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Research Article

# Using Electromagnetic Algorithm for Total Costs of Sub-contractor Optimization in the Cellular Manufacturing Problem

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## Abstract

In this paper, we present a non-linear binary programing for optimizing a specific cost in cellular manufacturing system in a controlled production condition. The system parameters are determined by the continuous distribution functions. The aim of the presented model is to optimize the total cost of imposed sub-contractors to the manufacturing system by determining how to allocate the machines and parts to each seller. In this system, DM could control the occupation level of each machine in the system. For solving the presented model, we used the electromagnetic meta-heuristic algorithm and Taguchi method for determining the optimal algorithm parameters.

**Keywords:** Cellular manufacturing system, Sub-contractor cost, Queuing theory, Electromagnetic algorithm.

## 1 Introduction

Group technology (GT) is a production philosophy that improves the proactivity of production by grouping the parts and productions based on their similarities in design and production process [1]. Cellular manufacturing system (CMS) framework is one of the applications of GT. Some of the constraints of this system in real world condition are as follows: the maximum number of cells limitation, minimum cost of available parts between the machines in a cell and efficient usage of the machines in a cell [2]. For drawing the problem near to real conditions, some system parameters like the time between two consecutive arrivals of the parts, the parts processing time, machines setup time, and the system demand in deferent periods can be considered as probabilistic and/or fuzzy [3]. Queuing theory and stochastic programming will be used to model the problem, if the parameters are not considered as deterministic [4]. In a real condition, some parts need the process in more than one cell that is called exceptional elements (EEs). One of the assumptions of CMS is that the parts cannot move between the cells, so for completing the production process of these parts using the sub-contractors is a useful policy [5]. In this regard, some more detailed research has been conducted in this area [6 and 7].

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Some of the costs of this model are as follows: the cost of allocating the machines to the cells, imposed costs of EEs, cost of losses, t cost of machines failures, and so on. When a part needs to process by a specific demand that is not allocated to the cell, the part must process by a sub-contractor and this part impose the penalty cost to system [8, 9]. Some of the investigations that have been made on CMS with stochastic parameters and EEs after 1970 are presented in Table 1.

Table 1: Research on CMS with EEs after 1970

| Authors | Research background | Year | Ref |
|---|---|---|---|
| Burbidge | Cell formation+ group scheduling+ EEs | 1975 | [10] |
| King, Nakornchai | A machine-component group formation +EEs | 1982 | [11] |
| Chan, Milner | Direct clustering algorithm for group formation in CMS+EEs | 1982 | [12] |
| Kumar, Vanelli | Strategic subcontracting +CMS+EEs | 1987 | [13] |
| Seifoddini | Duplication process +GT+EEs | 1989 | [14] |
| Kern, Wei | The cost of eliminating EEs+ GT | 1991 | [15] |
| Shafer, Kern, Wei | mathematical programming+ cell formation+ EEs | 1992 | [16] |
| Tsai, Chu, Barta | Cell formation+ uncertainty+ EEs | 1997 | [17] |
| Beradi, Zhang | mathematical programming+ cell formation+ EEs | 1999 | [18] |
| Mansuri, Husseini, Zegordi | Cell formation+ EEs | 2003 | [19] |

In this paper, we identify the EEs I system and the sub-contractor that has been allocated to these parts. Also we used the continuous probability functions for system parameters so that we have a probabilistic CMS with EEs. We used queuing theory by introducing each part as a customer and each machine as a server in the system.

This paper has five sections. In the second section, we present the mathematical model of the system. The third part deals with the solving method. A numerical example is presented in section four and the last part is devoted to conclusion and further studies.

## 2 Mathematical model

In the presented model in CMS, each machines is considered as a server with a queue of the customers (parts) waiting for service. The objective function is to minimize the imposed cost of sub-contractors. The processing time of each machine and the time between two consecutive arrivals have exponential p.d.f. So, we can consider an M/M/1 queuing model for this system and the service method is FIFO.

### 2.1. System assumptions

There is no opportunity for moving a part between the cells,
The system policy is using sub-contractors for EES,
All the cost parameters are deterministic,
The operational requirements of the part are determined by the net requirement matrix,
The DM expected occupation rate of each machine is pre-defined.

