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A Hybrid Meta-heuristic for the Dynamic Layout Problem with Transportation System Design

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ABSTRACT

Improving performance of the plant layout requires careful consideration of various factors including changes in flows between departments over time and design of transportation system. This paper primarily presents a comprehensive dynamic layout design model which involves the design of facility plant layouts problems based on a multi-period planning horizon. The presented model integrates layout and transportation system design via considering more realistic assumptions, such as taking account of fixed-position departments and distance between departments that endanger each other. In addition, specific criteria such as capacity, cost and reliability of facilities are considered in transportation system design decision. The combinatorial nature of the problem necessitates using a meta-heuristic approach to deal with this issue. Therefore, an efficient hybrid meta-heuristic based on variable neighborhood search (VNS) and simulated annealing (SA) is proposed to design a proper dynamic layout for a specific planning horizon. The validity of the superiority of the proposed solution method is proven through comparing with all of the other solution methods upon the original model available in the literature. Finally, an extensive computational results lead to the conclusion that the proposed method outperforms other existing methods. In addition, solving an example from the dynamic layout design of a home appliance manufacturer demonstrates the efficiency of the proposed model and solution algorithm in terms of solution quality to solve real-world instances.

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1. INTRODUCTION

Optimal design of plant layout alongside other important strategic decisions to operate production and service systems efficiently, has a significant impact on the long-term viability of the manufacturing system. A facility plant layout is concerned with the arrangement of departments and transportation system design. Studies show that material handling costs fluctuate between 20 to 50 percent of the total operating costs and between 15 to 70 percent of the total production costs [1]. A well designed plant layout will result in increased productivity, decreased work-in-process, decreased manufacturing lead time, ordered material handling and so on [1]. Therefore, plant layout design has made a lot of interest from researchers in the recent years, since they are complicated and normally NP-Hard [2]. Layout design is simply defined as the arrangement of departments in a facility with respect to the predefined performance measurements in a specific planning horizon, which in turn could consist of a number of planning periods. The problem is called static plant layout problem (SPLP) if the flow between departments is fixed over these periods. This problem, i.e. SPLP, can be formulated as a quadratic assignment problem [3]. If the flow between departments is variable over the planning periods, the problem is called dynamic plant layout problem (DPLP) which is more complicated than SPLP. Dynamic layout design problems are the generalization of the static layout design problems. Minimizing the total material handling costs is the main

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concern of DPLPs. Material handling costs depend upon certain factors such as, amount of flow of materials, distance, and transportation cost between two departments. There are some factors that affect the flow between departments as listed in the following [4]: (1) The change in designing new products, (2) Adding or removing a product from the production plan, (3) Changing the layout of the existing facilities and equipments, (3) Reducing the product life cycle, and (4) The change in production quantity and production plan.

In the dynamic layout design problems contrary to static layout design problems, which only involve one layout design, we deal with a set of layout designs in which each one is related to a particular period. Therefore, in the dynamic form, the total cost of the layout design is defined as the sum of the material handling cost and rearrangement costs of departments over all periods. The material handling costs strictly depend upon transportation system design which includes a transportation facilities selection. Transportation facilities range from simple pallet rack and shelving projects, to complex conveyor belt and Automated Storage and Retrieval Systems. Therefore, integration of dynamic plant layout and transportation system design could provide more realistic plant layout alternatives. In this paper, two distinctive contributions are presented as follows:

- First, the goal is set to present a decision making model to design the dynamic plant layout and transportation system simultaneously in a specific planning horizon. Considering the alteration in the materials flowing over different periods, the transportation facility is chosen among the different alternatives with respect to various criteria such as the flow of materials, the transportation cost of one unit of product per one unit of distance, the reliability of the transportation method and so on. To tackle this problem, the technique for order preference by similarity to ideal solution (TOPSIS) is utilized to decide which transportation method has to be chosen for handling materials between departments. In addition, some real world constraints are considered in designing a dynamic layout such as considering fixed departments and observing a minimum distance between the specific departments which should be kept away from each others. The goal of the model is to minimize the total net present value (NPV) of the material handling costs and the rearrangement costs of departments for planning periods.
- Second, a hybrid well-designed meta-heuristic which is a hybridization of the two well-known meta-heuristics, i.e. VNS and SA, has been utilized to find the best dynamic layout design. This hybrid solution algorithm is applied to solve the proposed model and general problem of dynamic layout plan with data of the real-world case studied and standard test problems from the literature, respectively. The computational results are compared against all of the competing algorithms proposed in the literature of DPLP over a set of benchmark test instances presented by Balakrishnan et al. [6]. To this aim, the quality of our method is validated compared with those presented in Baykasoglu et al., [6].

