Application of Genetic Algorithm and Variable Neighborhood Search to solve the Facility Layout Planning Problem in Job Shop Production System

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Abstract—**Today's techno savvy world is evolving with the prompt changes in technology, everyday fluctuation in demand of products as well as the increasing diversity of products, the exiting layout of facilities may invalid frequently. These changes lead to makes the improvement in the existing layout of available facilities on shop floor to cope up with the growing market competition. By keeping this concept in mind, the present study deals with the development of a model to solve facility layout problem evolving job shop production system. This problem is itself a Non-Polynomial hard and considering the various cost factors makes it more difficult to attain the optimum solution. Therefore, a nature inspired algorithm i.e. Genetic Algorithm (GA) is applied to deal with this problem while considering handling and moving cost of facilities as well as setup cost in a job shop type of production system. Moreover, the Variable Neighborhood Search (VNS) method has been integrated with GA to enhance the local search of optimal solution. The results revealed that the proposed approach is well suited to solve the problem effectively. Also, an attempt has been made to help the administration to decide the changes in the exiting layout by implementing the well-known "cost-benefit-analysis".**

Keywords-optimization; genetic algorithms; variable neighborhood search; cost; facility layout problem; facility planning

I. INTRODUCTION

The arrangement or layout of resources like men, machine and material in a manufacturing industry play the cardinal role to improve the optimum utilization of these resources. Therefore, the layout of these facilities in the shop floor is directly relates with the profit and productivity of the manufacturing firm. In addition, the handling of material among these facilities is also the adjoined factor. Also, the facility layout strategies are truly connected with both the quality and cost of the product. Hence, the ratio of supply and demand of products is also affected by the facility designs. In fact, the production industries are very conscious about their facility designs and they prearrange a good quantity of revenue as well as spends enough time to attain the effective and optimized designs of facilities. The objective of this function is the production of high quality product by optimal use of resources [1-2]. A significant number of contribution has been made by various researchers across the world to enhance the facility planning. Drira *et al.* [3] have been conducted a literature survey on facility layout problems. A good number of mathematical, simulation and computer-based models have been proposed with varying philosophies to solve the facility layout problem. Naqvi *et al.* [4] illustrated the comparison of various approached applied for layout design as well as presented the application of Systematic Layout Planning (SLP) method for a company producing high level of products variety. Anjosa and Vieirab [5] has been presented a detailed literature review on the mathematical approaches used for facility planning problem

Badiru and Arif [6] has proposed a software called Flexpert: facility layout expert system using fuzzy linguistic relationship codes to generate the optimal layout considering quantitative and qualitative constraints. Another important computer-based facility planning software has been proposed by [7]. It is capable to solve the multi objective facility planning problem based on a well-known hierarchical AHP/DEA methodology. Both ranking models are commonly used in practice. Hadi-Vencheha and Mohamadghasemi [8] proposed an integrated AHP-NLP methodology for quantitative and qualitative criterions and using Spiral software to generate the layout patterns. Altuntas et al. [9] proposed "fuzzy decision-making trial and evaluation laboratory" method called as fuzzy DEMATEL for facility layout planning, considering quantitative and qualitative criterions and tested the capability by handling a real problem of machinery industry. Hosseini et al. [10] proposed meta-heuristics to minimizing the three types of costs viz., fixed cost of material handling equipment's, cost of material handling as well as cost of rearrangement of facilities. Turanoğlu and Akkaya [11] proposed a model to stabilize the transportation and material handling cost for re-planning of facilities using fuzzy decision technique and comparison revealed that suggested model is better than traditional method of facility planning.

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Another approach is based on simulating method in which the factory facilities are simulated to mimic reality to calculate the performances and preplanning if required. Eneyo and Pannirselvan [12] established the process simulation and performed the analysis on capacity of facilities and find the significant improvements in process accomplishment. Zetu *et al.* [13] used Virtual Reality technique for facility planning. They can build a 3D model by accessing the data of physical facilities present in the plant. Duffy *et al.* [14] worked for improvements in work safety using an internet virtual layout system. Also, Phoon *et al.* [15] presented a virtual loop layout model working as an intuitive and interactive platform for loop layout planning and evaluation in real time control.

