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Designing rotatable machine layout in multiple row environment

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Abstract. Arranging of non-identical machines in the limited manufacturing shop floor is one of the essential plant designs to minimise handling distance. Shorten material handling distance can be considered as a key performance index of internal logistic activity in manufacturing industry. It leads to the efficiency of productivity and related costs. The layout design is also known as facility layout problem and classified into Non-deterministic Polynomial-time hard Problem. Most previous research related to machine layout has been focused on fixed machine orientation, which means that machine can not be rotated. The rotatable rectangular-shape machines usually have an affect on the location of pick up and drop off point, area requirement and material handling distance. This paper presents the application of Genetic Algorithm (GA) for designing rotatable rectangular machine layout in a multiple-row environment aimed to minimise the total material handling distance required for manufacturing products. Computational experiments were conducted using five datasets with different rectangular to square (R/S) ratios. The experimental results obtained were analysed. The average material handling distance decreased depending on the rotatable constraints and R/S ratio.

Keywords: machine layout; orientation; rotatable machine; genetic algorithm

Introduction

Machine layout design (MLD) is the process of arranging machines into shop floor area and usually has an effect on production cost and time (Ficko et al, 2004). The effective facility layout can help to reduce the production cost by 10-30% (Tompkins et al, 2010). Shorter handling distance of material flow between machines required for manufacturing products leads to quicker transfer time within the shop floor area. Material handling distance is considered as one of the internal logistic activity's assessments (Sabóia et al, 2006). The characteristics of the layout problem can be categorised (Drira et al, 2007) by manufacturing systems (fixed layout, process layout, product layout and cellular layout), layout configurations (single row, multi-rows, loop layout, open field layout and multi-floor layout) and constrains (area, position and budget constraints). The machine orientation is classified into the positioning constraint (Drira et al, 2007). This constraint refers to either fixed (non-rotatable) or non-fixed (rotatable) facility orientation. Non-rotatable machine can only be placed in certain position either horizontal position where the longest machine dimension is parallel to the x-axis, or vertical position where the longest machine dimension is parallel to the y-axis (Corry and Kozan, 2004; Dunker et al, 2005). The rotatable facility is quite common and usually found in both production and service contexts, such as machine, workstation, conveyor, service counter, table and shelve. It results in pick-up and drop-off (P/D) point, so that the material handling distance between machines is changed. Rotating rectangular machine results in variation of total material handling distance because of its dimension (length: L and width: W).

Machine shape can be classified as regular and irregular (Drira et al, 2007). The regular shapes are usually in geometric such as square, rectangle (Deb and Bhattacharyya, 2004; Anjos and Vannelli, 2008), circular and triangular. Irregular shapes refer to non-geometric shape e.g. L-shape, U-shape and polygon, which is a flat shape with at least three straight sides and angles (Chen et al, 2011). However, machines are famously designed in rectangular shape with different sizes of dimension. In manufacturing shop floor, there are several non-identical rotatable machines. The characteristics of rotatable machines may be considered in terms of the widest, longest, shortest (minimum width) or narrowest (minimum length) dimension of the machine.

Few research works have been previously focused on rotatable non-identical machine layout design. The rotatable rectangular machine can be placed at either 0° or 90° that helps to minimise transportation cost (Scholz et al, 2010). Rotatable non-rectangular machine randomly chooses only one out of all four right-angle orientations (0°, 90°, 180° and 270°) (Bock and Hoberg, 2007). The orientation can be also applied to other facilities. These are, for examples, examining orientations of equipment unit to achieve the minimisation of the connectivity cost (Barbosa-Povoa et al, 2002), studying different orientation of blocks for making P/D closer in the passage in order to minimise flow cost, dead space and area required (Deb and Bhattacharyya, 2005), and positioning the department to be both horizontal and vertical in dynamic facility layout problem and compared with the position of department in previous period and selected the best position respect to total cost (Dunker et al, 2005; McKendall and Hakobyan, 2010). However, there has been no report on the investigation of the rotation of machine and its dimension which have an influence on total material handling cost.