The rest of this paper is organized as follows. Section 2 reviews the existing studies in the field of DPLP, which were expressed in the literature, and the corresponding solution procedures related to this problem were offered in the previous researches. The proposed model of DPLP is elaborated in section 3. Section 4 is devoted to the proposed solution algorithm procedure. Computational results of examining the efficiency of the proposed solution algorithm and solving and numerical example are presented in sections 5 and 6, respectively. Finally, in section 7 the conclusions are presented as well as future research suggestions.

2. BACKGROUNDS AND LITERATURE REVIEWS

In this section, various aspects of DPLP studies as well as their solution methods are reviewed. Since developing the first dynamic layout design model by Rosenblatt [5], the great attention on this issue has been made by many researchers [6]. The original model is aimed at presenting a set of layout design for all planning periods so that the sum of the material handling costs and the rearrangement costs of departments over all periods is minimized. The preliminary assumptions of this model are considering a fixed planning horizon and having departments of equal size and shape during each period and over the entire horizon. Montreuil & Venkatadri [7] and Lacksonen [8] investigated the DPLP model regarding the inequality assumption to the size of departments over each period. Dunker et al. [9] considered the inequality assumption to the size of departments over each period and the possibility of changing the size of departments among all planning periods.

Apart from the DPLP model development, various solution methods were presented to cope with this issue. Balakrishnan & Cheng [4, 6] and Moslemipour et al. [10] reviewed the existing solution methodologies for DPLP in the literature. The first solution procedure was proposed by Rosenblatt [5] which is based on dynamic programming (DP) method. The incapacity of this method in finding the optimal solution is revealed when the number of departments increases. In this case, if there are N number of departments and t number of periods, then $(N!)^t$ different states should be checked directly or indirectly to obtain the optimal solution. To tackle this difficulty, Rosenblatt [5] proposed heuristic search methods, such as the CRAFT and steepest descent pairwise interchange methods, to restrict the number of states under examination at each stage. It should be noticed that in this case the optimal solution could not be guaranteed anymore [3]. Urban [11] presented a heuristic method based on the steepest descent pairwise interchanges, which has a better performance compared to the Rosenblatt's heuristic method.

Apart from heuristic methods, meta-heuristic approaches have been applied to solve DPLPs. Conway & Venkataramanan [12] and Kaku & Mazzola [13] applied genetic algorithm (GA) and Tabu search (TS) to solve DPLP. Balakrishnan et al. [14] proposed a GA which is more efficient than that of by [12]. Baykasoglu & Gindy [15] presented a simulated annealing (SA) method, which has a better performance than the proposed GA by Balakrishnan et al. [14]. Balakrishnan et al. [16] proposed a hybrid GA that is more efficient than SA the proposed by Baykasoglu & Gindy [15]. Erel et al. [17] proposed a three-step solution methodology to solve DPLP. In the first step of this approach, a set of good solutions is generated, and then in the second and third steps, the generated solutions are improved through DP and steepest descent pair wise interchange heuristic method. Dunker et al. [8] presented a hybrid method based on DP and GA to solve DPLP with the inequality assumption about the size of departments. In this method, through applying GA, a set of solutions is generated for each period in which each one is evaluated via DP. Baykasoglu et al. [18] used the ant colony optimization (ACO) method to solve DPLP considering budget constraint. In addition, Sahin et al. [19] proposed simulated annealing optimization method to solve DPLP with budget constraint, which outperforms especially in a large problem other presented algorithms for budget constraint DPLP. Mckendall et al. [3] presented a SA algorithm with look-ahead/look-back strategy, which has better performance rather than general SA. Finally, Kia et al. [20] proposed an efficient GA to solve a multi-floor layout design model of a dynamic cellular manufacturing system in which the cell formation and group layout are concurrently determined.

