



## **OPTIMAL DESIGN WITH GENETIC ALGORITHMS OF THE CELLULAR MANUFACTURING SYSTEMS**

### 1. INTRODUCTION

This article covers the optimization with genetic algorithms of the dynamic and deterministic cellular manufacturing systems (CMS). The model is developed under the following assumptions:

- The number of cells to be used must be specified in advance, and remains constant over time;
- Bounds on quantity of machines in each cell need to be specified in advance, and remains constant over time;
- Each machine type can perform one or more operations. Likewise, each operation can be done on one or more machine types with different times;
- Machines are available at the start of the period (zero installation time);
- No inventories are considered; Setup times are not considered;
- Backorders are not allowed. All demand must be satisfied the period it occurs. No queuing in production;
- Machine breakdowns are not considered;
- Processing capabilities are 100% reliable (i.e., no rework/scrap);
- Parts are moved between cells in batches (constant and independent of quantity of cells);
- Batch size is constant for all products and all periods;
- Are known also:
  - operating times for all part type operations on different machine types;
  - product mix and demand for each part type;
  - capabilities and capacity of each machine type (constants);
  - amortized cost per period to procure one machine of each type;
  - operating cost of each machine type per hour;
  - intercell material handling cost per batch between cells (constant for all moves regardless of distances);
- The time value of money is not considered in the above problem formulation due to the following reasons:
  - The length of a planning horizon is relatively short. It could be between one to two years at most. Thus, the time value of money is insignificant;
  - Existing cellular manufacturing design methods addressing dynamic production requirements do not consider this aspect;
  - Research in layout design is not concerned with the time value of money when dynamic production requirements are considered.

Multiple costs should be considered in the design objective in an integrated manner. All costs involved in the design of CMS's should be incorporated; however, it is not possible to

explicitly consider all costs in the model due to the complexity and computational time required. In this paper, costs are limited addressing dynamic and stochastic production environments and the use of routing flexibility. The objective is to minimize the sum of the following costs in an integrated manner since they could be contradicting in nature.

1. **Machine cost** refers to the amortized cost per period to procure machines. The amortized cost per period of each machine type is calculated based on the machine life, not horizon. This cost depends upon the number of machines of each type used in the CMS for a specific period.
2. **Operating cost** refers to the cost of operating machines for producing parts. This cost depends on the cost of operating each machine type per hour and the number of hours required for each machine type.
3. **Intercell material handling cost** refers to the cost of transferring parts between cells when the parts can not be produced completely in a single cell. The intercell material handling cost is incurred when batches of parts have to be transferred between cells. This occurs when parts need to be processed in multiple cells, because all the machine types required to process the parts are either not available in the cell to which the parts are allocated or because the cell does not have sufficient capacity.

## 2. CASE STUDY

There are ten different machine types available in the system. Eleven part types will be produced. The following assumptions are used for this example:

1. Each part type requires 2-4 operations. The machining requirements of part types are shown in Table 1. Each operation can be performed on at most two machine types. For instance, the first operation of part type 1 can be processed on either machine type 1 or 5 with different processing times and hence costs (shown in Table 1). The second operation, however, can be done on machine type 8 only.
2. Machine types for each operation are randomly generated. Operating costs of machine types are displayed in Table 2. Demands are shown in Table 3. A batch size for all part types is 50 units. The intercell transfer cost per batch is \$20.
3. Machine costs and capacities are shown in Table 2. Machine cost of type 8 is approximately about half of other machine costs because it can perform only one operation. Three manufacturing cells are assumed. Each cell must contain at least two machines and at most ten machines, and produce at least one part type.

## 3. OPTIMIZATION WITH GENETIC ALGORITHM

### *3.1 Objective function*

The objective function (1) minimizes the total sum of the machine investment cost, the operating cost, the intercell material handling cost over the planning horizon.

Table 1  
Machine Types, Processing Times, and Operation Costs for Part Type Operations

Part Type p	Machine/ Cell Time	Operation j							
		1		2		3		4	
		1	2	1	2	1	2	1	2
1	M/C T	M1 0.25	M5 0.78	M8 0.98					
2	M/C T	M10 0.47		M5 0.7	M8 0.65	M2 1		M7 0.92	
3	M/C T	M10 0.33		M4 0.75		M1 0.5			
4	M/C T	M9 0.32		M2 0.17	M4 0.82	M10 0.47			
5	M/C T	M3 0.13		M2 1	M4 0.55	M1 0.5		M6 0.93	
6	M/C T	M2 0.35	M4 0.53	M10 0.73					
7	M/C T	M3 1.05		M3 0.62					
8	M/C T	M5 0.35	M8 0.2	M4 0.63					
9	M/C T	M1 0.2	M5 0.47	M2 0.65	M4 0.35	M2 1.08		M3 0.15	
10	M/C T	M1 0.18	M5 0.47	M5 0.4	M8 0.9	M6 0.83			
11	M/C T	M9 0.2		M8 0.47		M2 0.62			

Table 2  
Resource Data

Machine type	Machine cost [\$]	Capacity [min]	Operating cost
1	1640	7000	24
2	1800	7000	74
3	1600	7000	36
4	1300	7000	40
5	1750	7000	47
6	800	7000	40
7	1700	7000	28
8	1700	7000	42
9	1500	7000	27
10	1500	7000	49

