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Routing and Production Scheduling for a Mobile Factory

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ABSTRACT

In last decades, mobile factories have been used due to their high production capability, carrying out their equipment, and covering rough and uneven routes. Nowadays, more companies use mobile factories with the aim of reducing the transportation and manufacturing costs. The mobile factory must travel between the suppliers, visit all of them in each time period, and return to the initial location of the mobile factory. In this paper, we present an integer nonlinear programming model for production scheduling and routing of mobile factory with the aim of maximization of profit. This problem is similar to the well-known Traveling Salesman Problem (TSP), which is an NP-hard problem. In addition, for each supplier, the scheduling problem for production is NP-hard. After linearization, we proposed a heuristic greedy algorithm. The efficiency of this heuristic algorithm is analyzed using the computational studies on 540 randomly generated test instances. Finally, the sensitivity analysis of the production, transportation, and relocation costs was conducted.

1. Introduction

During recent decades, mobile factories have been in use due to their high capability in production, carrying their equipment, and covering rough paths. In regions without industrial manufacturing infrastructure and in critical situations such as war, earthquake, and flood, the reconstruction process can be accelerated using mobile factory. Another reason for using this kind of factory is that companies can reduce their transportation costs, raw materials wastes, and high costs of construction and manufacturing [1-3].

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In order to have a more efficient operation, mobile factories are designed and built in three different types. The first type is the mobile factories that are installed within a large van or on the back of a truck. The location changes daily or weekly, and the products, such as agricultural and livestock products, are produced in these factories. The second type of mobile factories is the one that consists of several shipping containers capable of manufacturing multi-component products. In this kind of factory, the production location changes monthly. This kind of factory produces basic engineering tools and construction materials. The third type of mobile factories is made of several pre-fabricated volumetric elements transported by trucks and assembled in a suitable location to make a factory. These kinds of factories are much larger than a shipping container and are suitable for a production location that is fixed for up to several years [4].

Preeman [5] was the first to propound and design a mobile asphalt factory for producing asphalt mixes which could be transported to any desired location convenient for paving projects. Due to the necessity of re-asphalting roads periodically, Thurk [6] designed a mobile asphalt factory which could recycle asphalt roadway's materials into paving material on-site. In 1995, Isfahan Engineering Research Center [7] designed a mobile crusher factory in order to improve the operations in hilly areas and provide materials for road construction in rural areas. Cardu et al. [8] discussed mobile crusher factory instead of fixed one. Rossi [9] patented a compact mobile crushing and screening apparatus. In 2012, the World Health Organization [10] used mobile factories to produce high energy biscuits for hungry Afghan school children. In the past twenty years, the overuse of electronics industry has been changing the economic and environment quickly and has resulted in generating approximately 42 million tons of electrical and electronic wastes (e-wastes) per year. Rocchetti et al. [11] designed a mobile recycling factory installed in a container and used for processing e-wastes using a hydrometallurgical process. Zeng et al. [12] designed an integrated mobile recycling factory which performed the three processes of dismantling, crushing, and multi-level separating. Rauch et al. [13] introduced the concept of using mobile factories and its advantages for the construction industry. Fox [4] discussed the idea of mobile factories in remote areas lacking the manufacturing skills and infrastructure to build a factory. Benam et al. [14] presented a framework definition for designing mobile manufacturing system. Fox and Richardson [15] studied on mobile factory in industrialized economy by interviewing with different types of organizations. Fox and Mubarak [16] described mobile social manufacturing through the case study of fragile regions in Somalia.

Previous studies have explored the advantages of using mobile factory in different industries; however, till now, an analysis of the costs and gains of this kind of factories has not been conducted. In this paper, a multi-product model, which takes the routing and scheduling of production into consideration, is developed. Since the model cannot be solved in large-sized instance by Operation Research Software, a heuristic greedy algorithm is developed to solve such instances of the problem. This model can be used in food industry, such as dairy products, in which a variety of different products are produced by a raw material.

2. Problem Statement and Modeling

In this problem, a network consists of a mobile factory, several suppliers, and customers with certain predictable demands. The mobile factory must travel between the suppliers, visit all of them only once in each time period, and return to the start point, indicating the initial location of the mobile factory. In this section, a multi-product model is proposed for production scheduling and routing of mobile factory and is aimed to maximize total profit. All kinds of products must be produced by each supplier, and one of the main tasks of the model is scheduling the production in a way that the cost and setup time, which changes between variant products, be reduced. Fig.1 shows the mobile factory network, including 3 suppliers and 4 costumers. In the following, the notations or the models are introduced.