Several studies are conducted with nature inspired algorithms viz., Chen *et al.* [16] presented the Simulated Annealing approach with multi-dimensional scaling method by interchange the "scatter diagram" and established the efficient structure of facilities and minimize the travelling cost among the facilities; Moghaddain and Shayan [17] mapped GA to quadratic assignment problem for equal and unequal sizes of facilities. Also, Kochhar *et al.* [18] concluded that GA proves as a good substitute in a realistic situation of facility planning, they presented GA for an individual floor facility planning for both sizes of facilities. Moslemipour *et al.* [19] proposed a mathematical model for facility design having minimum total cost of handling the facilities for the re-planning of layout, formulated as a quadratic assignment problem and authenticated with benchmark data of available in literature.

Planning of fresh layout design of facilities is much easier task as compare to the modification and expansions in the existing layout design, which may term as "re-planning" of the facilities available on floor. Every industry under goes expansion or consolidation at any stage of life. Moreover, the arrangements of various manufacturing departments within the job shop production system is more challenging task, because of the performance of facilities layout is directly related with the cost involved to handle the material and its travelling distance among the facilities. So, the key performance measure is the material handling cost, which is to be minimized while initial planning and re-planning of facilities design [20].

Job shop production system is the well-known and most regularly used arrangement which mimic the actual production setup [21 & 22]. In this system, various type of manufacturing flexibilities can be considered but the most important is the routing flexibility. A good number of research findings has been presented during the search of optimal solution for the facility layout problems evolving job shop production system from different viewpoints as discussed by [23]. Chan [24] has presented the performance of production system with consideration of routing flexibility under distinct layouts. Lee [25] has proposed a facility design with minimized cost of material handling using similarity-based procedure. Phanden *et al.* [21, 22, 26-28] has successfully implemented simulation based GA for job shop scheduling problem considering various alternative process plans which includes various manufacturing flexibilities viz., operation flexibility, sequencing flexibility and, processing flexibility.

Garey *et al.* [29] stated that determining optimal facility planning with minimum cost of material handling is an NP-hard. Also, finding an optimal solution within worthwhile computation time is always a challenging task [30]. Hence, meta heuristic approach has been widely accepted to find the optimal solution for such type of problems. Moreover, latest studies are presenting that the GA as a well-suited approach to solve facility planning problem effectively [30, 31 & 32]. Thus, in the present study GA has been integrated with the VNS method to construct the facility planning system for a job shop production environment. Literature review clearly revealed that GA has not been used with VNS for the facility planning problem. So, in the present model, an attempt has been made to search an optimal facility design solution and the solution is validated for financial advantages as well. A comparison of the proposed approach has been made with the exiting GA approach for the same problem as given in [20]. Also, the model and case study of 25 work stations and 20 operation process is taken from [20] to validate the performance of the proposed hybrid approach.

II. Problem Formulation

In the job shop production system, the facilities are arranged according to the process layout. This layout is most suitable for the production houses which involve large size of product variety and small size of production volume. In this layout, every job is considered as an independent entity. The most challenging task is to organize the facilities or work stations according to the optimum movement of material from one station to another so that the cost of material handling can be minimized successfully. However, this cost is basically subjected to manufacturing processes used, the number of movements of entities among various stations during a time-span and, of course it also depends on the distance among two processing stations [20, 25, 30 & 31]. Yang *et al.* [20] have expressed the objective function for facility planning considering cost of moving, number of movements and the distance between stations. They have explained the calculation of cost of material handling for planning of new facilities using From-To chart analysis. Also, the present study utilizes the objective function proposed by [20], for re-planning of facilities and GA has been modified to integrate with VNS method to improve the local search space for optimization. Moreover, every company will agree for re-planning the facilities if, the cost of material handling is reducing in greater amount in comparison of the cost involved in relocating the facilities. However, there are certain aspects to relax while formulation of problems such as no more than one entity at a specific position in the given time, no more than one position located for entities in a given time, size of entity is not taken into account and the distance among two locations is fixed as one unit.

III. Genetic Algorithm and Variable Neighborhood Search

Many researchers have found that integration of GA with other heuristics is always enhance the performance of

solution search procedure as compare to finding the solution for hard problems with an individual conventional nature-inspired algorithm [21, 22 & 28]. The NP-hard problems are allied with a large size of populations or solution space. Therefore, the search of an optimal solution is in demand of a powerful computation strategies. A regular GA has been recognized as a well-suited algorithm and it is proficient to create the sections of solution space in an appropriate size of population. Thus, in the present work, the conventional procedure and steps of GA has been modified to accommodate the VNS method to search the optimal solution without compromising the computation time.

