THE DEVELOPMENT OF A DECISION-SUPPORT EXPERT SYSTEM FOR SOLVING FACILITIES LAYOUT PROBLEMS

M.H. Elwany, M.G. Abou-Ali and N.A. Harraz
Department of Production Engineering, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

In the manufacturing domain, every industrial plant has to obtain the optimal disposition of the physical facilities in order to attain a smooth and efficient production cycle. The area of facilities layout contains a mix of specialized models different in the approach, the type of the layout, the solution technique and the solution procedure. This work presents a comprehensive survey of the different features affecting the formulation of the problem, the evolution of solution techniques and the different procedures for the solution techniques. The work is concluded by introducing an outline of a solution methodology adopting the quadratic assignment programming (QAP) for the simulated annealing. The solution is carried out via a knowledge-based decision support system and an improvement algorithm.

Keywords: Industrial plants, Layout, Knowledge-based systems, Expert systems, simulated annealing.

1. INTRODUCTION

In the manufacturing domain, plant layout is defined as "The process of obtaining the optimal disposition of the physical facilities for a manufacturing unit [1]. In today's context, classical terms, such as plant layout, layout planning, layout problem become loose, and specific terms, such as facilities design, facilities allocation, facilities layout, machine layout would be preferred as they express individual cases. To date an adequate number of review papers have appeared such as [1-7]. In this work, chronological survey of solution techniques is presented. Different solution procedures for diverse techniques are discussed and compared. A solution methodology based on the use of knowledge-based systems, adopting the quadratic assignment programming (QAP) for the formulation, and the Simulated Annealing (SA) as a solution procedure is presented. At the end, conclusions are drawn.

2. THE FACILITY LAYOUT PROBLEM

Traditionally the facility layout problem was treated as a single objective, single criterion problem which could be solved by applying any simple management science technique. In the real life, problems contain a considerable number of variables, and may be also a number of conflicting constraints which makes the optimization of the problem a difficult task. The layout problem is " one of the truly difficult combinatorial problem that remains unsolved"[8]. Many elements and factors affect the presentation, and the solution of the problem which is encountered in diversified domain belonging to the profitable or to the public sectors, but each model is applicable to a particular problem scenario. This diverseness affects very much the presentation and the solution methodology of the problem.

The layout problem is an ill structured problem [9].

- There are multiple criteria (including qualitative and quantitative criteria) that must be considered to test alternate layouts.
- It is hard to determine a problem space that can represent all characteristics of the problem.
- There are many domain-specific and problem-specific constraints.

This nature of the problem makes the task of finding an optimal solution a very complicated one especially if the number of variables is large, in this case heuristics can be used to find near optimal solutions.

3. FEATURES OF THE GENERAL LAYOUT PROBLEM

The layout problem is represented after the subjective understanding of the situation. The most common features affecting the problem are described in Table (1). Some features are specific to some special cases. For example in the case of flexible manufacturing systems (FMS), machines are arranged in a linear single or double row if an automated guided vehicle is used, in a circular single row if a robot is used, or in multi row if a gantry robot is used [4].

4. EVOLUTION OF SOLUTION TECHNIQUES

Each combination of features form a problem scenario, and can be solved by applying the appropriate technique(s). The diversity of techniques is due to the natural evolution in the use of mathematics and different sciences. The evolution of techniques is surveyed from the early fifties till late nineties in Table (2).

5. SOLUTION PROCEDURES

The apparition of computer technology aided the mathematical solutions of the problem to evolve. The procedures used treated the problem as a well structured problem, those procedures could be solved by operations research or industrial engineering approaches. They usually consider one criterion and a very specific problem space, while The facility layout problem contains many conflicting criteria and objectives, most of them are subjective. From the survey of the solution techniques which is presented in Table (2), seven major ones were selected. They are the quadratic assignment programming [25-36],the nonlinear programming [3, 37, 38], the multicriteria aspect [39-42] the dynamic or multiperiod aspect [35, 43-47] the expert systems [9, 15, 16, 18, 24-23, 34], the simulated annealing [14, 48-50], and the fuzzy set theory[6]. Table (3) presents a comparison of the selected techniques and some of their solution procedures. The base of the comparison is the general characteristics, the inputs required, the limitations and the type of output.

6. THE FORMULATION OF THE PROBLEM

The problem considered is the layout of machine cells within a floor plan, the cells may be product layout cells or process layout cells, hence the quadratic assignment formulation can represent the problem.