Sets

$I = \{1, \dots, n\}$: a set of suppliers with the indices of i, e and set $I' = I \cup \{0\}$ in which $\{0\}$ determines the start point (the mobile factory's initial location)

$J\{1, \dots, m\} =$: A set of customers with the index j

$G = \{1, \dots, h\}$: Set of products with the indices of g, f and $G' = G \cup \{0\}$ in which $\{0\}$ determines a virtual product

Parameters

c_i: The cost of each unit of the raw material purchased from supplier i ($/per raw material unit)

c'_{fg}: Setup cost of producing product $g \in G$ immediately after product $f \in G$ ($)

c'_{0g}: Setup cost of producing product $g \in G$ in the case that g is the first product of the first visited supplier ($)

π_g: The cost of production per unit of product g ($/per product unit)

v_g: The cost of transportation of product g ($/km. per product unit)

θ: The cost of mobile factory relocation ($/km)

p_g: The sale price of product g ($/product unit)

S_i: The capacity of supplier i (per product unit)

k_g: The mobile factory capacity for producing product g (Product unit/ time unit)
D_{gj}: The demand of customer j for product g (per product unit)
l_{ij}: The distance between supplier i and customer j (km)
δ_{ie}: The distance between supplier i and supplier e (km)
σ_{fg}: The setup time of product g immediately after product f
σ_{0g}: The setup time of product g in the case that product g is the first product of the first visited supplier
β_g: The coefficient of the raw material conversion into product g (product unit/ raw material unit)
μ: The mobile factory average speed (km/ time unit)
α_g: The percentage of the raw material used to produce product g ($\sum_g \alpha_g = 1$)
$ymin_g$: The minimum number of product g in every restarting point of the production line
$zmax$: Duration of a period

Variables
X_i: The amount of received raw material from supplier i
Y_{gij}: The amount of product g sent from supplier i to customer j
W_{ie}: Binary variable that takes the value of 1 if the mobile factory moves from supplier i to supplier e and takes 0, otherwise
Z_i : The amount of time the mobile factory takes to produce a product by supplier i
Q_{ifg}: Binary variable that takes the value of 1 if product g is produced in supplier i immediately after product f and takes 0, otherwise
O_{ifr}: Binary variable that takes the value of 1 if, in supplier i, product f is produced as the rth product and takes 0, otherwise
Φ_{ifgr}: Binary variable that takes the value of 1, if, in supplier i, product f is placed in the rth position immediately before product g and takes 0, otherwise
Ω_{iefg}: Binary variable that takes the value of 1 if supplier e is immediately visited after supplier i and product f is the last product in supplier i and product g is the first product in supplier e and takes 0, otherwise
Ω'_{eg}: Binary variable that takes the value of 1 if supplier e is the first visited and product g is the first product in supplier e and takes 0, otherwise.

Model

$$Max\ A = A_1 - A_2 - A_3 - A_4 \tag{1}$$

$$A_1 = \sum_{i\in I}\sum_{j\in J}\sum_{g\in G} p_g Y_{gij} \tag{2}$$

$$A_2 = \sum_{i\in I} c_i X_i + \sum_{i\in I}\sum_{j\in J}\sum_{g\in G} \pi_g Y_{gij} \tag{3}$$

$$A_3 = \sum_{i\in I}\sum_{g\in G}\sum_{\substack{f\in G\\ f\neq g}} c'_{fg} Q_{ifg} + \sum_{i\in I}\sum_{e\in I}\sum_{g\in G}\sum_{f\in G} c'_{fg}\,\Omega_{iefg} + \sum_{e\in I}\sum_{g\in G} c'_{0g}\,\Omega'_{eg} \tag{4}$$

$$A_4 = \sum_{i\in I}\sum_{j\in J}\sum_{g\in G} v_g l_{ij} Y_{gij} + \sum_{i\in I}\sum_{e\in I} \theta \delta_{ie} W_{ie} \tag{5}$$