### 2.2. Nomenclatures

$P$: Total number of the parts, $i=1,2,\dots,P$,

$M$: Total number of the parts, $j=1,2,\dots,M$,

$C$: Total number of the parts, $k=1,2,\dots,C$,

$a_{ij}$: A binary parameter, if $a_{ij}=1$ means that the part number $i$ needs to be processed by machine number $j$ and if $a_{ij}=0$ it does not need,

$Cc_{ij}$ : The cost of processing on the part number $i$ using the machine number $j$ by sub-contractor,

$Cp_{ij}$ : The cost of processing on the part number $i$ using the machine number $j$ ,

$Cm_{ij}$ : The cost of allocating machine number $j$ to the cell number $j$ ,

$B$ : On hand budget for allocating the machines in the cells,

$M_{Max}$; Maximum machine capacity number of the cells,

$\rho_j$ : Occupation rate of machine number $j$ ,

$U_{aj}$ Acceptable occupation rate of machine number $j$ from the viewpoint of DM,

$\lambda_i$ : Processing rate of the part number $i$ ,

$\mu_j$ Processing rate of the machine number $j$ ,

$X_{ik}$ : A binary variable, if the part number $i$ is allocated to cell number $k$ , then $X_{ik} = 1$, else $X_{ik} = 0$ ,

$Y_{ik}$ : A binary variable, if the machine number $i$ is allocated to cell number $k$ , then $Y_{ik} = 1$ , else $Y_{ik} = 0$ .

## 2.3. Mathematical model

Considering the presented assumptions, the mathematical model of the system is as follows:

$$Min\,Z = \sum_{k=1}^{C}\sum_{j=1}^{M}\sum_{i=1}^{P} Cc_{ij}.a_{ij}.X_{ik}.\left(1 - Y_{jk}\right) \tag{2.1}$$

$$St: \quad \sum_{k\in C} X_{ik} = 1 \qquad ;\forall\, i \in \{1...P\} \tag{2.2}$$

$$\sum_{k\in C} Y_{jk} = 1 \qquad ;\forall\, j \in \{1...M\} \tag{2.3}$$

$$\sum_{j\in M} Y_{jk} \le M_{max} \qquad ;\forall\, k \in \{1...C\} \tag{2.4}$$

$$\sum_{k=}^{C}\sum_{j=1}^{M}\frac{\sum_{i=1}^{P}\lambda_i.a_{ij}.X_{ik}.Y_{jk}}{\mu_j} \le 1 \quad ; \quad j = 1,2,\ldots,M \tag{2.5}$$

$$\sum_{k=}^{C}\sum_{j=1}^{M}\frac{\sum_{i=1}^{P}\lambda_i.a_{ij}.X_{ik}.Y_{jk}}{\mu_j} \ge U_{aj} \quad ; \quad j = 1,2,\ldots,M \tag{2.6}$$

$$\sum_{k=1}^{C}\sum_{j=1}^{M} Cm_{jk}.Y_{jk} + \sum_{k=1}^{C}\sum_{j=1}^{M}\sum_{i=1}^{P} Cp_{ij}.a_{ij}.X_{ik}.Y_{jk} \le B \tag{2.7}$$

$$X_{ik}, Y_{jk} \in \{1,0\} \tag{2.8}$$

## 3 Solving algorithm

As the CMS belongs to Np-Hard problems, we used the electromagnetic meta-heuristic problem for solving the presented model. Electromagnetic algorithm is a population-based problem that was presented by Birbil and Fang in 2003 [20]. This algorithm has been used for solving periodic production planning [21], rout finding [22], single machine scheduling [23], limited non-linear optimization [24], facility location of re-adjustable production systems [25], and many other problems.

This algorithm is based on attraction- repulsion mechanism to find the appropriate solution. This algorithm has four basic processes:

- Algorithm initialization,
- Local search for finding local optimal solution,
- Calculation of the total power entered to each particle,
- Moving in the direction of the entered power.

The pseudo-code of electromagnetic algorithm is presented as follows:

```
ALGORITHM. EM (popsize, MAXITER, LSITER, $\delta$)
popsize: number of sample points
MAXITER: maximum number of iterations
LSIT ER: maximum number of local search iterations
$\delta$: local search parameter, $\delta \in [0, 1]$
Initialization ()
iteration=1
while iteration < MAXITER do
    Local(LSIT ER, $\delta$)
    F= CalcF()
    Move(F)
    iteration= iteration +1
end while
```

### 3.1. Parameter tuning

For parameter tuning of this algorithm, we used Taguchi method. The results of using this method are presented in Table 2.