6.1 *The Classical Quadratic Assignment*

Traditionally the problem has been formulated as:

$$\text{Min } Z = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} f_{ij} d_{kl} X_{ik} X_{jl} \tag{1}$$

$$\text{S.T. } \sum_{i=1}^{n} X_{ik} = 1, k = 1,2,..,n \tag{2}$$

$$\sum_{k=1}^{n} X_{ik} = 1, i = 1,2,..,n \tag{3}$$

$$X_{ik} \in \{0,1\} \ \forall i,k \tag{4}$$

Where

f_{ij} flow between facilities i and j

d_{kl} distance between sites k and l (from center to center as the facilities dimensions are assumed to be the same)

X_{ik} integer 0,1 variable

$X_{ik} = 1$ if facility i is assigned to location k

$= 0$ otherwise.

Table 1. Different features of the layout problem

Feature	Description	remark
• # of facilities	a) Single b) Multiple	
• Site presentation	a) Discrete b) Continuous	• Summation • Integration
• Relationship between variables	a) Linear b) Non-linear	• Such as in FMS. • Interaction between facilities (QAP.)
• Planning horizon	a) Static b) Dynamic (Multiperiod)	
• # of criteria	a) Single b) Multiple	
• Criteria type	a) Quantitative b) Qualitative c) Combination	• Objective • Subjective (Safety, noise level,...,etc.)
• # of floors	a) Single b) Multiple	
• Sector	a) Private b) Public c) Quasi-public	• The scope is mainly to increase profit. • The scope is to give services • The scope is to give services and realize a minimum profit
• Function	a) Allocation b) Minimization of the maximum variable (minimax problem). c) Facility layout	• such as in the case of allocating schools or
• Solution quality	a) Optimal, b) Sub-optimal	• (a) For small problems. (b)Large problems

Table 2. Evolution of solution techniques.

Period	Technique
Early to mid 1950	• Traditional schematic techniques The technique depended on the judgment and intuition of the analyst so it was subjective. The analyst used tools such as flow diagrams, templates, iconic models,.... etc. The technique depended heavily on the experience of the analyst
Mid 1950-early 1960	• Graphical systematic technique [10] Muther introduced the Systematic layout planning (SLP) technique [11] *, he used the flow charting and produced alternate layouts • Beginning of the mathematical modeling [12,13] Because of the trial and error methods the technique failed when the number of facilities was large
Late 60	Mathematical modeling and computer based algorithms • The formulation is mainly quadratic. The solution is optimal if the number of facilities is =< 15, sub optimal if the number of facilities is large • Heuristic algorithms are: -branch and bound, Computerized algorithms • The computer algorithms are: -Improvement algorithms, Construction algorithms
Mid to late 1970	• Special attention is given to the graph theory. The graph theory is more appropriate in the case of new layouts, it gives flexibility to the designer, but it may be not valid in certain cases
Early to mid 1980	• A great evolution in the mathematical modeling., interactive packages appear • Use of graphics • Multigoal approach • The Simulated annealing technique is introduced [14]
Mid 1980	• The general trend affects the problem and artificial intelligence is used to solve the problem. Knowledge bases and expert systems are used.[15-23]
Late 1980	• Fuzzy Set. The theory begun to be used in solving the problem [6]

Table 3. Comparison between some selected solution procedures for the major techniques

General characteristics

Technique	Quadratic assignment formulation												Nonlinear			Multicriteria				Dynamic aspect						Expert systems&D. S. S								SA				Fuzzy
Reference number	25	26	27	28	29	30	31	32	33	34	35	36	3	37	38	39	40	41	42	43	44	35	45	46	47	18	9	15	16	34	23	21	22	14	48	49	50	6
Year 19--	68	75	76	77	77	80	82	84	87	89	92	94	91	91	91	87	92	92	93	75	76	86	91	92	92	87	89	90	90	90	90	92	94	84	92	92	92	91
Qualitative criteria		x														x	x	x	x									x		x	x	x					x	x
Quantitative criteria	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x		x	x	x	x	x
Multicriteria																x	x	x	x							x	x	x		x		x	x				x	x
Interactive																x										x	x	x	x	x	x	x	x					
Multiobjective				x												x	x	x	x							x	x	x		x	x	x	x		x	x	x	x
Multifloor							x					x																										
Capacity	30	15	80	15	15	350		30	350	8	30	25				40	36	10	30	5	5			20	40	25									90		30	8