Kulturel-Konak [21] reviewed facility design problems by categorizing them into the dynamic and stochastic classes from uncertainty standpoint and surveyed all existing solution approaches, including exact, heuristic and meta-heuristic methods, for dynamic facility layout problem. He also studied different approaches for the stochastic facility layout peoblem. Drira et al. [22] reviewed the existing work in the literature and analyzed them from different aspects. Suo & Liu [23] analyzed the relationship among SFLP, DFLP and Robust layout problem. Sahin & Turkbey [24] developed a hybrid heuristic derived from SA algorithm and Tabu list concept. They showed the effectiveness of their proposed method over SA and TS algorithms. Dong et al. [25] considered the possibility of changing the type of the departments over the planning horizon in which some departments can be added to or deleted from a set of departments. They also considered departments of unequal size and solved the obtained model. First, convert it into a network model, and then the shortest path of the network, the one with the lowest cost, is selected using the SA method. Chen & Rogers [26] considered both quantitative and qualitative objectives for DFLP. The qualitative objective refers to maximizing the closeness rate of departments while quantitative objective concerns minimizing the distance-based costs. McKendall Jr. & Hakobyan [27] presented a three-stage solution technique for DFLP under the assumption of having an unequal department size. The first and second stages form boundary search technique, which provides a solution for DFLP. In the third stage, TS method is applied to improve the resulting solution. Despite the fact that many studies have been made on DPLP, models of DPLP require additional consideration of various layout design specifications within a real world setting. Therefore, relatively further studies are required to develop more effective DPLP model as well as an efficient solution algorithm. This paper improves the previous models by considering additional assumptions to the DPLP model to make it more compatible with the real world situations. The outcome of our proposed model presents the layout and transportation system designs simultaneously for each period of the planning horizon. In addition, an efficient solution algorithm based on the SA and VNS is presented to solve the proposed DPLP model. The superiority of the proposed solution method is proven through comparing with all of the other solution methods upon the general DPLP model available in the literature.

3. PROBLEM STATEMENT

The purpose of this study is to find an efficient dynamic plant layout which is integrated with the transportation system design. This model is properly compatible with requirements of manufacturing workshop plant layout which the flow of material may vary between pairs of departments with equal size over a specific planning horizon. The objective of the proposed problem is to minimize the total NPV of the material handling costs and the rearrangement costs of departments. One of the important factors that affect the material handling cost and eventually the layout cost is the transportation method type used for carrying materials between departments. Depending on some criteria such as costs, flexibility, reliability, volume of materials, distance between departments and so on, different transportation facilities such as conveyer, pallet, and fork-lift truck are used to carry materials between two departments. Therefore, a multi-attribute decision making transportation system design is integrated with layout design in this study.

Another important factor is the rearrangement costs subject to some constraints such as having fixed-position departments, minimum acceptable distance between departments and so on. There are fixed-position departments because of having fixed foundations as one which is installed in the pressing department, fixing some equipment such as a crane in a department, placing heavy equipment in a department, having special facilities in a department and so on. For instance, in the most industries such as home appliances, there is some equipment such as compressors which could not easily be moved or if it is possible it would incur a high cost. In addition, some departments endanger each other and should be kept far away. For instance, either a department with flammable products could not be located near a department with high temperature or a department consisting equipment which produce a high vibration could not be located near sensitive facilities such as computer numerical control (CNC) machines. Figure 1 shows the positions in which a department producing high vibration cannot be located in a very close position to a typical CNC department. In other words, two departments are considered each other's neighbor if they have at least one common edge, i.e. more than one point. The distance between the two departments is calculated based on the rectilinear distance. The following subsection presents the mathematical model of the aforementioned problem.

Possible	NO	Possible
NO	CNC Dep.	NO
Possible	NO	Possible

Figure 1. Illustrating neighborhood of a department

3. 1. Mathematical Model Formulation In this section, the proposed integrated model for designing a dynamic layout plant is discussed. The purpose of objective function (1) is to minimize the sum of the present value of material handling costs and the rearrangement costs over the entire planning horizon.

$$\text{Min} = \sum_{l,i,j,t\geq 2} \frac{A_{tijl} Y_{tijl}}{(1+r)^{t-1}} + \sum_{t,i,j,k,l} \frac{C_{tijklv} . X_{tij} . X_{tkl}}{(1+r)^{t-1}}, v \in V \quad (1)$$