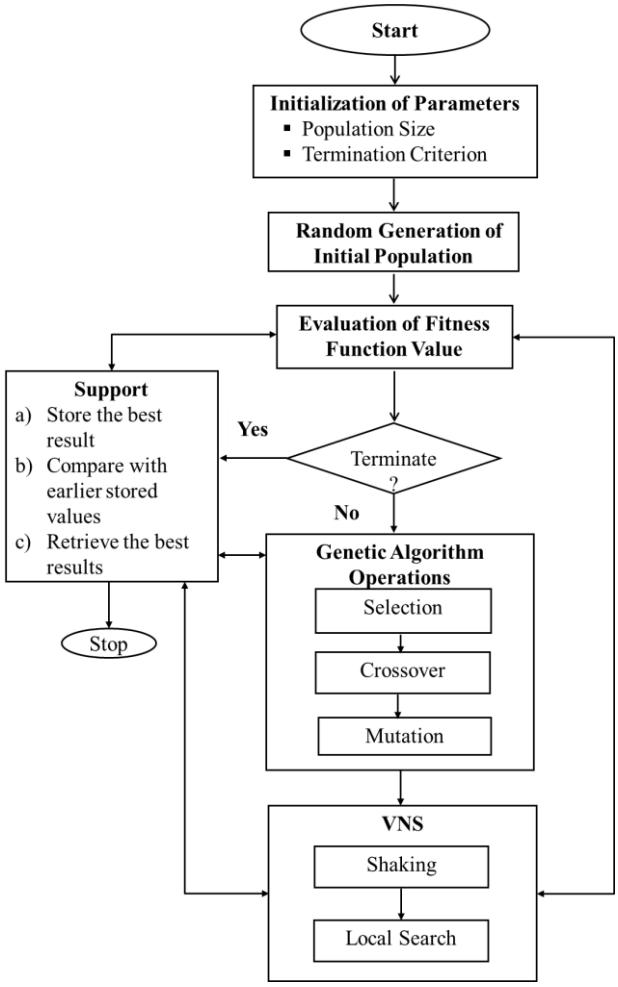

Figure 1. Adopted Methodology of GA and VNS.

The GA comprises of various steps such as (1) generation of initial population (2), evaluation of fitness function values, (3) genetic operations and reproduction (4) termination of algorithm etc. It works in iterative manner till the termination criteria meet. The most important task in GA is the design of its chromosome structure specially to achieve the integration with another heuristics technique. In the present work, the machine based chromosome structure has been chosen because, it is most popular and well suitable with VNS method. Moreover, the fitness function has been adopted from [20], to evaluate the performance of the layout which considering the cost of handling the facilities, cost of moving the facilities as well as the cost of setting the facilities at new location. Figure 1 shows the working methodology of GA and VNS for the present work.

A. Chromosome Structure and Initialization

The initial task is the encoding of solution as per the suitable and effective chromosome structure. The present work utilize machine based chromosome structure, in which each location is assigned as a gene of chromosome. It is the simplest type of structure which is most suitable for the job shop production systems. Here, a bit (gene) of a chromosome is formed by a facility number (i.e. alphabets) of initial layout. Each bit of the chromosome is in fixed order to represent associate facility of a layout. The initial population has been generated randomly which is the most preferred and suggested by various researchers [20].

B. Genetic Operations and Termination

The present work utilizes the tournament selection procedure which is known for its capability to avoid the premature convergence of GA. Every set of individuals or chromosomes under goes the tournament among their capability to win as per their fitness values. The tournament size is varied from 2 to 3 randomly as suggested in [33]. Two-point random crossover has been employed in this work. Also, the two points mutually exchanging mutation operator has been used for the present work. These types of operators are most generally used for the layout planning problems [34]. The termination of GA is most important when it is integrated with another search method. Various researchers are using either a fixed number of iteration, fixed processing time of CPU or, if the solution not improving after a fixed number of generation [20]. Termination of algorithm with these conditions may not provide the optimal results for hybrid algorithms. Therefore, in the present work the algorithm terminates after reaching the generations equal to the square of the total number of facilities available in a plant layout to be design or redesign.

C. Variable Neighborhood Search

Before The main idea of VNS is to enhance the existing solution through the systematically and regularly shifting of neighborhood structures during the progression of local search. Generally, every neighborhood structures have different current local optimal solutions [35]. The basic steps of VNS are enlightened in [35], which are as follows; (1) generate initial solution and state its neighborhood structures, (2) apply the shaking operator, (3) apply the local search to find the best neighborhood in the current solution space (neighborhood), (4) make the decision to stop or search again by comparing the current neighborhood structure with earlier neighbor.

