through workstations	No. of Parts
14	2-3-4-7-8-9-11-12-13	10
15	2-4-7-8-12	10
16	2-4-15	30
17	2-5-6-7-9-10-11	30
18	2-5-6-7-12-15	30
19	2-5-8-14	30
20	2-5-13	20
21	2-5-10-12	30
22	2-6-13	40
23	2-8-12-14	20
24	2-9-15	20
25	2-11-15	40
26	2-12-14	20
27	2-14-15	30
	Total number of parts	360

Table 4 Details of parts entering at workstation-2

Part Type	Sequence of flow through workstations	No. of Parts
14	2-3-4-7-8-9-11-12-13	10
15	2-4-7-8-12	10
16	2-4-15	30
17	2-5-6-7-9-10-11	30
18	2-5-6-7-12-15	30
19	2-5-8-14	30
20	2-5-13	20
21	2-5-10-12	30
22	2-6-13	40
23	2-8-12-14	20
24	2-9-15	20
25	2-11-15	40
26	2-12-14	20
27	2-14-15	30
	Total number of parts	360

Table 5 Details of parts entering at workstation-3

Part Type	Sequence of flow through workstations	No. of Parts
28	3-4-8-10-13	10
29	3-5-11	10
30	3-6-11-14	30
31	3-7-10-12	10
32	3-7-14	40
33	3-8-11-13-15	40
34	3-10-15	10
35	3-12-13	10
36	3-13-15	30
37	3-14-15	20
	Total number of parts	210

Table 6 Details of parts entering at workstation-

Part Type	Sequence of flow through workstations	No. of Parts
38	4-5-7-9-12	10
39	4-6-8-10-13	20
40	4-6-15	20
41	4-7-9-12	20
42	4-8-10-14	30
43	4-9-12-14-15	30
44	4-12-14	20
	Total number of parts	150

Assumptions

In order to ease the process of modeling and simulation the following assumptions are made:

1. All workstations are rectangular in shape.
2. The workstations are operated at the center of that space.
3. Processing times on all workstations are assumed to t value of 100 sec.
4. Loading and unloading times are assumed to be 10 sec.
5. Each job constitutes a unit load and mass is conserved during the network flow. This is a reasonable assumption as in a factory layout
6. The speed of the transporter is assumed to be proportional to cost matrix.
7. All workstations in the row look into the same direction as shown in Fig 2
8. There are 15 control points on the transporter route. The operator can be stopped at any control point and only at a control point. Most of these control points are designated pickup and delivery stations

These assumptions are based on prior research that has been carried out in this field. The above study assumptions also cover the input data. A model of the layout is created using the above assumptions.