$$\sum_{j=1}^{N} X_{tij} = 1, \forall i, t \quad (2)$$

$$\sum_{i=1}^{N} X_{tij} = 1, \forall j, t \quad (3)$$

$$Y_{tijl} = X_{(t-1)ij} . X_{til} \ , \forall i, j, l, t \geq 2 \quad (4)$$

$$Y_{tijl} = 0, \forall t, l. \exists i, j. \quad (5)$$

$$X_{tij} . X_{tkl} = 1, \forall t, \exists i, j, k, l \quad (6)$$

$$X_{tij} = \{0,1\}, \forall i, j, t \quad (7)$$

$$Y_{tijl} = \{0,1\}, \forall i, j, l, t \geq 2 \quad (8)$$

where, N indicates the total number of departments, T is the total number of periods, r is the value of the interest rate over the planning horizon, A_{tijl} is the rearrangement cost of department i displaced from position j to l in period t, and C_{tijklv} is the material handling cost between department i located in position j and department k located in position l in period t by transportation method of type v which is selected through TOPSIS method. It means that material handling cost between the two departments is variable and set after determining transportation facility. Some factors such as flow of material, the distance between departments, and the transportation cost of one unit of product per one unit of distance are considered in TOPSIS method as decision criteria. Therefore, each position in layout could make a different material handling cost for one department to the other ones because of different selected transportation method. X_{tij} and Y_{tijl} are binary variables defined as follows: (1) x_{tij} equals 1 if department i is assigned to location j in period t; 0 otherwise and (2) Y_{tijl} equals 1 id department i is shifted from location j to l at the beginning of period t; 0 otherwise. Constraint sets (2) and (3) assure that in each period, each department is assigned only to one position, and then each position is occupied with only one department. Constraint set (4) adds the rearrangement cost of one department within two consecutive periods to the total cost of the layout design. In other words, if facility i in period $t-1$ is located in location j ($X_{t-1,ij}$=1) and in period t is located in location l ($X_{t,il}$=1), then Y_{tijl} equals to one which is a rearrangement happens, and finally its costs should be considered in the objective function. Constraint (5) ensures that there exists facility i in which its position can be kept fixed over the whole planning horizon. In other words, if facility i in period $t-1$ is located in location *j* ($X_{t-1,ij}$=1), it cannot be located in any other positions such as *l* in period *t*. Then Y_{tijl}=0 in which the location of the facility *i* is fixed. Constraint (6) indicates that the positions of the two departments are kept fixed relative to each other over the entire planning horizon. For all period *t* there are facilities *i* and *k* that can be located in particular locations such as *j* and *l* which have a specific distance relative to each other. Constraints (7) and (8) show the binary nature of the decision variables of the model.

4. SOLUTION PROCEDURE

In this papar, due to considering the designing dynamic layout and the transportation design simultaneously, solving the proposed model is more difficult than general DPLP. As mentioned earlier, the dynamic layout problem is a generalized version of the quadratic assignment problem (QAP) which is an NP-hard problem [28]. Consequently, dynamic layout problems are known to be NP-hard [29] and heuristic or meta-heuristic approaches. Therefore, they are required to tackle this problem rather than exact methods. In the following subsection, we describe an efficient meta-heuristic design based on the simulated annealing algorithm to solve the proposed DPLP. In recent years, simulated anneling has been used previously to solve various engineering problems [30-35].

4. 1. The Proposed HVNS-SA The HVNS-SA is a well-developed meta-heuristic approach proposed in this paper for solving combinatorial problems especially dynamic layout problems. This algorithm is a hybridization of VNS and SA methods. Therefore, it benefits from both features. The main steps of this method are entering an initial layout, creating a neighboring layout through shaking procedure, and searching around this neighboring solution via the SA method as a local search tool. These steps will be explained here in more details, which are presented in Figure 2:

Step1: Entering an initial layout: This algorithm takes an initial layout as entry which is generally presented as a string of periods contains a layout design. Figure 3 shows this coding scheme for a DPLP with *N* number of departments in a plant area of *x* unit in width and *m* unit in length and *T* periods in a planning horizon.

Step 2: Shaking process: VNS is a well-known meta-heuristic approach which was initially proposed by Hansen & Mladenovic [36]. The main superiority of this method over other meta-heuristics is that it benefits considerably from systematically applying different neighborhood structures during its process. This process is well known as a shaking process. We make use of this advantage and apply different neighborhood structures for the dynamic layout problems which are listed as following: (1) Single random Pairwise interchange in which two departments are selected randomly and their positions are swapped, (2) Multi Pairwise interchanges in which for a specific number of iterations departments are selected randomly and their positions are exchanged, (3) Subsequence moving operator in which a group of departments are moved to another position altogether, (4) Insertion mechanism in which a randomly selected department is omitted from its position and inserted between two other positions which are selected randomly, (5) Subsequence shuffling operator in which a group of departments are selected and jumbled up. In other words, they are positioned without any specific order, (6) Inversion structure in which a group of departments are selected and positioned inversely, (7) Subsequence moving and inversion operator in which a group of departments is positioned inversely and moved to another position altogether, (8) Shifting neighborhood structure in which two random positions are selected depends on the first position, which is greater or less than the other one, the department located in the position of the first random number is shifted backward or forward, respectively, (9) Adjacent swap operator in which a department is selected randomly replaces its position probabilistically with its left or right position.

Handling constraints: The aforementioned neighborhood structures play a crucial role in boosting the performance of the proposed method. After applying neighborhood structures, constraints of the studying model may be violated and the resulted solution becomes infeasible. For example, fixed-position departments may be moved, two impermissible departments may be adjoined and one department may be located in different positions. There are some strategies to overcome this deficiency. In this paper, we utilize the repairing strategy to generate feasible solutions.

