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Modeling the Trade-off between Manufacturing Cell Design and Supply Chain Design

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A B S T R A C T

Nowadays, we are witnessing the growth of firms that distribute the production capacity of their products to a wide geographic range to supply the demand of several markets. In this article, the relationships and interactions between cell design and supply chain design are investigated. For this purpose, a novel integrated model is presented for designing dynamic cellular manufacturing systems in supply chain design. Different components in the supply chain design, such as location of production facilities at a number of candidate sites, procurement of raw materials from suppliers, shipment of raw materials to production facilities, manufacturing of products, and distribution of products to markets are considered in dynamic environments. The costs concerning these components are minimized. Since the proposed problem is NP-hard, however, a genetic algorithm is presented for application of the model to real-sized instances. Numerical examples demonstrate that the algorithm performs successfully in searching for optimal or near-optimal solutions.

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NOMENCLATURE

Indices			
p	Product types ($p=1,2,\ldots,P$)	C_{pqh}	Cost of producing product type p in a cell of size q and in time period h
i	Candidate sites ($i=1,2,\ldots,I$)	B_{pimh}	Outbound logistics cost of product type p from facility i to market m in time period h
k	Cells ($k=1,2,\ldots,K_i$)	B'_{cish}	Inbound logistics cost of component type c from supplier s of facility i in time period h
j	Machine types ($j=1,2,\ldots,J$)	UM	Maximum number of authorized machines in each cell
c	component ($m=1,2,\ldots,C$)	CP_{cp}	The amount of component c required for produce a unit of product p
m	Markets ($m=1,2,\ldots,M$)	RS_{csh}	Binary parameter, equals one if supplier s is capable of producing component c in period h ; equals zero otherwise
s	Suppliers ($s=1,2,\ldots,S$)	PS_{sch}	Cost of procuring component c from supplier s in time period h
q	Cell sizes ($q=1,2,\ldots,Q$)	M'	A great positive number
h	Time periods ($h=1,2,\ldots,H$)		
Parameters		**Decision Variables**	
A_j	Available time for a machine of type j in each time period	X_{pikmqh}	Binary variable, equals one if demand of market m for product type p in time period h is assigned to cell k of size q in facility i ; equals zero otherwise
K_i	Maximum number of cells that can be formed in facility i	W_{pikh}	Binary variable, equals one if product type p is assigned to cell k in facility i and in time period h ; equals zero otherwise

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U_q	Number of products that can be produced in a cell of size q	Z_{ikqh}	Binary variable, equals one if cell k in facility i and in time period h is of size q ; equals zero otherwise
F_j	Amortized cost of a machine of type j in each time period	R_{csih}	Volume of component type c transferred from supplier s to facility i in period h
S_j	The set of products that require machine type j	V_{ih}	Binary variable, equals one if facility i is established in time period h ; equals zero otherwise
$\alpha 1_j$	Cost of removing a machine of type j from a cell	Y_{jikh}	Number of machines of type j assigned to cell k of facility i in time period h
$\alpha 2_j$	Cost of transferring a machine of type j from a cell to another in the same facility	$Y1_{jikh}$	Number of machines of type j added to cell k of facility i at the beginning of time period h
$\alpha 3_j$	Cost of transferring a machine of type j from a cell to another facility	$Y2_{jikh}$	Number of machines of type j removed from cell k of facility i at the beginning of time period h
G_{ih}	Amortized fixed cost for establishment of facility i in time period h	$Y11_{jikh}$	Number of machines of type j transferred between cells in facility i . These machines are added to cell k of facility i at the beginning of time period h
T_{pj}	Time required for producing product type p on a machine of type j	$Y12_{jikh}$	Number of machines of type j transferred between facilities. These machines are added to cell k of facility i at the beginning of time period h
D_{pmh}	Demand of product type p in market m and in time period h	$Y13_{jikh}$	Number of machines of type j purchased for cell k of facility i at the beginning of time period h

1. INTRODUCTION

Consumers have always tended to select local products due to limited sales data and trade obstacles. Globalization, however, has provided modern consumers with easier access to global markets. The phenomenon has faced present-day business with new challenges. A supply chain is a complex logistics system that turns raw materials into goods, and distributes them to the final consumers. Raw materials are supplied by the facilities, and then converted into products, which are in turn converted into final goods, delivered to customers through a distribution system [1]. Group Technology (GT) has been common in the manufacturing environment for almost six decades. A Cellular Manufacturing System (CMS) is an application of GT. It is a production system where products families are defined as containing similar products, and different machines are assigned into machine cells [2].