In the present work, the VNS has been modified to suit the GA ladders. It possesses the following steps;

(1). Incumbent solution form GA: Initial solution is taken from GA after applying genetic operators. A set of neighborhood structure is created from the best solution of the last generated population of GA. The chromosome structure is decoded for VNS application.

(2). Shaking: The generated initial solution undergoes shaking procedure in which each gene is exchanges with each other to randomly for a predefined number of times. Moreover, a set of neighborhoods are calculated for their fitness values.

(3). Local Search: To avoid the cycling, a neighborhood is selected randomly to explore for its feasibility to survive in the structure. In this step, all machines/facilities are tried with the current neighborhood structure so that a most feasible and suitable fellow can be found to stay with it by trying all possible combination (say equal to the number of facilities in the layout).

(4). Termination of VNS: The local search procedure repeats in iterative manner till the finding of best neighbor. In the present work, the local search with all the facilities available with the selected neighborhood structure till the outcome of better than the earlier fellow. Otherwise, the previous structure is considered to send to the support directory of methodology as shown in figure 1.

IV. Results and Discussion

The developed model of GA and VNS has been tested and compared with the 20 orders problem with processing sequence and quantity for job shop production system given by [20]. The constraint of a fixed facility has been considered for a specific work station (i.e. "U") at the beginning stage of facility planning as shown in table 2. The assumptions are presented in section II of this article. Initial layout of 25 facilities is given in [20]. Table I presents the optimized layout of present case study. The proposed methodology is coded in MATLAB® programming language and executed on Intel® Core™ i5-4210U CPU @ 1.70 GHz on x64-based Window 10 platform.

TABLE I. Optimised Layout

O	*T*	*J*	*Q*	*N*
A	*V*	**"U"**	*K*	*P*
B	*L*	*V*	*D*	*R*
H	*X*	*M*	*I*	*W*
F	*G*	*Y*	*E*	*S*

Note: "U" is the fixed positioned facility.

Table II illustrating the results obtained as well as the comparison of results with the existing study for the taken case study of facilities planning solution as per the adopted methodology presented in the section III. The proposed approach of GA with integrated VNS is showing that it is producing promising results while comparing with [20].

Initially, the cost to setup the layout is $784,990. Whereas, the proposed GA provide a layout of costs $879,287 during the beginning of search while generating the random population, which is much lower than the existing study. After execution of proposed methodology, the costing reduces to $638,402 which is much lower as compare to the costing of GA proposed by [20]. Table II demonstrating the optimized concluding design after optimization. Hence, the difference of cost is $146,588 showing that the proposed planning of facilities is the more suitable and cost effective as compare to the initial layout. Also, the material handling cost is continually decreasing in every evolution of proposed methodology.

TABLE II. Comparison of Results for Taken Case Study with Yang et al. 2011

Cost & %age Improvements	***Yang et al. 2011 (GA)***	***GA+VNS***
Current Layout	$784,990	$784,990
GA Initial Solution	$840,195	$879,287
GA Solution	$684,285	$638,402 (GA+VNS Solution)
Cost Improvement	12.83%	18.68%
Calculation Improvement	18.56%	27.40%
Cost Difference	$100,705	$146,588

Literature review clearly revealed that the generating optimal solution is depends on the selection of the controlling parameters of GA. Table III show the values of the selected operators and comparison with the [20]. However, in the reference research article the parameters are selected on the factorial design, but the present parameters are producing the promising results. Time complexity is an important analysis which is used to measure the performance of an algorithm as well as it is advantages for optimizing the real-time efficiency of the algorithm. The time complexity is measure as per O(n3) proposed in [36]. In the present work, an average runtime for the proposed algorithm is 168 seconds for the fixed number of generation considered as the termination criterion, which is in line with genetic clustering method presented in [36].