Step 3: Local search: After shaking the studying solution through a chosen neighborhood structure, the output enters to a local search process. The applied local search is the famous simulated annealing method which was originally proposed by Metropolis et al. [37]. It also is further applied by Kirkpatrick et al. [38] to solve combinatorial problems. The reason which is applied as a local search for HVNS-SA is trying to reach a local optimum through even accepting an inferior solution probabilistically. There are two nested loops in the SA process. The outer loop controls the temperature condition of the system. This loop starts from a high temperature and decreases to a low level according to a cooling schedule pattern. In this paper, a nonlinear pattern is used in which the temperature is decreased slowly in the first iterations and sharply in the last iterations. According to the following formula (9):

$$T_i = T_0 - i^{\frac{\ln(T_0 - T_f)}{\ln(N)}} \quad (9)$$

where, T_i is the temperature in iteration *i*, T_0 is the initial temperature, T_f is the final temperature, and N is the total number of steps from the initial temperature to the final temperature. The inner loop probabilistically searches around the current solution at each temperature.

Layout evaluation: in the previously mentioned procedures a layout is evaluated through the systematic method presented in Figure 4 in which a layout design enters into this process as an input. As mentioned previously, a layout is evaluated by its cost that consists of both the rearrangement costs and the material handling costs. In the case of moving the location of a department in two consecutive periods, the rearrangement cost is considered. To calculate the material handling cost, it should be noted that material handling costs depend on some factors such as flow of material, the distance between departments, and the transportation cost of one unit of product per one unit of distance. Therefore, the distances between departments are calculated according to the rectilinear distance between them. To calculate the transportation cost, it is required to specify the type of the transportation method which is used for handling materials between two departments. For this purpose, we apply the TOPSIS method regarding some specific criteria. Then the transportation cost of the selected method is calculated and accordingly the handling costs are computed. Finally, the layout cost is obtained by summing up the material handling costs and the rearrangement costs of departments were calculated just before.

Procedure 1: Pseudo code of the proposed HVNS-SA

Begin

1. **Inputs:** the number of departments (*N*), the number of planning periods (*T*), the matrix of material flowed between departments in each period, the width and length of the plant space, the shape of each symmetric departments, the size of each departments, the value of interest rate considered over the planning horizon, the name of departments to be fixed, the name of departments to be kept far away each other, a set of transportation facilities
2. Specify initial and final temperature, cooling schedule pattern, the epoch length, the number of iterations;
3. Define a set of neighborhood structures N_k k=1,…, k_{max}
4. Generate a layout design (*L*) for *T* periods at random and set it as the initial layout inputted to the algorithm;
5. Evaluate the initial layout and denote it as *F(L)*.
6. **Repeat**
7. Set *K=1*;
8. **While** ($k \leq k_{max}$) **do**
9. Chose predefined number of periods randomly and generate a neighboring solution L' through shaking process from the *k*th neighborhood of *L*.
10. Apply local search method based on SA to L' to find the local optimum denoted with L'' :
    - 10.1. Set L' as the current layout L^c and the local best layout L'';
    - 10.2. **Repeat**
    - 10.3. **for** i=1 to *Epoch-length* **do**
    - 10.4. Generate a neighboring layout L^n of the current layout L^c;
    - 10.5. Evaluate the neighboring layout and name it $F(L^n)$;
    - 10.6. Calculate $\Delta = F(L^n) - F(L^c)$;
    - 10.7. **if** $\Delta<0$ **then**
    - 10.8. Replace L^c with L^n;
    - 10.9. **else if** random(0,1)< $e^{\frac{-\Delta f}{T}}$
    - 10.10. Replace L^c with L^n;
    - 10.11. **end-if**
    - 10.12. **end-for**
    - 10.13. Update L'';
    - 10.14. Decrease the temperature according to the predefined pattern and set it as *T*;
    - 10.15. **Until** the system is frozen
11. **If** $F(L'')<F(L)$
12. Update *L* and set *k=1*;
13. **else**
14. Set *k=k+1;*
15. **end-if**

end-while

Until stopping condition is fulfilled

Print the resulted dynamic layout design that is the best solution obtained from algorithm;

Print the transportation design corresponding to the best dynamic layout**;**

Print the minimum cost resulted from the best dynamic layout;

End.