Subject to :

$$X_i \le S_i \qquad \forall i \tag{6}$$

$$\sum_j Y_{gij} \le S_i \alpha_g \beta_g \quad \forall i \in I, \forall g \in G \tag{7}$$

$$\sum_j Y_{gij} \ge ymin_g \quad \forall i \in I, \forall g \in G \tag{8}$$

$$\sum_{i\in I} Y_{gij} \le D_{gj} \qquad \forall j \in J, \forall g \in G \tag{9}$$

$$X_i - \sum_{j\in J}\sum_{g\in G} \frac{1}{\beta_g} Y_{gij} \ge 0 \quad \forall i \in I \tag{10}$$

$$\sum_{g\in G}\sigma_{0g}\Omega'_{ig} + \sum_{e\in I}\sum_{g\in G}\sum_{f\in G}\sigma_{fg}\,\Omega_{iefg} + \sum_{g\in G}\sum_{f\in G}\sum_{r=1}^{h}\sigma_{fg}\Phi_{ifgr} + \sum_{j\in J}\sum_{g\in G}\frac{1}{k_g}Y_{gij} \le Z_i \quad \forall i\in I \tag{11}$$

$$\sum_{i\in I} Z_i + \sum_{i\in I'}\sum_{e\in I'}\frac{1}{\mu}\delta_{ie}W_{ie} \le zmax \tag{12}$$

$$\sum_{e\in I'} W_{ie} = 1 \qquad \forall i\in I' \tag{13}$$

$$\sum_{i\in I'} W_{ie} = 1 \qquad \forall e\in I' \tag{14}$$

$$W_{ie} + W_{ei} \le 1 \quad \forall i,e\in I' \tag{15}$$

$$\Phi_{ifgr} \le \frac{O_{ifr} + O_{ig(r+1)}}{2} \quad \forall i\in I, \forall g,f\in G, f\neq g \quad \forall r=1,\dots,h-1 \tag{16}$$

$$O_{ifr} + O_{ig(r+1)} - 1 \le \Phi_{ifgr} \quad \forall i\in I, \forall g,f\in G, f\neq g \quad \forall r=1,\dots,h-1 \tag{17}$$

$$Q_{ifg} = \sum_{r\in G}\Phi_{ifgr} \quad \forall i\in I, \forall g,f\in G, f\neq g \tag{18}$$

$$\sum_{r\in G} O_{ifr} = 1 \qquad \forall i\in I, \forall f \tag{19}$$

$$\sum_{f\in G} O_{ifr} = 1 \qquad \forall i\in I, \forall r \tag{20}$$

$$\Omega_{iefg} = O_{ifh}O_{eg1}W_{ie} \quad \forall i,e\in I, \forall g,f\in G \tag{21}$$

$$\Omega'_{eg} = O_{eg1}W_{0e} \quad \forall e\in I, \forall g\in G \tag{22}$$

$$Y_{gij}, X_i, Z_i \ge 0 \qquad \forall j\in J, i\in I', g\in G \tag{23}$$

$$W_{ie}, O_{ifr}, \Omega_{iefg}, \Omega'_{eg}, Q_{ifg}, \Phi_{ifgr} \in \{0,1\} \quad \forall i,e\in I', \forall g,f\in G, \forall r=1,\dots,h \tag{24}$$

The objective function (1) maximizes the total profit. In the objective function, the first term is the total expected revenue shown by (2). The second term is the raw material cost plus production cost (3). The third term is the setup cost (4), and the last term is the total transportation cost incurred in the delivery process and the mobile factory relocation (5). Constraint (6) is the supplier's capacity. Constraints (7)-(10) specify the amount of variable Y_{gij}. Constraints (11)-(12) ensure that the total time of producing and routing does not exceed the end of the planning time period. Constraints (13) to (15) are related to the routing. Constraints (13) and (14) indicate that the mobile factory can arrive at and depart from each supplier only one time. Constraint (15) prohibits any cycle creation between the suppliers in a feasible solution. Constraints (16)-(18) indicate whether or not product f is produced immediately before product g in the sequence. Constraint (19) guarantees that each position of the sequence is occupied by only one product. Constraint (20) ensures that each product is placed in only one position of the sequence. Constraints (21) and (22) indicate the first product in sequence for each supplier. Finally, constraints (23) and (24) specify the appropriate domain of each variable in the model.

2-1. Linearization

Constraints (21) and (22) are non-linear, whereas O_{ifh}, W_{ie}, and O_{eg1} are binary decision variables. In this paper, the model is linearized by replacing constraints (21) with additional constraints $O_{ifh} + O_{eg1} + W_{ie} \le 2 + \Omega_{iefg}$ and $O_{ifh} + O_{eg1} + W_{ie} \ge 3\Omega_{iefg}$. Also, constraints (22) are replaced with additional constraints $O_{ifh} + O_{eg1} + W_{ie} \le 2 + \Omega_{iefg}$ and $O_{ifh} + O_{eg1} + W_{ie} \ge 3\Omega_{iefg}$ [17, 18].