Traditionally, the problems of the CMS design and SC design are analyzed separately. In fact, firms first design the SC and determine the number and locations of facilities; demands for each of the facilities and distribution centers are then determined. The production system (i.e. job shop, flow shop, or cell design) within each facility are finally specified [3]. Through integration of the SCM with the SC, total costs can be reduced, and customer demand can be responded to more quickly, and, consequently, firms can obtain more profit by considering the SC and CMS design in an integrated procedure.

The structure of the article is organized as follows. In section 2, research conducted in the field of CMSs is investigated with a focus on the design of the systems in the SC. In section 3, the problem under investigation is presented in the form of a linear integer model. In section 4, a genetic algorithm (GA) is designed for solving the proposed model. The designed parameters and examples are stated in section 5, where the proposed mathematical model output, solution analysis, and GA output are also examined. Section 6 is dedicated to summarizing the article and presenting suggestions for future research.

2. LITERATURE REVIEW

The first stage in designing a CMS is the Cell Formation Problem (CFP), where a set of manufacturing cells are formed [4]. Concerning the specification of the components, locations and physical flow quantities, the network design problem has strategic importance for SCM [5]. Identifying the integration requirement of CMS and SCM, Rao and Mohanty [3] illustrated the interrelationships in designing issues between CMS and SC design through an example. They demonstrated that cell design can affect production facility location, raw material procurement, and finished goods distribution. Schaller [6] presented a new mathematical model with multiple production facilities and multiple markets to address the problems of facility location, allocation of market demands to facilities, and cellular manufacturing system design within each facility with an integrated approach. In order to present an integrated dynamic cellular manufacturing and supply chain design model, Saxena and Jain [7] considered different issues such as multi-plant locations, multiple markets, multi-time periods, and reconfiguration. They also solved their model by utilizing both ordinary and hybrid artificial immune systems.

Benhalla et al. [8] presented a novel mathematical model for integration of the cellular manufacturing system design into the supply chain design. They would produce several products in the proposed design, and the raw materials required by the factories would be procured from the suppliers. Graves and Willems [9] studied the supply chain in firms that seek to reconfigure their systems given the possibility to produce new products. They made decisions concerning product design and manufacturing. Kazemi et al. [10] presented a mixed-integer nonlinear programming model to design a DCMS by considering the burdened costs of processing part operations, idleness of cells and machines, inter-cell movements, installation/ uninstallation of machines, machine overhead, production lots, splitting production lots and dispersing machines among cells. Heydari et al. [11] presented a unified fuzzy mixed integer linear programming model to make the interrelated cell formation and supplier selection decisions simultaneously and to obtain the advantages of this integrated approach with product quality and, consequently reduction of total cost.

Aalaei and Davoudpour [12] presented a novel single-period mathematical programming model for integration of cellular manufacturing systems and supply chain design. The effect of new factors such as human resource allocation in the integrated model has been shown in the proposed model. Aalaei et al. [13] developed a two-stage approach to solve a multi-dynamic virtual cellular manufacturing system in multi-market allocation and production planning. For the purpose of minimizing the cost of holding and outsourcing, outbound transportation, machines and removal, hiring, firing, and salary workers, Aalaei and Davoudpour [14] presented a new mathematical model for integration of dynamic cellular manufacturing into the supply chain system. They extensively covered important manufacturing features, and considered multi-plant locations, multi-market allocation, and multi-period planning horizons. Aalaei and Davoudpour [15] presented a new mathematical model. They considered various conflicting objectives simultaneously. The objective functions of the model included different types of cost such as those of maintenance, outsourcing, and machinery.

Soolaki and Arkat [16] developed a novel model for integrating CMSs into the SC network. The purpose of the proposed model was to minimize various types of cost statements such as costs of intercellular movement, procurement, production, and machine breakdown. Soolaki and Arkat [17] presented a novel mathematical model for four-level SC design by considering the different stages of the chain (such as procurement, production, and distribution), making strategic and operating decisions simultaneously, presenting a proper plan for the procurement of the components and products in different periods, and designing the hybrid genetic ant lion optimization (HGALO) algorithm.