Machine layout design (MLD) problem is classified as Non-deterministic Polynomial-time hard (NP-hard) problem (Loiola et al, 2007), which means that the amount of computation required to find solutions increases exponentially with problem size. Solving this kind of problem by full numerical methods especially for the large size can be computationally expensive. If there are *n* non-rotatable machines, there are *n*! possible solutions. But if machines are rotatable, there will be $n!x2^n$ possible solutions. For example, layout design of ten non-rotatable machines, a number of possible solutions are 10! (3,628,800) and will be increased to 10! x 2^{10} ($3.715x10^9$) if considering rotatable. The approximation optimisation algorithms, for example, Genetic Algorithm (Balakrishnan and Cheng, 2006; Drira et al, 2007), Simulated Annealing (Wangta and Pongcharoen, 2010), Tabu Search (Wangta and Pongcharoen, 2010) have been successfully applied to solve MLD problem but these do not guarantee optimum solution (Pongcharoen et al, 2002).

The objectives of this paper were to i) apply Genetic Algorithm for designing rotatable rectangular machine layout in a multiple-row environment aimed to minimise the total material handling distance ii) investigate characteristics of rotatable machine (rotatable constraints) that result in the solution quality. The paper is organised as follows: section 2 describes the machine layout design problem followed by Genetic Algorithm process for solving MLD problem and its pseudo-code in section 3, the experimental results are presented in section 4. Finally, a conclusion is drawn in section 5.

Layout design of rectangular rotatable machines

An example of multiple-row machine layout design is shown in Figure 1. Machines were arranged row by row by started at row 1 (R1) from left to right based on F_L and gap (G) between machines (M). When there was not enough area for the next machine, it was then placed in the next row. Vehicles moving between rows were conducted either by moving to the left or the right side of the row and then moving up or down to the destination row. The distance of material handling was evaluated from the shortest distance. For example, if transportation of materials from M12 to M4, route (3) was shorter than route (4) and was thus selected. The objective function was to minimise the material handling distance as equation (1).

$$Z = \sum_{j=1}^{M} \sum_{i=1}^{M} f_{ij} d_{ij} \; ; i \neq j \qquad (1)$$

M was a number of machines, *i* and *j* were machine sequences (*i* and *j* = 1, 2, 3,…, *M*), f_{ij} was frequency of material flow between machine *i* and *j*, d_{ij} was the distance between machine *i* and *j*.

If the machine shape was rectangle, an orientation of machine changed the handling distance. The difference in dimension was measured in a form of rectangularity which was represented by a degree of rectangular as in equation (2) and Figure 2. It was 1 for square machine, otherwise the shape was rectangle. There were a few differences in width and length, so that the degree of rectangular closed to one.

$$\text{Degree of rectangular} = \frac{\max\{L, W\}}{\min\{L, W\}} \qquad (2)$$

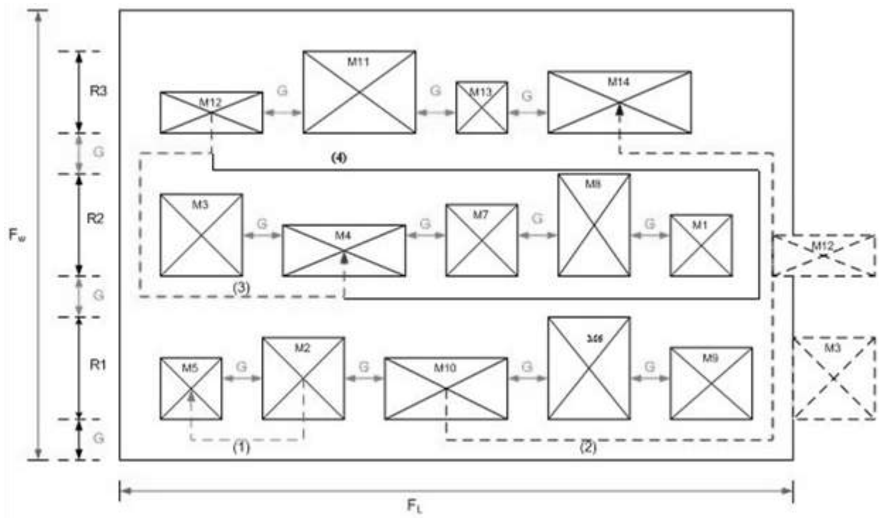
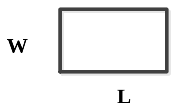
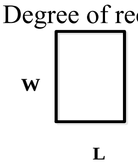


Fig. 1. Example of multiple-row machine layout design (Leechai et al, 2009)



a) if L > W ; Degree of rectangular = *L/W*



b) if W > L ; Degree of rectangular = *W/L*

Fig. 2. Calculation the degree of rectangular

In this work, the following assumptions were made in order to simplify and formulate the problem: i) the material handling distance between machines was determined from the centroid of machine; ii) there were enough sizes of shop floor area for machine arrangement; iii) the movement of AGV was a straight line; iv) a gap between machines was similar and v) the quantity of products, processing time and moving time were not taken into consideration.