3. Constructive Heuristics

The relocation of the mobile factory between the suppliers is similar to the well-known traveling salesman problem (TSP) that is NP-hard [19,20]. Also, for each supplier, the scheduling problem for production is NP-hard [21], so the mentioned problem is NP-hard as well. In this section, we present a heuristic approach based on a greedy algorithm [22,24,25,26]. This algorithm introduces the profit gained from visiting the suppliers as the basis of choosing the route. For example, assume that the mobile factory is at the start point, the gained profit by visiting each of the suppliers is calculated, and the supplier providing the maximum profit is chosen and the factory moves to the selected supplier from the start point. This process is also repeated for the rest of the route; when all suppliers are visited, the algorithm stops. In addition to the previously mentioned parameters, other parameters are defined as in the following.

Parameter

A: The total gained profit

A_{ie}: The profit gained from selecting supplier e after supplier i

Π_i: The profit gained from production and distribution of products to the customers in the supplier i

$CostSeq$: The cost of the current sequence at each step

$timeseq$:The time of the current sequence at each step

AD_{igj}: The demand of costumer j for product g if supplier i is chosen

D'_{gj}: The demand of costumer j for product g

T_{ig}: The percentage of the raw material used to produce product g in supplier i

g^{prev}: The last product produced by the previous supplier ($g^{prev}=0$ is assumed for the start point)

$step$: The steps of algorithm for selection of suppliers

$sign_i$: The sign of supplier i that is $true$ if supplier i is selected and is $false$, otherwise

pro: Supplementary set for the products

Algorithm 1. Heuristic Algorithm based on a greedy algorithm

Step 1. Let $g^{prev}=A=e=0$، $i=1$، $time={}^{zmax}/_{n}$ ،$sign_i=true$; $\forall i \in I$ $step=1$.

Step 2. Let $pro=G$، $timeseq=costseq=0$

$\Pi_i=0$; $\forall i \in I$

$A_{ei}=0$; $\forall i$، $e \in I$

$T_{ig}=0$; $\forall i \in I$، $\forall g \in G$

$D_{gj}=0$; $\forall g \in G$، $\forall j \in J$

$AD_{igj}=0$; $\forall i \in I$، $\forall g \in G$، $\forall j \in J$.

Step 2.1. If $g^{prev}=0$ then

Let

$g = Arg\left\{ {}^{min}_{f\in pro}\left(c'_{g^{prev}f} \times \sigma_{g^{prev}f}\right)\right\}$,

$timeseq=timeseq+\sigma_{g^{prev}f}$ and $costseq=costseq+c'_{g^{prev}f}$.

else

let $g=g^{prev}$.

Step 2.2. Let $pro=pro\backslash\{g\}$.

If $pro=\emptyset$ then

let $g^{prev}=g$ and go to step 2-4.

Step 2.3. Let

$f^*=Arg\left\{ {}^{min}_{f\in pro}\left(c'_{gf}\times \sigma_{gf}\right)\right\}$,

$costseq=costseq+c'_{gf^*}$,

$timeseq=timeseq+\sigma_{gf^*}$, $g=f^*$

and go to step 2.2.

Step 2.4. If $sign_i=false$, then go to step 2.10.

else

let $g=1$,

for all $j\in J$ and for all $g\in G$: let $Y_{gij}=0$,

and let $Z_i=0$.

Step 2.5. Let $T_{ig}=\alpha_g S_i$ and $D'_{gj}=D_{gj}; \forall j\in J$.

If $T_{ig}<ymin_g$ or $\sum_j D'_{gj}<ymin_g$,

no feasible solution can be found, stop.

Step 2.6. For all $j\in J$ that $D'_{gj}>0$

let $j^* = Arg\left\{ {}^{min}_{j}\left(\frac{l_{ij}}{min\left(D'_{gj},T_{ig}\right)}\right)\right\}$

let $Y_{gij}=Y_{gij}+min\left(D'_{gj},T_{ig}\right)$

and $Z_i=Z_i+{}^{Y_{gij}}/_{k_g}$.

Step 2.7. Let $T_{ig}=T_{ig}-min\left(D'_{gj},T_{ig}\right)$ and $D'_{gj^*}=D'_{gj^*}-min\left(D'_{gj^*},T_{ig}\right)$.

Step 2.8. Let

$\Pi_i=\Pi_i+Y_{gij}\left(p_g-v_g l_{ij}-\pi_g-\frac{c_i}{B_g}\right)$

if $T_{ig}\neq 0$ and $\exists j\in J: D'_{gj}\neq 0$

go to step 2.6.