Table 3  
Part demand

Part type									
1	2	3	4	5	7	8	9	10	11
1030	990	980	1000	1840	990	880	870	990	1100

$$\begin{aligned} \min : & \sum_{c=1}^C \sum_{m=1}^M N_{mc} \cdot \alpha_m + \sum_{c=1}^C \sum_{m=1}^M \sum_{p=1}^P \sum_{j=1}^{O_{p-1}} D_p \cdot t_{jpm} \cdot x_{jpmc} \cdot \beta_m + \\ & + \sum_{p=1}^P \left[ \frac{D_p}{B} \right] \left( \sum_{c=1}^C \sum_{m=1}^M \sum_{j=1}^{O_{p-1}} \gamma \cdot |x_{j+1,pmc} - x_{jpmc}| \right) \end{aligned} \quad (1)$$

where:

- $c$  – index for manufacturing cells ( $c = 1, \dots, C$ );
- $m$  – index for machine types ( $m = 1, \dots, M$ );
- $p$  – index for part types ( $p = 1, \dots, P$ );
- $h$  – index for time periods ( $h = 1, \dots, H$ );
- $j$  – index for operations required by part  $p$  ( $j = 1, \dots, O_p$ );
- $t_{jpm}$  – time required to perform operation  $j$  of part type  $p$  on machine type  $m$ ;
- $D_p$  – demand for product  $p$ ;
- $B$  – batch size;
- $\alpha_m$  – amortized cost of machine of type  $m$ ;
- $\beta_m$  – operating cost per hour of machine type  $m$ ;
- $\gamma$  – intercell material handling cost per batch.

The first term represents the cost of all machines required in all the CMS. The machine investment cost is obtained by summing the product of the number of machines of each type and their respective costs. The second term is the cost of operating machines. It is the sum of the products of the number of hours of each machine type and their respective costs. The last term is the intercell material handling cost. Total intercell material handling cost is obtained by summing the products of the number of intercell transfers for each part type and the cost of transferring a batch of each part type.

### 3.2. Constraints

$$\sum_{c=1}^C \sum_{m=1}^M \alpha_{jpm} \cdot x_{jpmc} = 1, \quad \forall j, p \quad (2)$$

$$\sum_{p=1}^P \sum_{j=1}^{O_p} D_p \cdot t_{jpm} \cdot x_{jpmc} \leq T_m \cdot N_{mc}, \quad \forall m, c \quad (3)$$

$$L_B \leq \sum_{m=1}^M N_{mc} \leq U_B, \quad \forall c \quad (4)$$

where:

$$\alpha_{jpm} = \begin{cases} 1, & \text{if operation } j \text{ of part type } p \text{ can be performed on machine type } m \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

$$x_{jpmc} = \begin{cases} 1, & \text{if operation } j \text{ of part type } p \text{ is done on machine type } m \text{ in cell } c \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

and

$T_m$  – capacity of each machine of type  $m$  (hours);

$LB$  – lower bound cell size;

$UB$  – upper bound cell size;

$N_{mc}$  – number of machines of type  $m$  used in cell  $c$ ;

Constraint set 2 ensure that each part operation is assigned to one machine and one cell. Constraint set 3 ensures that machine capacities are not exceeded and can satisfy the demand. Constraint sets 4 specify the lower and upper bounds of cells.

### 3.3. Genes

For defining the chromosome, there were identified 25 genes (problem variables). The first 11 genes represent the technological itinerary of the 11 pieces which are produced. The next 11 genes show from which cell is taken the machine to process the operation  $j$  of part type  $p$ . The last 3 genes represent the structure of cells.

### 3.4. Results

The main parameters of the Genetic Algorithm were: population of 100 individuals, rank fitness assignment, roulette-wheel selection, crossover rate of 0.7, and mutation rate was 0.01.

After decoding the best solution, from the first 11 genes, the technological itinerary of the pieces which are produced is presented in table 4.

Table 4  
Technological itinerary

Variant	Machine			
	1	2	3	4
2	1	8	0	0
1	10	8	2	7
3	10	4	1	0
0	9	2	10	0
3	3	4	1	6
0	2	10	0	0
1	3	3	0	0
3	8	4	0	0
1	1	4	2	3
0	1	5	6	0
1	9	8	2	0

For example, the first technological itinerary, the first operation from part type 1 is processed on the machine number 1, and the second operation is processed on the machine number 8.

After decoding the best solution, the next 11 genes show from which cell is taken the machine to process the operation  $j$  of part type  $p$ . The results are presented in table 5.

The first technological itinerary, for example, the first operation from part type 1 is processed on the machine number 1 from cell number 3(value 2 from table 5 means cell number 3), and the second operation is processed on the machine number 8 from cell number 1(value 1 from table 5 means cell number 2).

For obtaining cell structure, those values must be decoded. After decoding the solutions are presented in table 6.

Table 5  
Machine's loading

Part type	Operation			
	1	2	3	4
1	2	1	0	2
2	1	0	1	2
3	2	1	2	1
4	2	1	2	0
5	0	1	1	0
6	0	1	1	0
7	0	0	1	0
8	0	0	0	1
9	1	1	0	1
10	2	0	0	0
11	1	0	0	0

Table 6  
Cells structure

Machine	Cell		
	1	2	3
1	0	0	1
2	0	0	1
3	0	0	1
4	0	0	1
5	0	0	0
6	1	0	0
7	0	1	0
8	0	1	0
9	1	0	0
10	0	0	1

The cell number 1 contains 2 machine types, as well as cell number 2; cell number 3 contains 6 machine types. The first technological itinerary, for example, the first operation from part type 1 is processed on the machine number 1 from cell number 3 (value 2 from table 5 means cell number 3). It is checked in table 6 if cell number 3 contains machine number 1. It is true. The second operation is processed on the machine number 8 from cell number 1 (value 1 from table 5 means cell number 2). It is checked in table 6 if cell number 2 contains machine number 8. It is true.