Genetic algorithm for solving MLD problem

Genetic Algorithm (GA) is classified as population-based nature-inspired algorithm (Yang, 2008). A set of candidate solutions (population) is generated and individually performed through evolutionary search process. Within the evolution, exploitation and exploration processes are carried out simultaneously via crossover and mutation operations, respectively. These features play an important role in terms of getting trap or escape from local optimal. GA has been widely applied to solve various science and engineering problems especially in the productions and operations management (Aytug et al, 2003; Chaudhry and Luo, 2005).

The pseudo-code of the proposed GA for MLD shown in Figure 3 can be described as follow: i) encode the problem to produce a list of gene using alphanumeric string. Each chromosome contains a number of genes, each representing machine number, so that the length of chromosome is equal to the total number of machines to be arranged. ii) prepare input data (Number of machines: N_m and dimension of machines: width (w) x length (l), number of parts: N_p and its machine sequences: S_i) and identify parameters (Population size: Pop_size, Number of generation: G_{max}, Probability of crossover: P_c, Probability of mutation: P_m, floor length (F_L), floor width (F_W)) and gap between machines (G). iii) randomly generate an initial population based on Pop_size. iv) apply crossover and mutation operators to generate new offspring based on P_c and P_m respectively. v) arrange machines row by row based on F_L and F_W and go to rotating step in case of rotatable machine. vi) evaluate the fitness function value. vii) select the best chromosome having the shortest material handling distance using the Elitist Selection. viii) choose chromosomes for next generation by using the Roulette Wheel Selection (Gen and Cheng, 1997) and ix) stop the GA process according to the G_{max}. When GA process is terminated, the best-so-far solution is concluded.

Genetic Algorithm based machine layout designing program has been developed and coded in modular style using the Tool Command Language and Tool Kit (Tcl/Tk) programming language (Ousterhout, 2010). The program has been user-friendly designed to redefine the GA parameters and operators for each computational run. The program has been verified and validated before performing computational experiments (described in the next section), for being designed and conducted on personal computer with Intel Core i5 2.8 GHz and 4 GB DDR3 RAM.

Experimental design and analysis

In this work, five datasets were generated with different degrees of rectangularity and ratios of a number of rectangular to square (R/S) machines in order to conduct the computational experiment. Rectangular degrees were considered for three degrees: 1.25, 1.75 and 2.5, whilst the R/S ratios of 0/100, 25/75, 50/50, 75/25 and 100/0 were considered.

Two Point Centre Crossover (2PCX) and Two Operations Random Swap (2ORS) recommended by Vitayasak and Pongcharoen (2011) were adopted in this work. The probabilities of crossover and mutation used in this work were 0.9 and 0.5, respectively. The population size and number of generations had a considerable impact on the amount of search in the solution space and should therefore be related to the problem size. However, if the population size and number of generation were too high, the probability of achieving a good solution was increased but they had a significant effect on the computational time and resources. According to the previous research on the multiple-row machine layout design using Rank-based Ant System (RAS) and Shuffled Frog Leaping (SFL) (Leechai et al, 2009); the minimum results were partially obtained within 2,500 generated solutions, this figure was therefore adopted in this work.

```
Input problem dataset (Nm , w, l, Np , Si )
Parameter setting (Pop_size, Gmax, Pc, Pm, FL, FW, G)
Randomly create initial population (Pop_size)
Set i  = 1 (first generation)
While i ≤ Gmax do
For j =  1 to cross do (cross = round ((Pc x Pop_size)/2)))
Crossover operation (2PCX)
End loop for
For k =  1 to mute do (mute = round(Pm x Pop_size))
Mutation operation (2ORS)
End loop for
Arrange machines row by row based on FL , FW and G
If rotatable machine, choose machine based on constraint and rotating
Calculate material handling distance
Elitist Selection
Chromosome Selection using Roulette wheel method
i = i + 1
End loop while
Output the best solution
```

Fig. 3. Pseudo-code of GA for MLD problem

The experiment was aimed to study an influence of machine orientations (non-rotatable and rotatable) on the total material handling distance. Rotatable machines were divided into two cases: i) machines were randomly rotated without any constraints; and ii) machines were rotated according to the predefined constraints including the widest, shortest, longest, and narrowest dimension of machine. The rotating steps can be described as follows: i) choose the rotatable machine according to predefined constraints. The chosen machine was called candidate machine; ii) rotate the candidate machine by 90° and arrange machines row by row; iii) evaluate total material handling distance based on candidate machine. If it was decreased, the candidate machine was rotated. Otherwise, it was oriented as before; iv) terminate rotating and go to next step of GA. In case of constraint rotation, the candidate machine had been considered in every row. Otherwise, go to next row and return to step 1.