Table 2: The electromagnetic parameter levels in Taguchi method

| **Algorithm** | **Algorithm** | **Parameters** | **Low** | **Medium** | **High** |
|---|---|---|---|---|---|
| **EM** | *Pop size* | 10-30 | 10 | 20 | 30 |
| | *LSITER* | 3-7 | 3 | 5 | 7 |
| | $\delta$ | 0.1-0.3 | 0.1 | 0.2 | 0.3 |
| | *MAXITER* | 100-200 | 100 | 150 | 200 |

### 4 Numerical example

In this section, a numerical example is solved. In this problem, we considered a system with 3 cells, 5 machines, and 10 different parts. The maximum number of machines that can be allocated to each cell is considered 2 and the available budget is 200. In Table 3, the matrix of part-machines requirement is presented. Table 4 contains the processing cost without using sub-contractor and the processing cost using sub-contractors is presented in Table 5. The costs of allocating machines to the cells are presented in Table 6. Table 7 contains the minimum occupation rate and processing rate of the machines. Finally Table 8 contains the input and output rate of the parts.

Table 3: Part-machines requirement

| $a_{ij}$ | Machine 1 | Machine 2 | Machine 3 | Machine 4 | Machine 5 |
|---|---|---|---|---|---|
| Part 1 | 0 | 1 | 0 | 0 | 1 |
| Part 2 | 1 | 0 | 1 | 0 | 1 |
| Part 3 | 0 | 0 | 0 | 1 | 1 |
| Part 4 | 1 | 0 | 1 | 0 | 0 |
| Part 5 | 1 | 0 | 0 | 1 | 1 |
| Part 6 | 1 | 1 | 0 | 0 | 0 |
| Part 7 | 1 | 0 | 1 | 1 | 0 |
| Part 8 | 0 | 0 | 1 | 1 | 1 |
| Part 9 | 1 | 1 | 0 | 0 | 0 |
| Part 10 | 1 | 0 | 1 | 1 | 0 |

Table 4: Processing cost without using sub-contractor

| $Cp_{ij}$ | Machine 1 | Machine 2 | Machine 3 | Machine 4 | Machine 5 |
|---|---|---|---|---|---|
| Part 1 | 4.5 | 2.1 | 5.4 | 4.3 | 4.2 |
| Part 2 | 2.3 | 3.7 | 4.6 | 1.2 | 4.6 |
| Part 3 | 4.2 | 5.9 | 1.9 | 2.8 | 4.3 |
| Part 4 | 1.3 | 2.2 | 4.1 | 2.9 | 4.4 |
| Part 5 | 5.2 | 3.1 | 2.7 | 4.6 | 4.9 |
| Part 6 | 5.3 | 2.1 | 2.5 | 4.1 | 5.6 |
| Part 7 | 1.7 | 3.6 | 5.7 | 3.4 | 1.8 |
| Part 8 | 4.4 | 1.4 | 2.2 | 2.1 | 2.6 |
| Part 9 | 3.3 | 4.9 | 4.7 | 1.9 | 2.8 |
| Part 10 | 5.2 | 5.6 | 1.7 | 1.3 | 4.7 |

Table 5: Processing cost using sub-contractors

| $Cc_{ij}$ | Machine 1 | Machine 2 | Machine 3 | Machine 4 | Machine 5 |
|---|---|---|---|---|---|
| Part 1 | 9.5 | 7.1 | 10.4 | 9.3 | 9.2 |
| Part 2 | 7.3 | 8.7 | 9.6 | 6.2 | 9.6 |
| Part 3 | 9.2 | 10.9 | 6.9 | 7.8 | 9.3 |
| Part 4 | 6.3 | 7.2 | 9.1 | 7.9 | 9.4 |
| Part 5 | 10.2 | 8.1 | 7.7 | 9.6 | 9.9 |
| Part 6 | 10.3 | 7.1 | 7.5 | 9.1 | 10.6 |
| Part 7 | 6.7 | 8.6 | 10.7 | 8.4 | 6.8 |
| Part 8 | 9.4 | 6.4 | 7.2 | 7.1 | 7.6 |
| Part 9 | 8.3 | 9.9 | 9.7 | 6.9 | 7.8 |
| Part 10 | 10.2 | 10.6 | 6.7 | 6.3 | 9.7 |

Table 6: The cost of allocating the machines to the cells

| $Cm_{jk}$ | Cell 1 | Cell 2 | Cell 3 |
|---|---|---|---|
| Machine 1 | 20 | 12 | 23 |
| Machine 2 | 16 | 15 | 21 |
| Machine 3 | 22 | 13 | 24 |
| Machine 4 | 14 | 17 | 23 |
| Machine 5 | 19 | 21 | 25 |

Table 7: Minimum occupation rate and processing rate of the machines

| | Machine 1 | Machine 2 | Machine 3 | Machine 4 | Machine 5 |
|---|---|---|---|---|---|
| $U_{aj}$ | 0.1195 | 0.1557 | 0.1094 | 0.1915 | 0.1930 |
| $\mu_j$ | 10.722 | 11.7745 | 10.5508 | 11.8308 | 8.9628 |

Table 8: Input and output rate of the parts

| | Part 1 | Part 2 | Part 3 | Part 4 | Part 5 | Part 6 | Part 7 | Part 8 | Part 9 | Part 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ${}_i\lambda$ | 3.5576 | 2.8469 | 2.1816 | 2.5329 | 2.3073 | 2.5620 | 2.8802 | 3.0543 | 2.9148 | 3.7507 |

The presented example was solved with electromagnetic algorithm and tuned parameters. The convergence trend is presented in Figure 1. Also the final results are presented in Tables 9 and 10.