Inputs Required

Reference number	25	26	27	28	29	30	31	32	33	34	35	36	3	37	38	39	40	41	42	43	44	35	45	46	47	18	9	15	16	34	23	21	22	14	48	49	50	6
Faclities dims.													x	x	x								x	x	x				x	x	x	x						x
Dims. of floors												x			x	x							x	x	x			x		x	x	x						x
Flow matrix	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
Rel. matrix		x														x	x	x	x							x	x	x			x	x	x					x
Site location	x	x	x	x			x	x		x	x	x		x	x	x	x	x	x	x	x			x	x	x	x	x			x		x	x	x	x	x	x
Number of floors							x					x																										
Number of periods																				x	x	x	x	x	x													
Initial solution	x					x	x	x				x	x				x		x			x	x	x	x									x	x	x	x	

Limitations

Reference number	25	26	27	28	29	30	31	32	33	34	35	36	3	37	38	39	40	41	42	43	44	35	45	46	47	18	9	15	16	34	23	21	22	14	48	49	50	6
Impractical	x	x	x																																			x
Travel // to edge																														x								
Path dependent	x						x	x		x																												

Type of Output

Reference number	25	26	27	28	29	30	31	32	33	34	35	36	3	37	38	39	40	41	42	43	44	35	45	46	47	18	9	15	16	34	23	21	22	14	48	49	50	6
Block diagram						x	x		x			x		x	x	x	x	x					x			x			x	x								
Space relationship	x	x	x	x						x	x		x						x	x	x	x		x	x		x	x			x	x		x	x	x	x	x
At each stage	x						x	x		x		x			x	x	x	x	x			x	x	x	x	x	x	x	x	x		x			x			

The constraint given by equation number (2) assures that each location is assigned one facility. The constraint given by equation number (3) assures that only one facility will be assigned to one location. The numbers of facilities and sites are assumed to be equal, otherwise dummy facilities with flow of material equal to zero are used.

6.2. *Inclusion of the Qualitative and Quantitative Criteria*

There have been some attempts to handle the two types of criteria in the same function, for example,[6, 39-42]. According to the approach of Harmonosky and Tothero[40],

- All qualitative factors were quantified so that they could be handled mathematically.
- The factors are normalized so that each will have an equivalent effect on the layout
- Weights are applied to each factor to reflect its importance
- All factors are combined into one composite factor.

The mathematical model is used in the improvement part to evaluate the alternate configuration, the model proposed by Harmonsky and Tothero [40] is appropriate as it incorporates the qualitative and quantitative criteria in the same function. They defined S_{ijm} as the relationship value between departments i and j for factor m, T_{ijm} as the normalized relationship value between departments i and j for factor m ($T_{ijm} = S_{ijm} / \sum_i^n \sum_j^n S_{ijm}$), and α_m as the weight representing the relative importance of each factor.

$$\text{Min } Z = \sum_i^n \sum_k^n \sum_j^n \sum_l^n \sum_m^n \alpha_m T_{ijm} d_{kl} X_{ik} X_{jl} \quad (8)$$

$$\text{S.T.} \sum_i^n \sum_j^n T_{ijm} = \forall m \quad (9)$$

$$\sum_{i=1}^{n} X_{ik} = 1, k = 1, \ldots, n \quad (10)$$

$$\sum_{k=1}^{n} X_{ik} = 1, k = 1, \ldots, n \quad (11)$$

$$X_{ik} = 0, 1 \; \forall i, k \quad (12)$$

Where

α_m	weight for factor m
t	number of factors
n	number of departments
d_{kl}	distance between location k and l
x_{ik}	1 if department i is assigned to location k 0 otherwise
i, j	stands for department numbers and,
k, l	stands for location numbers

7. THE SUGGESTED SOLUTION METHODOLOGY

The analytical models are not applicable in the industrial domain because they generally consider only quantifiable factors, and are difficult to implement especially if the number of facilities to be allocated is considerable (fifteen in the case of quadratic programming) A knowledge based approach can address the totality of factors involved in the problem in a structured logical way. Better solutions are obtained when knowledge based systems work in a tandem mode (i.e. combine rules with optimization approaches). A solution methodology is suggested. The solution is performed via a knowledge-based decision support system, the resultant layout can be seeded to an improvement algorithm . In order to prevent falling in a local minimum region the improvement algorithm is based on the recent technique " the simulated annealing". The problem is presented in a quadratic form, as preceded. The outline of the methodology is presented in Figure (1).