With five datasets and six cases, each of which had thirty replications, the total computational runs of 900 were carried out. The results obtained from the computational experiment were analysed using the analysis of variance (ANOVA) as shown in Table 1 and 2.

Table 1. Analysis of variance in R/S ratios (ANOVA).

Source	*DF*	*Type of rotatable* *Non*		*Random*		*widest*		*shortest*		*longest*		*narrowest*	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
R/S Ratio	4	13.31	0.000	7.67	0.005	3.32	0.012	5.52	0.000	6.8	0.000	6.17	0.000
Error	145												
Total	149												

Table 2. Analysis of variance in orientations (ANOVA).

Source	*DF*	*R/S ratio* *0/100*		*25/75*		*50/50*		*75/25*		*100/0*	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Orientation	5	0.00	1.000	0.43	0.828	3.36	0.006	5.06	0.000	4.17	0.001
Error	174										
Total	179										

From Table 1, R/S ratio was a significant factor with 95% confident interval with the P values of less than or equal to 0.05 in all cases of rotation. ANOVA in Table 2 shows that orientations also affected significantly the total material handling distances especially in the R/S ratios of 50/50, 75/25 and 100/0. The results suggested that both R/S ratio and orientation significantly affected the design of machine layout. Mean and standard deviation (STD) of total material handling distances with different R/S ratios and orientations are summarised and ranked in Table 3, in which the best solutions for each R/S ratio are indicated in bold. This suggested that the appropriate orientation was to rotate the widest machine in each row. The student's t-test was applied to compare the differences between the mean of total handling distances within R/S ratios and orientations. The results showed that there were no statistically significant differences on a 25/75 ratio. For other ratios, there were statistically significant differences in some orientations.

Table 3. Relative performance of orientations in each dataset.

R/S ratio	*Orientation*											
			Rotatable machine									
			Without constraint: Randomly rotate		*With constraint:*							
	Non-rotatable				*Widest*		*Shortest*		*Longest*		*Narrowest*	
	Mean	*STD*	*Mean*	*STD*	*Mean*	*STD*	*Mean*	*STD*	*Mean*	*STD*	*Mean*	*STD*
0/100	**8245.80**	226.97	**8245.80**	226.97	**8245.80**	226.97	**8245.80**	226.97	**8245.80**	226.97	**8245.80**	226.97
25/75	8364.73[2]	219.16	8390.27	181.21	**8328.84**[1]	210.99	8365.51[3]	201.52	8391.21	255.17	8395.84	198.51
50/50	8651.90	222.27	8520.84[3]	144.72	**8399.77**[1]	259.75	8529.53	275.96	8541.61	268.15	8511.40[2]	245.08
75/25	8441.86	212.54	8374.32	229.27	**8210.05**[1]	209.65	8306.39[2]	232.99	8308.94[3]	232.99	8358.15	218.97
100/0	8498.92	253.57	8453.49	217.61	**8288.81**[1]	195.97	8333.54[2]	269.38	8353.59[3]	170.90	8464.05	236.71

Table 3: (1) The best solution, **(2)** The second best solution and **(3)** The third best solution.

In each orientation, designing of machine layout with R/S ratio of 0/100 acquired the best material handling distance. Although the handling distance in case of R/S ratio of 75/25 with widest-machine orientation was shorter than the former case. However, the averages of the distances between two ratios were not significantly different by t-test. If machine shape was square or value of degree of rectangular closed to one, material handling distance was decreased. Otherwise, designing rectangular machine layout had to be considered for the orientation which related to P/D point of machine. If the machine was capable of operating in more than one side, it could be placed in both vertical and horizon position as well as in degree position. Therefore, the machine design had some effects on material handling distance.

Conclusions

This paper presents the application of Genetic Algorithm for designing non-identical rotatable machine layout by minimising total material handling distance. The effect of the R/S ratios and type of orientations on the layout design was also investigated. The computational experiment was designed using five datasets with different R/S ratios and six cases of orientation. The experimental results indicated that R/S ratio and rotatable machines significantly affected the total handling distance. Proper orientation also helped to obtain lower material handling distance.

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