Figure 2. Pseudo code of the proposed hybrid VNS-SA

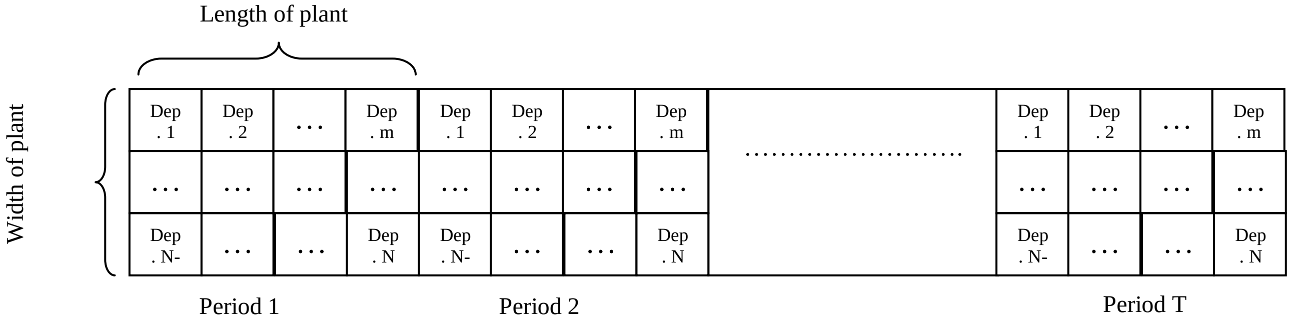

Figure 3. Coding scheme of the HVNS-SA meta-heuristic for DPLP

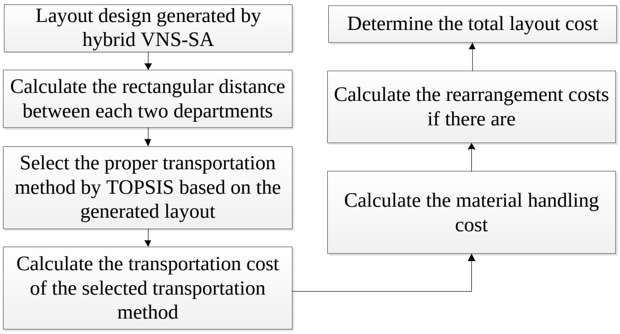

Figure 4. Systematic method for solution evaluation

TABLE 1. The comparison between the proposed HVNS-SA results and the best existing solution in the literature which are declared by Baykasoglu et al., [18].

No. of Periods	Prob. No.	Number of departments								
		6			15			30		
		Best of HVNS-SA	Best of Literature	Dev%	Best of HVNS-SA	Best of Literature	Dev%	Best of HVNS-SA	Best of Literature	Dev%
5	1	106419	106419	0.00	473191	481378	-1.70	561774	579741	-3.09
	2	104834	104834	0.00	476517	478816	-0.47	547864	570906	-4.03
	3	104320	104320	0.00	485020	487886	-0.59	554554	577402	-3.95
	4	101870	101870	0.00	477184	481628	-0.92	544642	569596	-4.38
	5	106399	106399	0.00	480843	484177	-0.69	531621	561078	-5.25
	6	105628	105628	0.00	477638	482321	-0.97	537843	567154	-5.16
	7	103985	103985	0.00	478481	485384	-1.42	535399	568196	-5.77
	8	106439	106439	0.00	476108	481378	-1.09	555650	575273	-3.41
10	1	214313	214313	0.00	970372	982298	-1.21	1106720	1171178	-5.50
	2	212134	212134	0.00	972635	973179	-0.06	1126740	1169138	-3.63
	3	207987	207987	0.00	972145	985364	-1.34	1118190	1165525	-4.06
	4	212741	212741	0.00	958551	974994	-1.69	1117950	1152684	-3.01
	5	211022	211022	0.00	915374	938846	-2.50	1107410	1128136	-1.84
	6	209932	209932	0.00	953724	968323	-1.51	1123460	1143824	-1.78
	7	214252	214252	0.00	962984	977410	-1.48	1124290	1142494	-1.59
	8	212588	212588	0.00	964981	985041	-2.04	1124980	1167163	-3.61

$$Dev\% = \frac{F_{HVNS-SA} - F_{Literature}}{F_{Literature}} \times 100$$

TABLE 2. The results of running HVNS-SA regarding the proposed model

Test problem	Mann-Whitney U-value	Critical value of U at p≤ 0.05	Statistically significant difference at p≤ 0.05
6-5	32	13	Not significant
6-10	32	13	Not significant
15-5	7	13	Significant
15-10	10	13	Significant
30-5	1	13	Significant
30-10	0	13	Significant

Note: α: the probability of Type-I error (i.e. 0.05). If $U< U_{critical}$ then Difference between mean of two samples is statistical significant.