7.1 *The Decision Support System*

The data input

The data input consists of all the information needed to describe the problem.

The priorities identification

The end user must assign a weight to each criteria to identify its priority. Upon the assigned weight the inference engine conduct the solution towards the appropriate set of rules.

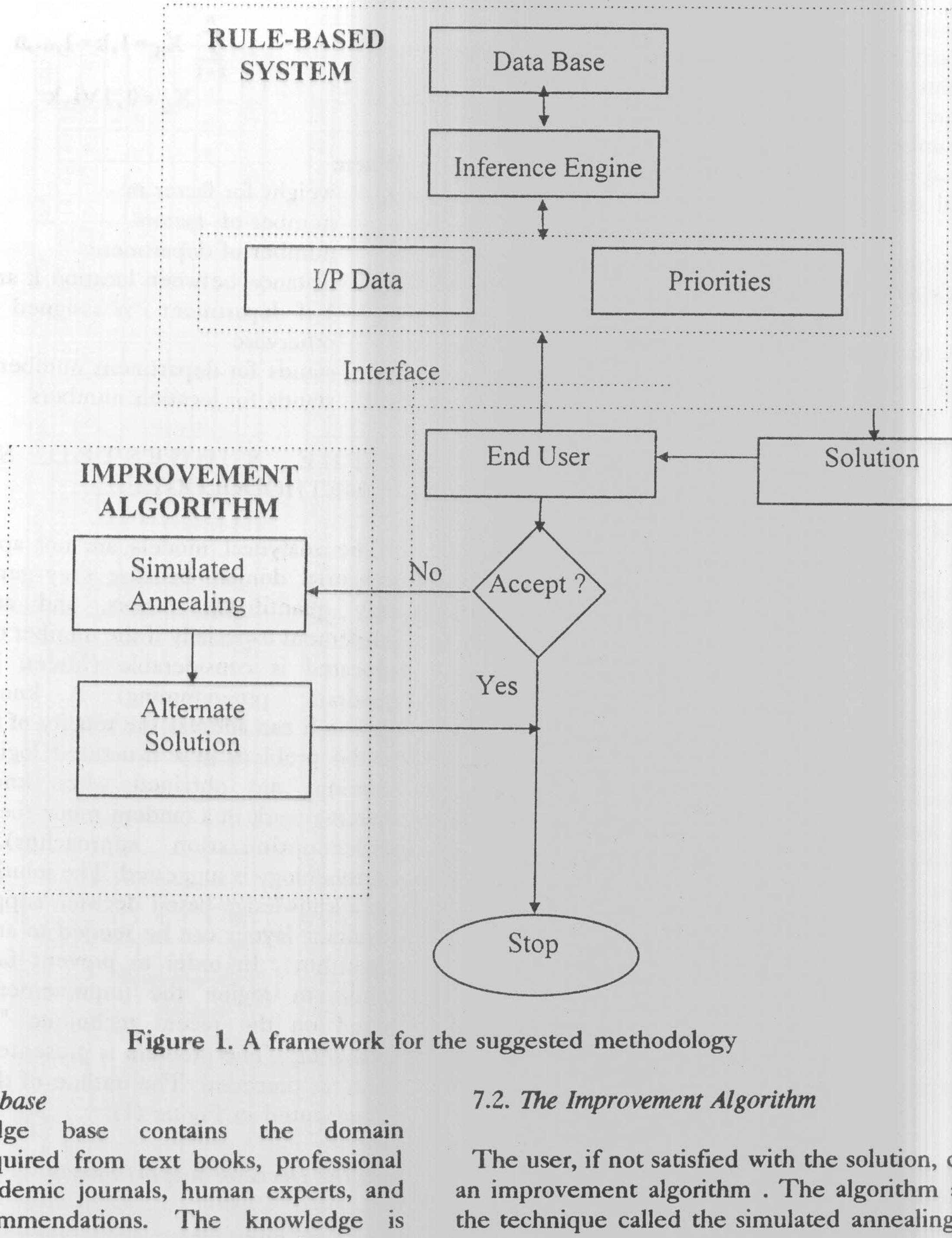

Figure 1. **A framework for the suggested methodology**

The knowledge base

The knowledge base contains the domain knowledge acquired from text books, professional magazines, academic journals, human experts, and standard recommendations. The knowledge is presented in the form of production rules. The rules generate alternate path of reasoning.

The inference engine

The inference engine is needed to link the rules and managing them by choosing the appropriate ones for assigning facilities according to the priorities given to the diverse criteria.