Figure 1: Convergence diagram of Electromagnetic algorithm

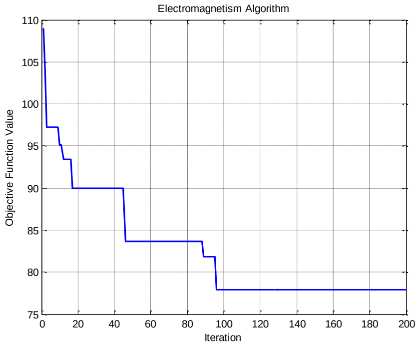

Table 9: Allocating parts to the cells

| $X_{ik}$ | Cell 1 | Cell 2 | Cell 3 |
|---|---|---|---|
| Part 1 | 0 | 1 | 0 |
| Part 2 | 0 | 0 | 1 |
| Part 3 | 1 | 0 | 0 |
| Part 4 | 0 | 0 | 1 |
| Part 5 | 1 | 0 | 0 |
| Part 6 | 0 | 1 | 0 |
| Part 7 | 0 | 0 | 1 |
| Part 8 | 1 | 0 | 0 |
| Part 9 | 0 | 1 | 0 |
| Part 10 | 0 | 1 | 0 |

Table 10: Allocating the machines to the cells

| $Y_{jk}$ | Cell 1 | Cell 2 | Cell 3 | $\rho_j$ |
|---|---|---|---|---|
| Machine 1 | 0 | 1 | 0 | 0.9161 |
| Machine 2 | 0 | 1 | 0 | 0.7673 |
| Machine 3 | 0 | 0 | 1 | 0.7829 |
| Machine 4 | 1 | 0 | 0 | 0.6376 |
| Machine 5 | 1 | 0 | 0 | 0.8416 |

We used the results of this example for solving the problems in different sizes. All the examples have been solved with a Pentium 4 (1.73 GHz, 4 GB Ram) PC using Matlab 7.12. The parameters and the results of this problem are presented in Table 11. All other parameters $\left(a_{ij}, Cp_{ij}, Cc_{ij}, Cm_{jk}, U_{aj}, \lambda_i, \mu_j\right)$ were produced randomly using the uniform distribution function as follows:

- The value of demand matrix using uniform p.d.f between 0, 1.
- Other parameters:

$$\left(Cp_{ij} \sim U[4,10], Cc_{ij} \sim Cp_{ij} + U[2,5], Cm_{jk} \sim U[10,20], U_{aj} \sim U[0.1,0.2], \lambda_i \sim U[2,4], \mu_j \sim U[10,20]\right)$$

Table 11. Results for the examples with different sizes

| Problem | C | M | P | B | $M_{max}$ | Z |
|---|---|---|---|---|---|---|
| 1 | 3 | 3 | 5 | 120 | 2 | 28.67 |
| 2 | 3 | 4 | 6 | 160 | 2 | 32.22 |
| 3 | 3 | 4 | 8 | 190 | 3 | 66.35 |
| 4 | 3 | 6 | 10 | 240 | 4 | 89.46 |
| 5 | 3 | 12 | 25 | 500 | 12 | 257.32 |
| 6 | 3 | 15 | 25 | 600 | 12 | 298.12 |
| 7 | 4 | 20 | 30 | 700 | 14 | 341.23 |
| 8 | 4 | 25 | 35 | 800 | 17 | 497.60 |
| 9 | 5 | 28 | 40 | 1000 | 19 | 579.83 |
| 10 | 5 | 30 | 50 | 1500 | 24 | 744.16 |

## 5 Conclusion and further studies

In this paper a non-linear binary programing for optimizing total cost of sub-contractors in a CMS in a stochastic area has been developed. Because this problem belongs to Np-Hard problems we used electromagnetic meta-heuristic algorithm for solving the problem and tuned the algorithm parameters with Taguchi algorithm. Many different problems with different sizes have been solved and the results compared with each other's.

For further studies adding some assumptions for changing in state-space diagram and the queuing model can be consider. Also this problem can be solved with other methods.

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