Step 2.9. Let $g=g+1$.

if $g\leq h$ go to step 2.5.

else let $Z_i=Z_i+timeseq+{}^{\delta_{ei}}/_{\mu}$.

If $Z_i\geq time$

for all $g\in G$ that ${}^{Z_i-time}/_{k_g}<T_{ig}$ let $g^*=Arg\left\{ {}^{min}_{g}\left(p_g\right)\right\}$

, $D'_{g^*j}=D_{g^*j}, T_{ig^*}=T_{ig^*}-$

$Z_i - time \Big/ k_{g^*}$

and go to step 2.6.

else

let $A_{ei} = \Pi_i - costSeq - \delta_{ei}\theta$

and for all $j \in J$ and all $g \in G$:

let $AD_{igj} = D'_{gj}$.

Step 2.10. Let $i = i + 1$.

if $i \le n$

go to step 2-4.

Step 3. Let $i^* = Arg\{^{max}_{i}(A_{ei})\}$

, $A = A + A_{ei^*}$

, for all $j \in J$ and all $g \in G$: let $D_{gj} = AD_{i^*gj}$

, $sign_{i^*} = false$ and $e = i^*$.

Step 4. Let $i = 1$ and $step = step + 1$.

if $step \le n$

go to step 2.

Step 5. Let $A = A - \theta\delta_{e0}$ and stop.

In the algorithm, the first step is to initialize the main parameters. In Step 2, the products are selected for scheduling based on previous supplier and profits are calculated for all of the suppliers that have not been visited. In step 3, the supplier with maximum profit is selected and its sign is set to false. Step 4 is then designed to examine the situation where no eligible supplier is in I, otherwise Step 2 is repeated. Step 5 calculates total profit, and stops.

4. Computational Experiments

To investigate the performance of the presented algorithm, 540 random test instances were generated and divided into three groups of small-l, medium-, and large-sized data. The algorithms were coded in C++ and run on a portable computer with an Intl core i5 and 6 GB of RAM. The model was also solved by the ILOG CPLEX 12.3.

4-1. Date set generation

We designed the test instances based on the following parameters. The number of the suppliers of small-, medium-, and large-sized instances is taken from the sets {2,10,20,30,40}, {50,60,70}, and {80,90,100}, respectively, and the number of the products is randomly chosen from the sets {2,3,4}, {5,6}, and {7,8,9} sequentially. The number of the customers is u times of the number of suppliers where u={1, 2}. Finally, for each of these 54 combinations, 10 random instances were generated by uniform distribution, so that 540 test instances are considered when evaluating the developed solution method. Other parameters take values based on the numbers or uniform distributions determined in Table1.

Tab. 1. Initialization of the parameters.

Initialization	parameters
c_i	$\sim U[1,3]$
c'_{fg}	$\sim U[0.1,5]$
π_g	$\sim U[1,5]$
v_g	$\sim U[0.01,1]$
θ	2
p_g	$\sim U[10,60]$
S_i	$\sim U[1000,10000]$
k_g	$\sim U[2,10]$
D_{gj}	$\sim U[900,5000]$
l_{ij}	$\sim U[50,300]$
δ_{ie}	$\sim U[50,300]$
σ_{fg}	$\sim U[1,30]$
β_g	$\sim U[0.2,0.9]$
μ	2

4-2. Analysis algorithms

To analyze the performance of the algorithm, the algorithm was compared with the optimal results obtained by ILOG CPLEX. In the second and third columns of Table 2, the average CPU run time and the maximum CPU run time of the mathematical model are presented. The fourth and fifth columns respectively represent the average CPU run time and the maximum CPU run time of the algorithm. In the last column, the average percentage deviation (GAP) of the obtained solutions from the best optimal result is demonstrated for various scales of problems. As evident from Table 2, the average percent deviation is less than 0.5 and the average time for all cases has decreased by the algorithm that indicates its efficiency.

4-3. Sensitivity analysis

In this section, the effect of parameters on the objective function is analyzed. The sample instance studied in this paper contains two suppliers, customers, and products. In this problem, one month (or 28 days) is considered as one Period of time and 2 km per unit of time is taken into account as the average speed of mobile factory. In Tables 3 to 6, the values of several parameters are presented.