In short, the contribution aspects of our paper are as follows:

- presentation of a new model for integration of dynamic cellular manufacturing system design into three-level supply chain design,
- presentation of an appropriate solution for making operational and strategic decisions simultaneously in each time period in the supply chain system,
- design of the genetic algorithm and demonstration of its efficiency in finding the optimal and near-optimal solutions to small- to large-sized problems.

In view of the previous works summarized above, it could be useful to incorporate the multi-supplier problems and procurement of raw materials in the integration of CMS and SCM. To make up for these omissions, the CMS, SCM and sourcing decisions for each production facility are integrated in the proposed model.

3. MATHEMATICAL MODEL

In the present research, it is assumed that a large firm seeks to establish a number of facilities (manufacturers) to develop its production activities in multiple geographically scattered markets. Use of the CMS seems to be a proper alternative due to the great variety and large demand size of products. As the consumer market of the products produced by the above firm is widespread, the facilities will be located in a distributed fashion to reduce shipment costs. One or more machine cells are formed in each of the facilities for production of one or more product families. Since some of the machines are expensive, it is possibly preferred that machines are transferred between different facilities for performing some of the processes instead of using multiple identical machine in the facilities. The main purpose of the problem is to select a number of potential sites for establishment of facilities. Furthermore, it must be specified what machines are established in each facility, what products are produced, and which suppliers the raw materials are supplied from. On the other hand, in light of the variability of parameters such as customer demand and costs of production and distribution during the planning periods, decisions must be made about reconfiguration of the production network. The decisions are made so that the sum of the total cost of the system, including the five cost items of production, procurement and inbound logistics of raw materials to facilities, outbound logistics of products to markets, establishment of facilities at active sites, and

machinery, is minimized. The suppliers could have different production costs based on labor or raw material costs. It is assumed in modeling the problem that the demand of market sectors and cost items of facility location, production, and distribution in each time period are specified. Furthermore, the cost of production of each product in each cell and in each time period is considered as a function of the number of products produced in the cell, such that the cost of production of each product increases as the number of products grows. It is possible in every time period to purchase new machines or transfer them between two cells (located in a single facility or different facilities).
The mathematical model of the problem is presented as follows:

$$\min z = z1 + z2 + z3 + z4 + z5 \quad (1)$$

$$z1 = \sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{k=1}^{K_i}\sum_{m=1}^{M}\sum_{h=1}^{H}\sum_{q=1}^{Q} C_{pqh} X_{pikmqh} D_{pmh} \quad (2)$$

$$z2 = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{s=1}^{S}\sum_{c=1}^{C}\left(PS_{sch} + B'_{cish}\right) R_{csih} \quad (3)$$

$$z3 = \sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{k=1}^{K_i}\sum_{m=1}^{M}\sum_{h=1}^{H}\sum_{q=1}^{Q} B_{pimh} X_{pikmqh} D_{pmh} \quad (4)$$

$$z4 = \sum_{h=1}^{H}\sum_{i=1}^{I} G_{ih} V_{ih} \quad (5)$$

$$z5 = \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K_i} F_j Y_{jik1} + \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K_i}\sum_{h=2}^{H} F_j Y13_{jikh} + \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K_i}\sum_{h=2}^{H} \alpha1_j Y2_{jikh} + \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K_i}\sum_{h=2}^{H} \alpha2_j Y11_{jikh} + \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K_i}\sum_{h=2}^{H} \alpha3_j Y12_{jikh} \quad (6)$$

$$\sum_{p=1}^{P} W_{pikh} = \sum_{q=1}^{Q} U_q Z_{ikqh} \qquad \forall i, k, h \quad (7)$$

$$\sum_{q=1}^{Q}\sum_{m=1}^{M} X_{pikmqh} \le M' W_{pikh} \qquad \forall i, k, p, h \quad (8)$$

$$\sum_{\substack{p=1 \\ p\in S_j}}^{P}\sum_{q=1}^{Q}\sum_{m=1}^{M}\sum_{k=1}^{K_i} X_{pikmqh} T_{pj} D_{pmh} \le \sum_{k=1}^{K_i} A_j Y_{jikh} \qquad \forall i, j, h \quad (9)$$