7.2. *The Improvement Algorithm*

The user, if not satisfied with the solution, can call an improvement algorithm . The algorithm applies the technique called the simulated annealing.

7.2.1. *The simulated annealing*

The Simulated Annealing technique resembles to the annealing process utilized for bringing the metal to its lowest energy state. The metal is first heated up to its melting temperature and is cooled slowly to allow the release of all internal stresses. During this process, a change in the state of the metal is likely to occur if it leads to a lower energy state. The same principle is utilized in order to minimize the objective function of a combinatorial problem within finite time.

A change in the configuration is allowed if it reduces the value of the objective function. The change is also allowed, with a lower probability if the value of the objective function increases.

7.2.2. *Parameters required for the simulated annealing*

To perform this algorithm some parameters are required, they are summarized in Table (4).

Table 4. Recommended values for the parameters required to perform the simulated annealing algorithm.

	Parameter	Recommended value	Reference
Initial temperature	t	999	48
Cooling ratio	r	0.9	48,49,50
Maximum number of accepted Configurations for a certain temperature	*Nlimit*	*10N*	49,50
Maximum Number of Configurations for a certain temperature	Nover	100N	49,50
Last temperature	Itempmax	50 (100)*	48,49
Probability of acceptance	P	0.85	50

*50 for good solutions and reasonable CPU time and 100 for large number of facilities and when the value of the objective function is a dominant factor. N : The number of facilities.

7.2.3. *The simulated annealing algorithm*

The flow chart of the algorithm, written in "C" is shown in Figure (2), and hereafter the steps of the algorithm.

Step 0 Set S = initial solution; Z the corresponding Objective function value;

Itemp = 0; t = 999; r = 0.9; Itempmax =50, Nover = 50N; Nlimit = 10 N.

Step 1 With S as the initial solution apply the 2 way exchange. If Z`<=Z, set S+S` and Z =Z', otherwise step 2.

Step 2 If Z' > Z compute the difference D = Z'-Z, set S` = s with probability exp (-D/t).

Step 3 repeat step 1 Nover times or until the number of successful configurations is equal to Nlimit.

Step 4 Set t = r.t and itemp = itemp + 1, if itemp = itempmax go to step 1 otherwise stop.

8. CONCLUSIONS

In this work, the facility layout problem has been surveyed over the last three decades. It is concluded that the layout problem possesses a combinatorial nature, and to attain optimal solutions a high CPU time is required, hence heuristics may be used to give reasonable solutions in an adequate time. Various solution techniques and different related procedures were surveyed and compared. A solution methodology is suggested. The methodology works in a tandem mode, i.e. it combines the expert system with an optimization algorithm, the two parts are capable to solve the problem for more than two factors handling the qualitative and quantitative criteria similarly. In the first part, the expert system generates the solution using the rules that act in a way to satisfy the requirements and the designated priorities. The solution obtained from the first part serves as a seed solution for the second part, which is the improvement algorithm. The improvement algorithm - Simulated annealing - is a global optimization algorithm. Another advantage of the algorithm used in the methodology is that, instead of exchanging the locations of departments randomly, which can increase the CPU time, the exchanges is performed according to the two-way exchange procedure, which have been proved in the literature to outperform the tree-way exchange procedure in the CPU time, and the comparably inferior quality solution is overcomed by the use of the simulated annealing technique. The facility layout problem implies long hours to perform manual iterations, subjects humans to extreme mental stress, and solutions to unpredeteminated calculations errors. The suggested methodology economizes time and human effort that can be abused in solving the multidisciplinary problem.