Tab. 2. Comparison between the developed algorithm and the CPLEX

Level	CPLEX		Algorithm		the average percentage deviation
	the average CPU run time	the maximum CPU run time	The average CPU run time	the maximum CPU run time	
Small	46.50	80.39	1.63	2.83	0.30
Medium	768.02	1341.14	4.80	8.60	0.33
Large	2901.43	4095.38	9.54	15.92	0.37

Tab. 3. Parameters related to products

g	v_g	π_g
1	0.025	3
2	0.02	1

Tab. 4. The products demand

g \ j	1	2
1	1000	1500
2	1500	900

Tab. 5. The distance between suppliers and customers

i \ j	1	2
1	130	160
2	260	140

Tab. 6. The distance between the start point and the suppliers

i	Start point	1	2
Start point	0	140	220
1	140	0	180
2	220	150	0

According to the results of CPLEX, the optimal profit is 39538.6. In the following, the sensitivity analyses of the production cost (π_g), the cost of products transportation (v_g), and the mobile factory relocation cost (θ) are conducted, and the data, such as the value of the objective function, the manufacturing, and logistics cost, that include the product transportation cost and relocation of the mobile factory are presented.

4-3-1. Production cost

In Table 7, the production cost has increased up to %400 for each supplier. The results show that by increasing this parameter more than %300, production is decreased to compensate for costs augmentation.

One of the advantages of using mobile factory is reduction in the logistics costs. As Table 7 shows, by increasing this parameter to more than %80, the cost of production becomes more than that of logistics, and using mobile factory is not economically feasible.

4-3-2. Transportation cost

Table 8 depicts the impact of changing the transportation cost on the objective function. In this table, the transportation cost has increased up to %400 for each product. The results show that by increasing this parameter, objective function decreases and, in the case of increase to more than %300, the amount of the products to be produced will be minimized and the acquired profit is negative; therefore, the manufacturer must change its logistics system and use Lean Logistics approaches such as Cross Docking, VMI, Milk Runs, and Third Party Logistics [23].

4-3-3. Relocation cost

In this section, the effects of the relocation cost of mobile factory is studied. Estimating the relocation cost of mobile factory, especially in critical condition such as war, earthquake and flood, is very difficult. As Table 9 shows, changing relocation cost has low effect on the objective function; so, profit can be guessed without having accurate estimates of relocation cost.

Tab. 7. Sensitivity analysis of the production cost (π_g)

the increase percentage of production costs per	The objective function	the decrease percentage of objective function	The total production cost	The logistic cost

unite				
0	39538.6	0	7350	12990
%20	38068.5	4	8820	12990
%40	36598.6	7	10290	12990
%60	35128.6	11	11760	12990
%80	33658.6	15	13230	12990
%100	32188.6	19	14700	12990
%300	17488.6	56	29400	12990
%400	11098.5	72	12000	7440

Tab. 8. Sensitivity analysis of the product transportation cost (v_g)

the increase percentage of transportation cost	The objective function	the decrease percentage of objective function	The total production cost	The logistic cost
0	39538.6	0	7350	12990
%20	37144.5	6.1	7350	15384
%40	34750.6	12.2	7350	17778
%60	32356.6	18.17	7350	20172
%80	29962.6	24.22	7350	22566
%100	27568.6	30.27	7350	24960
%200	12358.6	68.74	7350	36930
%300	3628.6	90.1	7350	47880
%400	-1836.5	105	1600	7095

Tab. 9. Sensitivity analysis of the relocation cost (θ)

the increase percentage of relocation cost	The objective function	the decrease percentage of objective function	The production cost	The logistics cost
0	39538.6	0	7350	12990
%20	39322.5	0.5	7350	13194
%40	39106.5	1.1	7350	13398
%60	38890.5	1.6	7350	13602
%80	38674.5	2.2	7350	13806
%100	38458.5	2.7	7350	14010

5. Conclusions

In this paper, a model for scheduling a mobile factory was presented. This model was formulated as an integer nonlinear programming model with the aim of maximizing profit. After linearization, due to the complexity of solving this model, a heuristic algorithm based on a greedy idea was presented. The efficiency of the heuristic algorithm was analyzed using computational studies on 540 randomly generated test instances. The computational studies show that the developed heuristic algorithm is efficient because it has no more than 0.5 average deviation. Finally, the sensitivity analysis of the production, transportation, and relocation costs was conducted. The analyses show that the objective function is reduced by an increase in production and transportation costs, and it is necessary to use management tools to control costs. It also indicates that changing the relocation cost has little effect on the objective function and its exact estimation is not necessary. For future research, using the vehicle routing problem (VRP) for relocation of mobile factory and considering routing problem for distribution are suggested.

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