$$\sum_{k=1}^{K_i}\sum_{q=1}^{Q} Z_{ikqh} \le M' V_{ih} \qquad \forall i, h \quad (10)$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K_i}\sum_{q=1}^{Q} X_{pikmqh} = 1 \qquad \forall m, p, h \quad (11)$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K_i} W_{pikh} \le 1 \qquad \forall p, h \quad (12)$$

$$\sum_{k=1}^{K_i}\sum_{m=1}^{M}\sum_{p=1}^{P} CP_{cp} W_{pikh} D_{pmh} \le \sum_{s=1}^{S} R_{csih} RS_{csh} \qquad \forall i, h, c \quad (13)$$

$$\sum_{q=1}^{Q} Z_{ikqh} = 1 \qquad \forall i, k, h \quad (14)$$

$$Y_{jikh} \le M' \sum_{q=1}^{Q} Z_{ikqh} \qquad \forall h, i, j, k \quad (15)$$

$$Y_{jikh} = Y_{jikh-1} + Y1_{jikh} - Y2_{jikh} \qquad \forall h > 1, i, j, k \quad (16)$$

$$Y11_{jikh} \le \sum_{\substack{k2=1 \\ k2\ne k}}^{K_i} Y2_{jik2h} \qquad \forall h > 1, i, j, k \quad (17)$$

$$\sum_{k=1}^{K_i} Y12_{jikh} \le \sum_{\substack{i2=1 \\ i2\ne i}}^{I}\sum_{k=1}^{K_i} (Y2_{ji2kh} - Y11_{ji2kh}) \qquad \forall h > 1, i, j \quad (18)$$

$$Y1_{jikh} = Y11_{jikh} + Y12_{jikh} + Y13_{jikh} \qquad \forall h > 1, i, j, k \quad (19)$$

$$\sum_{j=1}^{J} Y_{jikh} \le UM \qquad \forall i, h, k \quad (20)$$

$$X_{pikmqh}, W_{pikh}, Z_{ikqh}, R_{csih}, V_{ih} \in \{0,1\},\; Y_{jikh}, Y1_{jikh}, Y2_{jikh}, Y11_{jikh}, Y12_{jikh}, Y13_{jikh} \in Z^{+} \qquad \forall c, i, k, q, h, m, j, s, p \quad (21)$$

In Expression (1), the objective function of the proposed model is calculated as the sum of 5 different cost terms. In Relation (2), the production costs are calculated. In Relation (3), the costs of procurement of raw materials and their shipment to facilities are calculated. In Relation (4), the costs of shipment of products to markets are calculated. In Relation (5), the costs of establishment of facilities at active sites are calculated, and in Relation (6), the costs of procurement of machines and their removal and shipment among and within facilities are calculated. Constraint (7) calculates the size of each of the manufacturing cells based on the number of products allocated to it. Constraint (8) assures that at least one product is produced in each cell. Constraint (9) considers the availability times of machines. Constraint (10) demonstrates that cells must be formed in active facilities. Constraint (11) assures that the demand for each product from each market in each time period is met by a single cell. Constraint (12) assures that each product is allocated only to one cell in one facility in each time period. Constraint (13) specifies how raw materials are procured from suppliers. Constraint (14) assures that a unique number is allocated to the size of each cell in each time period. Constraint (15) assures that at least one machine is located in each cell. Constraints (16) to (20) specify the number of machines transferred, removed, or added at the beginning of each time period and in each cell. Constraint (21) demonstrates the domains of the decision variables of the model.

The presented model is a mixed integer linear one, and it can thus be solved using common integer optimization software for small sizes of the problem. As stated previously, it is not possible to optimally solve the problem under investigation on a large scale as it is NP-hard. Nevertheless, a GA is introduced in the following section for solving the problem on a large scale.

4. GENETIC ALGORITHM

The algorithm begins with the (often random) creation of the initial generation. In each generation, the chromosomes are selected based on the fitness criterion for creation of the future generation. Through application of the genetic operators of crossover and mutation, the new chromosomes, called offspring, are generated from the chromosomes of the current generation, called parents, and participate in a competition against the chromosomes of the current generation in order to survive. The chromosome structure designed in the algorithm contains a set of matrices, where each matrix corresponds to a candidate site and a period. Each of the matrices contains four columns, and the number of rows in each of the matrices equals the sum of the numbers of parts and machines. For each row of the matrices, if the product or machine depending on the row is not subject to cellular distribution, all the entries of the row are set to zero. Furthermore, in this matrix, the first and second columns represent facility number and cell number. In the third column, supplier numbers are considered for the rows concerning parts and the number of the machines for the rows concerning machines, and the last column represents period number. For a better understanding of the introduced structure, an instance of the structure is presented in Figure 1.