TABLE III. Comparison of GA Parameters for Taken Case Study with Yang et al. 2011

GA Parameters	***Yang et al., 2011***	***Proposed GA Parameters***
Total Number of Generations	500	625 (i.e. Square of Number of Facilities)
Size of Population	30	30
Crossover Probability	60.00%	80%
Mutation Probability	5.00%	20%
Average Runtime (sec.)	Not Given	168

The facility planning as well as the handling of material is play the cardinal role to enhance the profit of the manufacturing company. It goes without saying that poor design of facility layout leads to raise in the cost of handling of material, the completion time of product also increases and, the work in process grows significantly, consequently it is challenging to control the quality and cost of product. Generally, at the opening of a plant, the facilities are arranged according to the sequence of operations and keeping material handling cost at lowest level to minimize the operating cost. Eventually, due to technological advancements, changes in the demand and product variety, the performance of plant declined. Thus, the re-planning of facilities in the plant is a dynamic and regular activity for a company to stay competent. Present work is an attempt in this direction, to accomplish the re-planning of work stations for a job shop production system using GA and VNS optimization algorithm.

V. CONCLUSION

In a job shop production system, each job order has separate process plans to be followed, which disturb the movements of material in the plant. Therefore, the present study deals with the re-planning of facilities considering the job orders. A hybrid approach of GA and VNS has been proposed to solve the facility planning which helps organizations to make decision on the bases of cost-benefit breakdown. The proposed approach is using the objective function and the case study given in [20]. Results reveals that proposed methodology is out performed while comparing with exiting regular GA-based approach. The future plan includes the testing of proposed algorithm for capability to handle a real problem of machinery industry.

REFERENCES

[1] S. Heragu, "Facilities Design," 1997, PWS Publishing Company, Boston.

[2] E.F. Meyers and P.M. Stephens, "Manufacturing facilities design and material handling,", 2nd Ed., 2000, Prentice Hall, New Jersey

[3] A. Drira, H. Pierreval and S. Hajri-Gabouj, "Facility layout problems: A survey," Annual Reviews in Control, Vol. 31(2), pp. 255-267, Dec. 2007. DOI:10.1016/j.arcontrol.2007.04.001

[4] S. A. A. Naqvi, M. Fahad, M. Atir, M. Zubair and M. M. Shehzad, "Productivity improvement of a manufacturing facility using systematic layout planning," Cog. Eng., Vol. 3, 2016, DOI:10.1080/23311916.2016.1207296

[5] M. F. Anjosa and M.V.C. Vieirab, "Mathematical optimization approaches for facility layout problems: The state-of-the-art and future research directions," E. J. of Oper. Res., Vol. 261, Issue 1, Aug. 2017, pp. 1-16.

[6] A.B. Badiru, A. Arif, "Flexpert: facility layout expert system using fuzzy linguistic relationship codes," IIE Trans., Vol. 28: 1996, pp. 295–308.

[7] T. Yang, and C. Kuo, "A hierarchical AHP/DEA methodology for the facilities layout design problem,". Eur. J. Oper. Res., Vol. 147, 2003, pp. 128–136.

[8] A. Hadi-Vencheha and A. Mohamadghasemi, "An integrated AHP–NLP methodology for facility layout design," Journal of Manufacturing Systems, Vol. 32, 2013, pp. 40– 45.

[9] S. Altuntas, H. Selim and T. Dereli, A fuzzy DEMATEL-based solution approach for facility layout problem: a case study," Int J Adv Manuf Technol, Vol. 73, 2014, pp. 749–771, DOI 10.1007/s00170-014-5826-3

[10] S. S. Hosseini and M. Seifbarghy, "A novel meta-heuristic algorithm for multi-objective dynamic facility layout problem," RAIRO-Oper. Res. Vol. 50, 2016, pp. 869-890

[11] B. Turanoğlu and G. Akkaya, "The Dynamic Facility Layout Problems with Closeness Rate: A Fuzzy Decision Support System Approach, Selcuk Univ. J. Eng. Sci. Tech., v.5, n.3, 2017, DOI: 10.15317/Scitech.2017.90

[12] E.S. Eneyo and G.P. Pannirselvam, "Process simulation for facility layout,". IIE Solut., Vol. 31, 1999, pp. 37–40

[13] D. Zetu, P. Banerjee, and P. Schneider, "Data input model for virtual reality-aided facility layout,". IIE Trans., Vol. 30, 1998, pp. 597–620

[14] V. G. Duffy, F. F. Wu and P.P.W. Ng, "Development of an internet virtual layout system for improving workplace safety,". Comput Ind., Vol. 50, 2003, pp. 207–230

[15] S. Y. Phoon, H. J. Yap, Z. Taha and Y. S. Pai, "Interactive solution approach for loop layout problem using virtual reality Technology," Int. J. of Adv. Manuf. Techn., March 2017, Vol. 89, Issue 5, pp. 2375–2385.