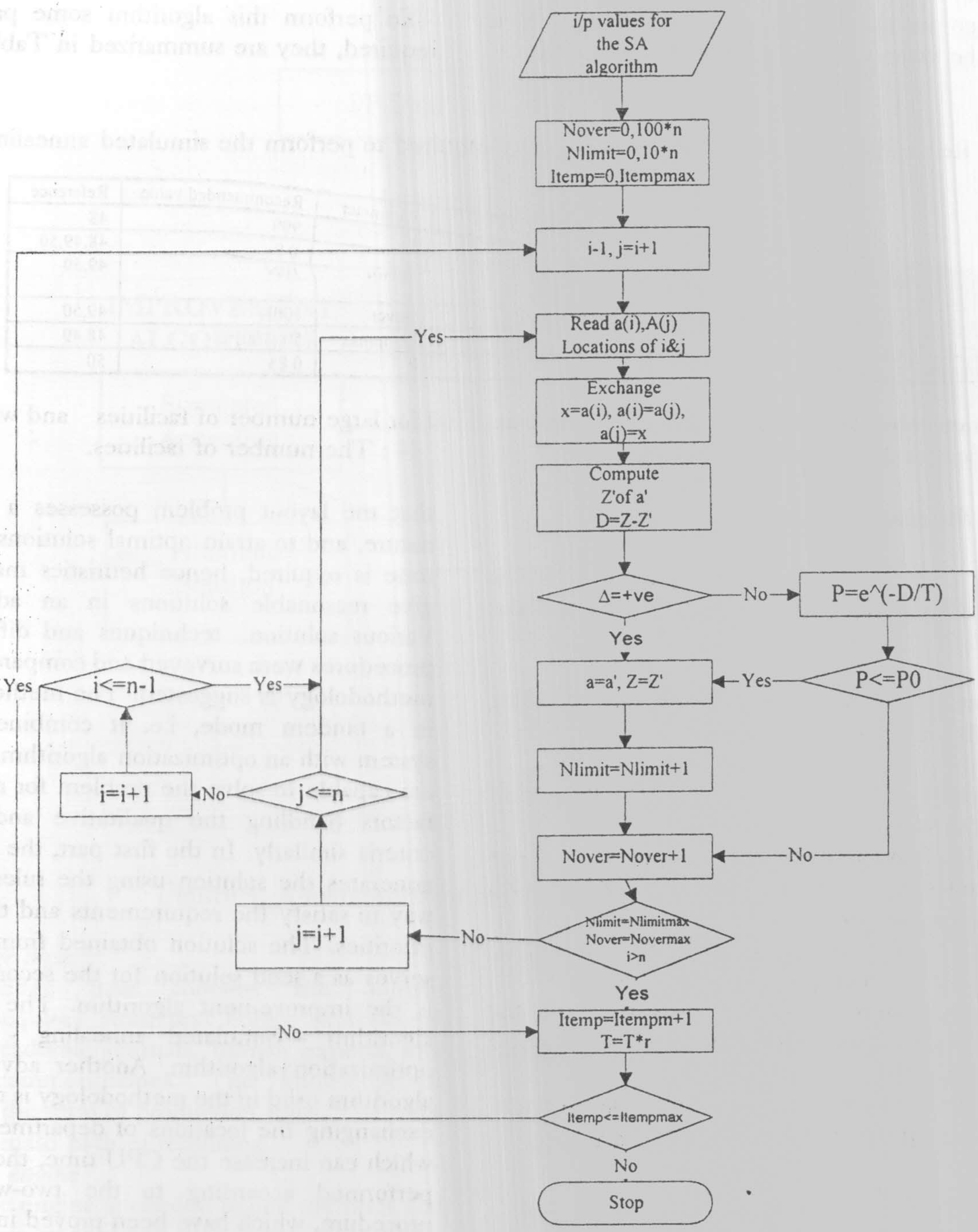

Figure 2. The flow chart of the simulated annealing algorithm.

REFERENCES

[1] T.E. El-Rayah, T.E. and Hollier, R. H., 1970, "A Review of Plant Design Techniques", *International Journal of production Research,* vol. 8, No. 3, pp. 263-279.

[2] L.R. Foulds, "Techniques for Facilities Layout Deciding Which Pairs of Activities Should Be Adjacent", *Management Science.*, vol.29, No.12, pp. 1414-1426, 1983.

[3] S.S. Heragu and A. Kusiak, "Efficient Models for the Facility Layout Problem". *European J. of Operational Research.*, vol. 53, pp. 1-13, 1991.

[4] A. Kusiak and S.S. Heragu, "The Facility Layout Problem." *European J. of operational research.*, vol. 29, pp. 229-251 ,1987.

[5] R.R. Levery and S. Kalchick, "Facilities Layout- A Survey of Solution Procedures". *Computers and Industrial Engineering.*, vol.9, No. 2, pp. 141-148, 1985.

[6] A.D. Raoot And A. Rakshit, "A "Linguistic pattern" Approach for Multiple Criteria Facility Layout Problems", *International Journal of Production Research,* vol.31, No. 1, pp. 203-222, 1993.

[7] R. Yaman, D.T. Gethin and M.J. Clarke, "An Effective Sorting Method for Facility Layout Construction", *International Journal of Production Research,* vol. 31, No. 2, ppp. 413-427, 1993.