We use matrix A2 to display the information concerning the products and machines for facility 1 in the second period. The second row of the matrix, i.e., [1 2 1 2], denotes that for the second period, the second product is produced in cell 2 of facility 1, and the raw materials for production of the product are procured from supplier 1.

In the initial generation, attempts are made to preferably consider the constraints of the problem and generate plausible solutions to the problem.

$$C_1 = \begin{bmatrix} A_1 & A_2 \\ B_1 & B_2 \end{bmatrix}_{12\times 8} = \begin{bmatrix} \begin{bmatrix} 0&0&0&0 \\ 0&0&0&0 \\ 0&0&0&0 \\ 0&0&0&0 \\ 0&0&0&0 \\ 0&0&0&0 \end{bmatrix}_{6\times 4} & \begin{bmatrix} 1&1&2&2 \\ 1&2&1&2 \\ 0&0&0&0 \\ 1&1&1&2 \\ 1&2&1&2 \\ 0&0&0&0 \end{bmatrix}_{6\times 4} \\ \begin{bmatrix} 2&1&1&1 \\ 2&1&2&1 \\ 2&2&1&1 \\ 2&2&1&1 \\ 2&1&2&1 \\ 2&2&3&1 \end{bmatrix}_{6\times 4} & \begin{bmatrix} 0&0&0&0 \\ 0&0&0&0 \\ 2&1&1&2 \\ 2&1&1&2 \\ 2&2&1&2 \\ 2&1&3&2 \end{bmatrix}_{6\times 4} \end{bmatrix}_{12\times 8}$$

Figure 1. An example of the chromosome structure

In compensation for the constraints where this is impossible, i.e., which may be violated by the initial population structure, the following relation is used for penalizing the solution. Here, the fitness function includes the objective function of the problem and penalty for violation of a number of the constraints. The crossover operator operates on a pair of chromosomes from the producing generation, and generates a new pair of chromosomes. The crossover on the columns of the two parent chromosomes is taken into account. Here, two parents are first selected. Then, two randomly selected columns (representing a period) of each chromosome are exchanged, and two new offspring are generated.

The mutation operator is needed to prevent premature convergence and to search more parts of the solution space. As there are a very large number of genes in each chromosome, each changeable gene is mutated with a small likelihood (5 percent, for instance). The mutation operator is applied in each non-zero submatrix to the entries in accordance with the cell number, supplier number, and number of machines, and randomly changes the genes in accordance with these factors.

5. COMPUTATIONAL RESULTS

A number of problems are presented in this section for analysis of the proposed model and performance of the GA. Two procedures are introduced for solving the problems. In the first procedure, the CPLEX 11 software is used on a system with the specifications Intel Core i5 2.50 GHz and 4 GB RAM, and in the second procedure, the GA run by MATLAB 2013. In the GA, we run the code 5 times for each problem. Each time the code is run, we try to change the parameter rates by a maximum of 10 percent, and record the best solution. For the proposed algorithm, the parameters are considered through repetitive pilot runs as follows:
population size = 100, number of generations = 100, crossover rate = 0.80, mutation rate = 0.10, elitism percentage = 0.05.

Table 1 presents the costs of producing the products in each period based on the size of each cell.

We solved the model proposed in this article with two procedures here. Table 2 displays the values of the cost terms and the total costs with the solution procedure of CPLEX.