TABLE 3. The results of running HVNS-SA regarding the proposed model

No. of Periods	Prob. No.	Number of departments		
		6	15	30
5	1	1527010	7677410	13768011
	2	1843430	8863960	12507699
	3	1705810	8425650	13107766
	4	1611460	7294970	12849644
	5	1924880	7608410	12453856
	6	1650350	7196700	12102545
	7	1777050	8214320	12726923
	8	1612270	7882690	13464701
10	1	2465770	12537500	27123600
	2	2691330	11580300	25723400
	3	1770050	11599100	26430200
	4	3030530	11327000	26375600
	5	2958030	12657700	25942400
	6	3363850	12938000	25280100
	7	2708020	11719900	26725400
	8	2910200	13421000	27260900

5. COMPUTATIONAL RESULTS OF EXAMINING THE EFFICIENCY OF THE PROPOSED HVNS-SA

The computational results of examining the efficiency of the proposed HVNS-SA are presented herein. The proposed HVNS-SA is coded in C^{++} programming language and applied to data samples obtained from Balakrishnan et al. [14]'data. At first, the HVNS-SA meta-heuristic is run regarding a basic model of Balakrishnan et al. [28]. The results of running the proposed HVNS-SA, as shown in Table 1, are compared with the best existing solution in the literature ([18]) using the percent deviation criterion. Statistical results based on Mann-Whitney test indicate the superiority of the proposed HVNS-SA over the other existing meta-heuristics which are proposed to solve the DPLP in the literature. The results obtained from the statistical test are presented in Table 2. After testing the validity of the proposed HVNS-SA, we apply it to the proposed new model. The results of running the algorithm are presented in Table 3.

6. NUMERICAL EXAMPLE

To clarify our proposed model, a numerical example is illustrated herein. Let us consider a factory consisting of six departments; each with square shape and one square unit of space. The six departments are located in an area with two units in width and three units in length, as illustrated in Figure 5. To minimize the material handling costs, which make up the major part of the manufacturing costs, the manager decided to present a proper layout design for a five-year planning horizon. To calculate the transportation cost of material handling between each two departments, first the TOPSIS method is implemented to choose the proper transportation method for carrying materials according to some specific criteria. These include fixed cost of transportation method selection, variable cost of material handeling by each transportation method, as well as reliability and carrying time of each transportation method. The variable cost obtained by dividing a material flow between two departments by a capacity of each alternative multiplied by moving cost of each alternative. In addition, the variable cost resulted from dividing the speed of the candidate alternative by the distance between two departments. In this paper, we consider three alternatives whose corresponding data are shown in Table 4.

To design the dynamic layout, the decision maker faces with the constraints that painting department, because of having flammable materials, and casting department, because of having a high temperature, should not be located next to each other and there should be at least one department between them. In other words, their rectilinear distances should be greater than one. In addition, CNC and Pressing departments could not be moved due to containing fixed facilities such as air conditioner and fixed foundations. As mentioned earlier, fixed-position departments are Pressing and CNC departments are represented by the numbers of 1 and 4, and located in the fourth and fifth positions, respectively. The two departments which should be avoided placing near each other are painting and casting departments are shown with numbers of 3 and 6, respectively. Figure 6 shows the initial solution inputted into the HVNS-SA, which further evolves, and then the best layout is obtained as presented in Figure 7.

In addition, as shown in Figure 7, the transportation design is determined to decide which facility should be used regarding each department. From the transportation patterns illustrated in Figure 7, it is visible that facilities types 1 and 2 are frequently used, but facility type 3 is rarely used (and only during periods 3, 4, and 5). In addition, the layout designs are the same in periods 3, 4, and 5. The initial layout cost is 1566130 units of money, thus after applying the proposed HVNS-SA it is reduced to 1156590 units of money for the best layout.

3 units

2 units

Painting	Welding	Assembly
Pressing	CNC	Casting

Figure 5. Schematic design of the studying plant layout

Casting (6)	Welding (5)	Assembly (2)
Pressing (1)	CNC (4)	Painting (3)

Initial layout of period 1

Painting (3)	Assembly (2)	Welding (5)
Pressing (1)	CNC (4)	Casting (6)

Initial layout of period 2

Painting (3)	Welding (5)	Casting (6)
Pressing (1)	CNC (4)	Assembly (2)

Initial layout of period 3

Welding (5)	Casting (6)	Assembly (2)
Pressing (1)	CNC (4)	Painting (3)

Initial layout of period 4

Casting (6)	Welding (5)	Painting (3)
Pressing (1)	CNC (4)	Assembly (2)

Initial layout of period 5

Figure 6. Initial layout generated randomly as a seed for HVNS-SA

	1	2	3	4	5	6
1	0	1	2	1	1	2
2	1	0	2	2	2	2
3	1	2	0	2	2	2
4	2	2	1	0	1	2
5	2	2	1	2	0	2
6	2	1	1	2	1	0