[8] P.C. Yip, Percy, "New Optimizer for the Facility Layout Problem" *Proceedings of the International Jt. Conference on Neural Networks,* vol. 2, pp. 1573-1576, 1993.

[9] B. Malakooti and A. Tsurushima, "An Expert System Using Priorities for Solving Multiple-Criteria Facility Layout Problems", *International Journal of Producton Research,* vol. 27, No. 5, pp. 793-808, 1989.

[10] L.R. Foulds, P.B. Gibbons, J.W. Giffin, "Facilities Layout Adjacency Determination : an Experimemtal Comparison of Three Graph Theoritic Heuristics", *Operations Research,* vol. 33, No. 5, pp. 1091-1105, 1985.

[11] R.L. Francis and J.A. White, "*Facility Layout and Location : An Analytical Approach*", Prentice Hall, 1974.

[12] K.C. Lockyer, "*Factory and Production Management*", ELBS 1st.edition, 1978.

[13] A. Muhlemann, J. Oakland and K. Lockyer, "*Production and Operation Management*". Pitman. Sixth edition, 1993.

[14] R.E. Burkard and F. Rendl, "A Thermodynamically Motivated Simulation Procedure for Combinatorial Optimiztion Problems", *European Journal of Operational Research,* vol. 17, pp. 169-174, 1984.

[15] G. Abdou and S.P. Dutta, "An Integrated Approach to Facilities Layout Using Expert System", *International Journal of Production Research,* vol. 28, No.4, pp. 685-708, 1990.

[16] C.S. Chen, K. Kengskool, "An Autocad-Based Expert System for Plant Layout", *Computers Industrial Engeneering,* vol. 19, No. 1-4, pp. 299-303, 1990.

[17] S.S. Heragu and A. Kusiak, "Machine Layout: An Optimization and Knowledge Based Approach", *International Journal of Production Research,* vol. 28, No. 4, pp. 615-63, 199.0

[18] S.R.T. Kumara, R.L. Kashyap and C.L. Moodies, "Expert System for Industrial Facilities Layout Planning and Analysis" *Computers and Industrial Engineering,* vol. 12, No. 2, pp. 143-152, 1987.

[19] S.R.T. Kumara, R.L. Kashyap and C.L. Moodies, "Application of Expert System and Pattern Recognition Methodologies to Facilities Layout Planning", *International Journal of Production Research,* vol. 26, No. 5, pp. 905-930, 1988.

[20] J.O. Matson, J.M. Mellichamp and S.R. Swaminathan, "EXCITE : Expert Consultant for In-Plant Transportation Equipment", *International Journal of Production Research,* vol. 30, No.8, pp. 1969-1983, 1992.

[21] D.T. Pham and H.H. Onder, "A Knowledge-Based System for Optimizing Workplace Layout Using a Generic Algorithm", *Ergonomics,* vol. 35, No. 12, pp. 1479-1487, 1992.

[22] J.F. Repede and J.J. Bernardo, "Developping and Validating a Decision Support System for Locating Emergency Medical Vehicles in

Louisville, Kentucky", *European Journal of Operational Research,* vol. 75, pp. 567-581, 1994.

[23] B.M. Worrall and H.P.. Gibbs, "Design of a Facility Layout Decision Support System", *International industrial engineering conference proceedings,* Institute of Industrial Engineers, pp. 218-223, 1990 .

[24] A.D. Raoot and A. Rakshit, "An Experimental Comparison of Systematic Placement for Facility Layout Design", *International Journal of Production Research,* vol. 31, No. 7, pp. 1735-1756, 1993.

[25] C.E. Nugent, T.E. vollmann and J. Ruml, "An Experimental Comparison on Techniques for The Assignment of Facilities to Locations", *Operation Resesach,* vol. 16, No. 1, pp. 150-173, 1968.

[26] A.P. Jr. Hurter, M.K. schaefer and R.E. Wendell, "Solution of Constrained Location Problems", *Management Science,* vol. 22, No.1, pp. 51-56, 1975.

[27] A.W. Chan and R.L. Francis, "A Least Total Distance Facility Configuration Problem Involving Lattice Points", *Management Science,* vol.22, No.7, pp. 778-787, 1976.

[28] D. Erlenkotter, "Facility Location with Price Sensitive Demands: Private, Public and Quasi Public", *Management Science,* vol.24, No. 4, pp. 378-386, 1977.