TABLE 1. The production costs for the products in each period

	Cell size						
	1	**2**	**3, 4**	**5-7**	**8-10**	**11-14**	**≥15**
Product	1	5	10	15	20	25	30

TABLE 2. The optimal objective function values of CPLEX for example 1

Cost terms	Objective function
Production	32200
Purchasing and inbound logistics	866450
Outbound logistics	134800
Amortized fixed	80060
Machine	41258
Total	1154768

In the first problem, a firm is considered that distributes the production capacity of its products to a wide geographic range (in the form of two sites with known production capability) to supply the demand of two markets. The firm has the capability of reconfiguration; i.e., it can reconfigure its production networks for two different periods. The number of components is assumed to be twice the number of products. Furthermore, the facilities established at potential sites procure the raw materials from 2 different suppliers. In this problem, there are 4 different types of machines, and the distributed CMS is used for production of 4 product types. The information concerning the parameters of the problem appear in Table 3:

TABLE 3. The sources of random generation of the nominal data

Parameter	Range
A_j	35000
K_i	5
$\alpha 1_j$	Uniform Distribution [20, 60]
$\alpha 2_j$	Uniform Distribution [2, 10]
$\alpha 3_j$	Uniform Distribution [100, 700]
F_j	Uniform Distribution [30, 72]×100
S_j	Uniform Distribution [0, 1]
G_{ih}	Uniform Distribution [20000, 25000]
T_{pj}	Uniform Distribution [1, 10]
D_{pmh}	Uniform Distribution [1000, 2000]
PS_{sch}	Uniform Distribution [1, 20]
RS_{csh}	Uniform Distribution [0, 1]
B_{pimh}	Uniform Distribution [1, 10]
B'_{cish}	Uniform Distribution [5, 20]

For a better understanding of distributed CMS design, we analyze the model output and results concerning important decisions here. The cell design distribution in two periods is displayed in Figure 2.

In the above figure, two factories have been located at two candidate sites for each period. As clear in the figure, in the first period, product 4 (in cell 1), product 3 (in cell 2), and product 1 (in cell 3) are produced in factory 1, and product 2 (in cell 1) is produced in factory 2. The decisions concerning resource allocation are specified. For instance, in the second period, factory 2 procures the raw materials of product 2 from supplier 2. The types and numbers of the machines in each cell are also specified in the figure. For instance, there is one machine of type 2 and one machine of type 4 in factory 1 (in cell 2) in the first period. A new configuration is presented for the production network in period 2. As clear in Figure 4, product 4 (in cell 1) and product 1 (in cell 2) are produced in factory 1, and product 2 (in cell 1) and product 3 (in cell 2) are produced in factory 2. Here, a number of the machines are transferred between cells within or between factories. For instance, machine 2 (in cell 2) of factory 1 is transferred in period 1 to cell 1 of factory 2 in the second period, and undergoes an inter-factory transfer.

Furthermore, for demonstration of the efficiency of the procedure of the designed GA, 9 other problems are examined here. Here, we try to increase the numbers of suppliers, facilities, markets, and periods to design problems of medium and large sizes. The values of the objective function and CPU times for the two procedures of solution with CPLEX and GA are recorded in Table 4.

As clear from Table 4, the optimization software CPLEX obtains the optimal objective function value and optimal solution for small-sized problems. For medium- and larger-sized problems, however, CPLEX fails to obtain the optimal objective function values even after a long time passes.

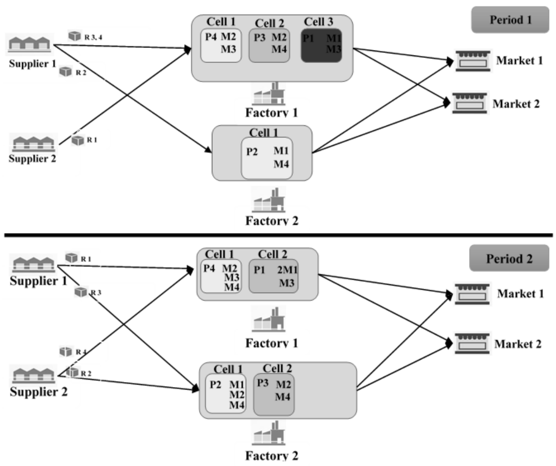

Figure 2. Distributed CMS design in the SC

TABLE 4. Summary of the computation results.