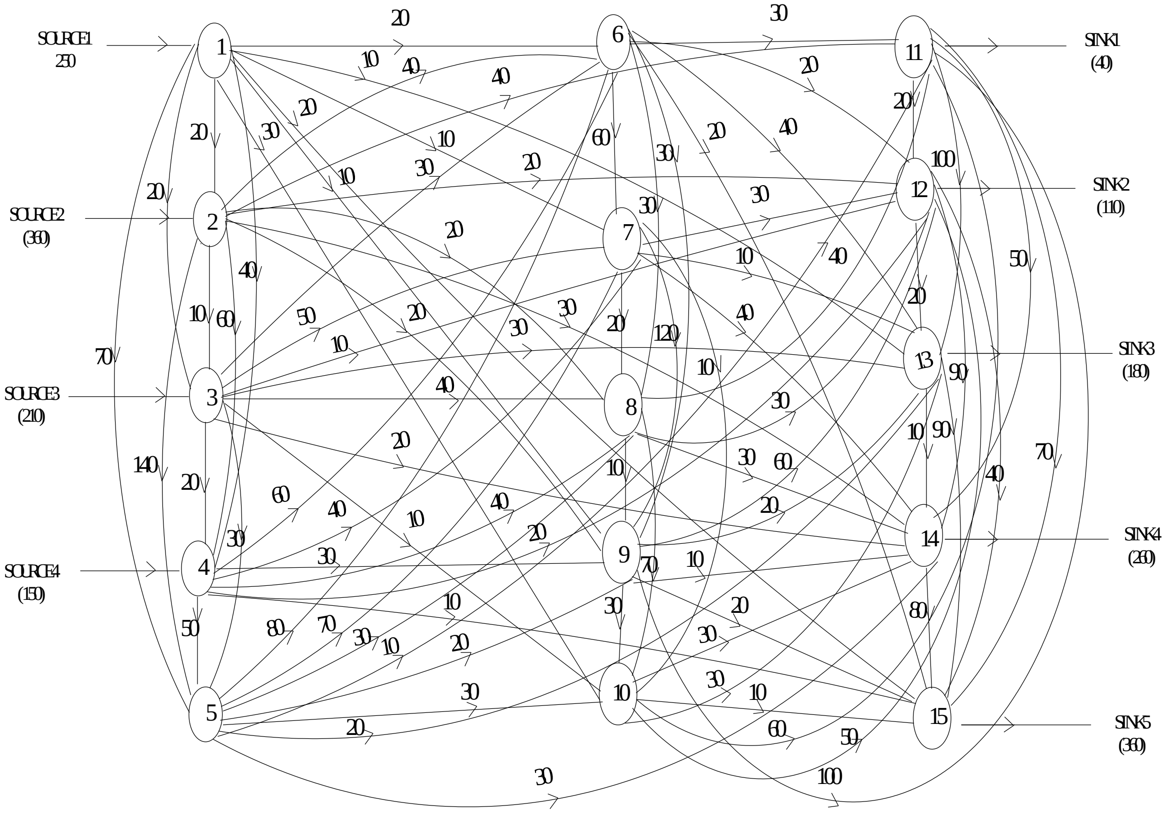
Building the model

First the model of the layout is created using Flexsim software. The model is built taking into consideration the inputs and incorporating the assumptions, so that it represents the real problem as closely as possible. The multi-row 15-workstation FMS model with a maximum length of row of 31m, row width of 4m and the distance between rows as 4m is built as shown in fig 2.

Four sources, where the parts originate, are created at workstations 1, 2, 3 and 4. 15 workstations with input and output buffers, 44 item types (970 parts) and corresponding transporters are also created. Five sinks are created at workstations 11, 12, 13, 14 and 15, where the parts leave the system.

Simulation

After building the entire model, connections are made for each item type so that every part follows its respective route through the FMS. Then simulation is performed on the model with the set parameters. A screen shot of the simulation in progress is shown in fig. 3.



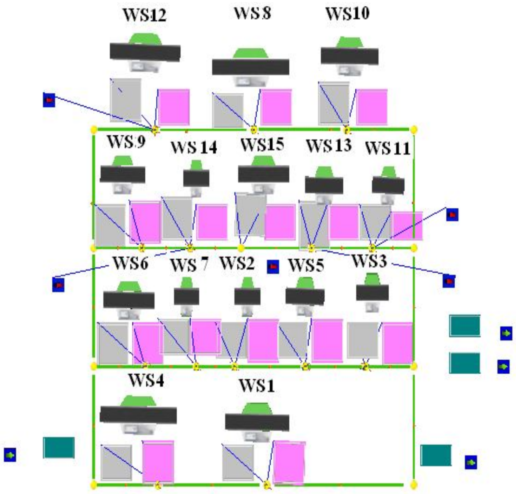


Fig 2 Model of the 15 w/s multi-row FMS for the optimum layout obtained from ACO

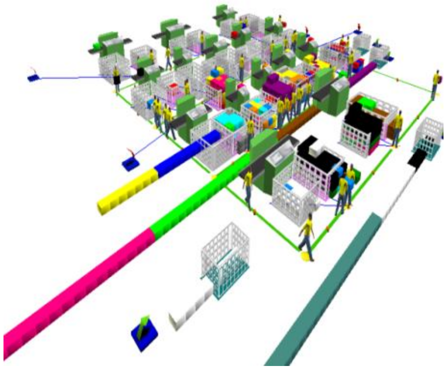


Fig 3 Screen shot of the 15 w/s multi-row FMS during simulation

Other two near optimal layouts obtained from ACO are also modeled and simulation studies performed in a similar manner. The results thus obtained are shown in Table 7. Make span is used as the criterion for evaluating the alternative layouts in Flextime.

Table 7 shows the optimum and near optimum sequences of the workstations, the corresponding values of the total cost of transportation obtained from ACO and the make span obtained from Flexsim. From these results it can be seen that, for the 15 workstation multi-row FMS, the optimum sequence of workstations obtained from ACO is 12 – 8 – 10 – 9 – 14 – 15 – 13 – 11 – 6 – 7 – 2 – 5 – 3 – 4 – 1. The make span obtained from Flexsim is also the least for the same sequence.

Table 7. Simulation results for multi-row FMS
(a =31m; r =4m; w =4m)

S.no	Sequence of workstations	Total Transportation cost from ACO	Makespan from flexsim
1	12-8-10-9-14-15-13-11-6-7-2-5-3-4-1	257928	48228
2	11-8-10-9-13-14-15-12-7-2-5-4-6-3-1	278688	48256
3	12-8-10-6-7-14-3-5-4-1-2-9-13-15-11	323452	48419

Hence the optimum arrangement of workstations obtained by ACO is in concurrence with the simulations results obtained from Flexsim

Conclusion

In summary, this paper involves developing the model and performing simulation on the layout of work stations for a 15 workstation multi-row FMS. Optimum layout and two near optimum layouts are obtained by the application of ACO for the FMS. Models of these layouts are built and simulation runs carried out using Flexsim software to validate the results by ACO. Thus it can be concluded that simulation can be used as an important tool in the layout design of multi-row Flexible Manufacturing Systems and to understand the system behavior in a more accurate way.

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