[29] V.F. Dokmeci, "A Quantitative Model to Plan Regional Health Facility Systems", *Management Science,* vol.24, No.4, pp. 411-419, 1977.

[30] Z. Drezner, "DISCON: A New Method for the Layout Problem", *Operations Research,* vol.28, No. 6, pp. 1375-1384, 1980.

[31] R.V. Johnson, "Spacecraft for Multi-floor Layout Planning", *Management Science.,* vol.28, No.4, pp. 407-417, 1982.

[32] C.J. Picone and V.E. Wilhelm, "Solution to the Facilities Layout problem", *Management Science,* vol. 30, pp. 1238-1249, 1984.

[33] Z. Drezner, "A Heuristic Procedure for the Layout of A Large Number of Facilities", *Management Science,* vol. 33, No. 7, pp. 907-915, 1987.

[34] B. Golany And M.J. Rosenblatt, "A Heuristic Algorithm for the Quadratic Assignment Formulation to the Plant Layout Problems", *Intenational Journal of Production Research,* vol.27, No.2, pp. 293-308, 1989.

[35] M.J. Rosenblatt, "The Dynamics of Plant Layout", *Management Science,* vol. 32, No. 1, pp. 76-86, 1986.

[36] Y.A. Bozer, R.D. Meller and S.J. Erlebacher, "An Improvement Type Layout Algorithm for Single and Multiple-Floor Facilities", *Management Science,* vol. 40, No.7, pp. 918-932, 1994.

[37] D. Riopel and A. Langevin, "Optimizing the Location of Material Transfer Stations Within Layout Analysis" *International Journal of production economics,* vol. 22, pp. 169- 176, 1991.

[38] D.J. Van Camp M.W. Carter, A. Vannelli, "Nonlinear Optimization Approach for Solving Facility Layout Problems", *European Journal of Operational Research,* vol. 57, No.2, pp. 174-18, 1992.

[39] F.R. Jacobs, "A Layout Planning System With Multiple Criteria and a Variable Domain Representation " *Management Science,* vol. 33, No. 8, pp. 1020-1034, 1987.

[40] C.M. Harmonosky and G.K. Tothero, "A Multi-Factor Plant Layout Methodology", *International Journal of Production Research,* vol. 30, No.8, pp. 1773-1789, 1992.

[41] S.C. Sarin P. Loharjun, C.J. Malmborg, B. Krishnaumar, "Multiattribute Decision-Theoretic Approach to the Layout Design Problem", *European Journal of Operatinal Research,* vol. 57, No. 2, pp. 231-242, 1992.

[42] J.S. Shang, "Multicriteria Facility Layout Problem : An Integrated Approach", *European Journal of Operational Research,* Vol. 66, pp. 291-304, 1993.

[43] G.O. Wesolowsky and W.G. Truscott, "The Multiperiod Location-Allocation Problem with Relocation of Facilities", *Management Science,* vol. 22, No. 1, pp. 57-65, 1975.

[44] D.J. Sweeney and R. Tatham, "An Improved Long Run Model for Multiple Warehouse Location" *Management Science,* vol. 22, No. 7, pp. 748-758, 1976.

[45] B. Montreuil and U. Venkatadri, "Strategic Interpolative Design of Dynamic Manufacturing Systems Layouts" *Management Science,* vol. 37, No. 6, pp. 682-694, 1991.

[46] J. Balakrishnan, F.R. Jacobs, M.A. Venkataramanan, "Solution for The Constrained Dynamic Facility Layout Broblem" *European Journal of Operational Research,* vol.57, pp. 280-286, 1992.

[47] U.S. Palektar, R. Batta, R.M. Bosch and S. Elhence, "Modelling Uncetainities in Plant Layout Problems" *European Journal of Operational Research,* vol 63, pp. 347-359, 1992.

[48] S.S. Heragu, A.S. Alpha, "Experimental Analysis of Simulated Annealing Based Algorithms for the Layout Problem", *European Journal of Operational Research,* vol. 57, No. 2, pp. 190-202, 1992.

[49] S. Jajodia, I. Minis, G. Harhalakis and J. Proth, "CLASS : Computerized Layout Solutions Using Simulated Annealing", *International Journal of Production Research,* vol.30, No. 1, pp. 95-108, 1992.

[50] P. Kouvelis, W. Chiang, J. Fitzsimmons, "Simulated Annealing for Machine Layout Problems in the Presence of Zoning Constraints" *European Journal of Operational Research,* vol. 57, No. 2, pp. 203-223, 1992.