	Problem Size						CPLEX		GA	
	P	J	S	I	M	P	OF	Time (s)	OF	Time (s)
1	4	4	2	2	2	2	1154768	17	1154768	7
2	6	6	3	3	3	2	2085340	43	2085340	12
3	8	6	3	3	3	3	3556702	50	3556905	18
4	10	8	4	4	3	3	5616148	203	5616201	21
5	10	8	4	5	4	3	6063290	654	6063302	24
6	10	10	5	5	5	3	-	>10800	6984329	27
7	10	10	5	5	5	4	-	>10800	9847943	33
8	12	10	7	7	7	4	-	>10800	18738372	42
9	15	12	9	9	9	5	-	>10800	34901768	83
10	20	12	10	12	12	7	-	>10800	87244917	179
11	22	12	10	12	12	7	-	>10800	90124399	192
12	24	12	10	12	14	7	-	>10800	96721052	258
13	25	15	12	14	14	7	-	>10800	112633572	329
14	30	15	12	14	14	7	-	>10800	135631550	415
15	30	15	14	14	16	9	-	>10800	185039210	681

As observed in Table 4, for problems 6 to 15, optimal solutions have not been observed even after 3 hours have passed. Therefore, the proposed GA procedure is effective for large-sized real-world problems as clear in Table 4 and deliver the optimal and near-optimal solutions within logical times. In general, metaheuristic algorithms do not assure that exact, optimal solutions are obtained, and the genetic algorithm has successfully obtained near-optimal solutions to Problems 3-5, as shown in Table 4. The results in the above table for the problems demonstrate that the error rates for the GA algorithm are around 0–0.0057% for all the small- and medium-sized problems. This demonstrates that the algorithm obtains solutions of very high quality within logical times.

6. CONCLUSION

In this article, firms that distribute the production capacity of their products to a wide geographic range were studied. Here, for each period, production facilities were established at candidate sites, and compete with each other for allocation of production capacity. Holding the capability of reconfiguration, these firms can reconfigure their production networks (including scattered facilities) for a specific manufacturing process or a family of products. Interactions were observed here between CMS design and SC design. We presented a novel integrated mathematical model in a dynamic environment to demonstrate the interaction. Different types of decision are made here, such as ones concerning the selection of suppliers for each of the facilities, resources, locations and number of facilities, and supplying market demand. The proposed integer mathematical model is aimed at minimizing different costs, such as costs of the sector for procurement of raw materials and their shipment to facilities, costs of production, costs of location of facilities at candidate sites, costs of machinery, and costs of shipment of final products to the market. The optimal solutions were obtained in solving the small-sized problems using the optimization software CPLEX, but a GA was designed since the procedure was not effective for the problems of the real-world size. The results of the suggested examples demonstrate the efficiency of the proposed GA.

The innovative aspects of our procedure proposed in this article include: modeling the interaction between CMS design and SC design in a dynamic environment, considering the decisions concerning supplier selection for active facilities, transferring machines between cells, and designing a GA for medium- and large-sized problems. For future research, the integrated procedure introduced in this article can be developed. Stochastic parameters can be taken into account in the model in these studies. Furthermore, other meta-heuristic algorithms can be used for solving the model.

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Modeling the Trade-off between Manufacturing Cell Design and Supply Chain Design

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چکیده

امروزه شاهد افزایش روزافزون بنگاه‌های‌اقتصادی هستیم که برای تأمین تقاضای چندین بازار، ظرفیت تولیدی محصولات خودرادرگستره جغرافیایی وسیعی توزیع می‌نمایند.به منظور بررسی چنین شرکت‌هایی، دراین مقاله ارتباطات وتعاملات بین طراحی سلولی تسهیلات تولیدی و طراحی زنجیره تأمین، بررسی می‌شود. برای این منظور، یک مدل یک پارچه ریاضی جدید برای طراحی سیستم‌های تولیدسلولی پویادرطراحی زنجیره تأمین ارائه می‌شود. مولفه‌های مختلفی از طراحی زنجیره تأمین مانندانتخاب مکان تسهیلات تولیدی ازبین تعدادی سایت کاندیدا،تهیه موادخام ازتامین کنندگان، حمل ونقل مواداولیه به تولیدکنندگان، تولیدوتوزیع محصولات به بازارهادریک محیط پویادرنظرگرفته می‌شودوهزینه‌های مربوط به این مولفه‌ها، کمینه‌سازی می‌گردد. از آن جاییکه مساله پیشنهادی ناچندجمله‌ای سخت است برای کاربرد مدل دراندازه‌های دنیای واقعی، یک الگوریتم ژنتیک ارائه می‌گردد. مثال‌های عددنشان می‌دهد که الگوریتم درجستجوی راه‌حل‌های بهینه یا نزدیک به بهینه، به گونه‌ای موفق و کارا عمل می‌کند.

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