Transportation design of Period 1

	1	2	3	4	5	6
1	0	1	1	2	2	2
2	1	0	1	1	2	2
3	2	1	0	2	2	1
4	2	1	1	0	1	2
5	2	2	1	1	0	2
6	1	1	2	1	1	0

Transportation design of Period 2

	1	2	3	4	5	6
1	0	2	1	3	1	1
2	1	0	1	2	2	2
3	2	2	0	2	1	2
4	2	2	2	0	1	1
5	2	2	1	2	0	1
6	3	2	1	1	1	0

Transportation design of Period 3

	1	2	3	4	5	6
1	0	2	2	1	1	1
2	2	0	2	1	1	3
3	1	2	0	1	1	1
4	2	2	1	0	2	1
5	1	2	1	1	0	1
6	1	2	2	2	2	0

Transportation design of Period 4

	1	2	3	4	5	6
1	0	1	2	1	1	2
2	3	0	2	2	1	1
3	1	2	0	1	1	2
4	1	1	1	0	3	2
5	1	1	2	1	0	1
6	2	1	2	1	1	0

Transportation design of Period 5

Figure 7. Synchronized transportation and layout designs obtained from HVNS-SA

TABLE 4. Data for the considered criteria

Alternative	Fixed cost	Reliability	Speed	Capacity	Moving cost
1	10000	0.70	35	400	150
2	8000	0.75	18	150	400
3	2000	0.98	6	50	500

7. CONCLUSIONS

In this paper, a comprehensive model to design dynamic layout and transportation system simulantously is proposed in this paper. The transportation method is chosen among the different alternatives with respect to various. To tackle this problem, the TOPSIS is utilized to decide which transportation method has to be chosen for handling materials between departments. In addition, some real world constraints are considered in designing a dynamic layout. The goal of the model is to minimize the total net present value of the material handling costs and the rearrangement costs of departments for planning periods. In addition, an efficient hybrid meta-heuristic to solve the proposed DLP model. The superiority of the proposed HVNS-SA over all other existing solution algorithms which are presented in the literature to solve the general DPLP, i.e. the model was proposed by Balakrishnan et al., [28]. The results indicate that our proposed method significantly outperforms other existing methods in the literature.

For future studies, some possibilities could be considered such as considering capacitated transportation vehicle and other limitations of the transportation system including availability of the vehicles and budget constraints to improve application of the proposed model. In addition, the other plant layout design considerations such as rolling horizon rather than the fixed horizon, uncertainty of the demands of material flow, an unequal department size, and non-symmetrical shapes of departments can be taken into consideration. Finally, developing a mathematical model as well as an efficient solution algorithm to tackle the aforementioned extensions could be of interest to researchers.

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A Hybrid Meta-heuristic for the Dynamic Layout Problem with Transportation System Design

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چکیده

بهبود طرح چیدمان تسهیلات نیازمند به‌خوبی لحاظ‌نمودن فاکتورهای متنوع شامل تغییر در جریان مابین تسهیلات در طی زمان و طراحی سیستم حمل‌ونقل است. در این مقاله نخست یک مدل ریاضی جامع برای طراحی چیدمان پویا براساس یک افق برنامه‌ریزی چند دوره‌ای ارائه شده است. در این مدل طراحی چیدمان و سیستم حمل‌ونقل به‌صورت یکپارچه با در نظر گرفتن فرضیات واقعی مانند بخش‌ها با موقعیت ثابت و فاصله مشخص مابین بخش‌های خطرناک ارائه شده است. علاوه بر آن، معیارهای مشخص نظیر ظرفیت، هزینه و قابلیت اطمینان تسهیلات نیز در طراحی سیستم حمل‌ونقل نظر گرفته شده است. ماهیت پیچیده مسئله استفاده از الگوریتم حل فرا ابتکاری را الزامی نموده است. بنابراین، یک الگوریتم فرا ابتکاری کارا مبتنی بر جستجوی همسایگی متغیر و شبیه‌سازی تبرید برای طراحی چیدمان پویا برای چند دوره زمانی پیشنهاد شده است. اعتبار برتری روش حل پیشنهادشده با مقایسه نتایج کسب‌شده از دیگر روش‌های حل ارائه‌شده برای حل مسئله پایه‌ای در ادبیات موضوع اثبات شده است. درنهایت، نتایج محاسباتی گسترده حاکی از آن است که روش حل ارائه‌شده از تمامی روش‌های موجود برتر است. علاوه بر آن، حل مسئله نمونه موردی از صنعت لوازم تولید خانگی نیز کارای مدل و روش حل پیشنهادشده را از نظر کیفیت جواب در دنیای واقعی نشان می‌دهد.

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