[16] Y. K. Chen, S. W. Lin and S.Y. Chou, "An efficient two-stage approach for generating block layouts,". Comput. Oper. Res., Vol. 29, 2002, pp. 489–504.

[17] R. Tavakkoli-Moghaddain and E. Shayan, "Facilities layout design by genetic algorithms,". Comput. Ind. Eng., Vol. 35, 1998, pp. 527–530.

[18] J. S. Kochhar, B. Foster and S. S. Heragu, (1998) "Hope: a genetic algorithm for the unequal area facility layout problem,". Comput Oper Res 25:583–594

[19] G. Moslemipour, T.S. Lee, Y.T. Loong, "Performance Analysis of Intelligent Robust Facility Layout Design," Chinese J. of Mech. Engineering, Vol. 30, 2017, pp.407-418, DOI: 10.1007/s10033-017-0073-9

[20] C. L. Yang, S. P. Chuang and T. S. S. Hsu, (2011). "A genetic algorithm for dynamic facility planning in job shop manufacturing,". Int J Adv Manuf Technol, Vol. 52, 2011, pp. 303–309.

[21] R. K. Phanden, A. Jain, A., and R. Verma, "A Genetic Algorithm-based approach for flexible job shop scheduling,". Appl. Mech. and Mat., Vol. 110, 2012, pp. 3930-3937.

[22] R. K. Phanden, A. Jain, A., and R. Verma, "A genetic algorithm-based approach for job shop scheduling," J. of Manuf. Techno. Manag., Vol. 23. 2012, pp. 937-946.

[23] S. P. Singh and R.R.K. Sharma, "View of different approaches to the facility layout problems,". Int J Adv Manuf Technol., Vol. 30, 2006, pp. 425–433.

[24] F.T.S. Chan, "Evaluations of operational control rules in scheduling a flexible manufacturing system,". Robot Comput-Integr Manuf. Vol.15, 1999, pp.121–132.

[25] G. H. Lee, "Design of components and layout of machines for material handling,". Int J Adv Manuf Technol, Vol. 52, 2011, pp. 303–309.

[26] R. K. Phanden and A. Jain, "Assessing the impact of changing available multiple process plans of a job type on mean tardiness in job shop scheduling," Inter. J. of Adv. Manuf. Techno., Vol. 81, 2015.

[27] R. K. Phanden and A. Jain, "Assessment of makespan performance for flexible process plans in job shop scheduling," IFAC-PapersOnLine, Vol. 48, 2015, pp. 1948-1953.

[28] R. K. Phanden, "Multi Agents approach for Job Shop Scheduling Problem using Genetic Algorithm and Variable Neighborhood Search method,". Proc. of the 20th WMSCI, July 2016, pp. 275-278..

[29] M. R. Garey, D. S. Johnson and R. Sethi, "The complexity of the flowshop and jobshop scheduling,". Math Oper Res, Vol. 1, 1976, pp. 117–129.

[30] K. L. Mak, Y. S. Wong, F.T.S. Chan, "A genetic algorithm for facility layout problems,". Comput Integ Manuf Syst., Vol. 11, 1998, pp.113–127.

[31] M. Sharma, R. K. Phanden, and P. Sharma, "Comparative evaluation of facility layout alternatives based on material handling cost,". Inter. J. for Techno. Res. in Eng., Vol. 7, 2015, pp.748-751.

[32] T. S. Felix, S. H. Chan, L. Y. Chung, F. T. S. Chan, G. Finke and M. K. Tiwari, "Solving distributed FMS scheduling problems subject to maintenance: genetic algorithms approach,". Robot Comput-Integr Manuf., Vol. 22, 2006, pp. 493–504.

[33] S. Vaghefinezhad and K. Y. Wong, "A Genetic Algorithm Approach for Solving a Flexible Job Shop Scheduling Problem,". Inter. Journal of Computer Science Issues, 2012.

[34] Y. H. Lee, M. H. Lee, "A shape-based block layout approach to facility layout problems using hybrid genetic algorithm,". Comput Ind Eng., Vol. 42, 2002, pp. 237–248.

[35] L. Gao, X. Li, X. Wen, C. Lu and F. Wen, "A hybrid algorithm based on a new neighborhood structure evaluation method for job shop scheduling problem,". Comp. & Ind. Eng., Vol. 88, 2015, pp. 417–429.

[36] Z. M. Nopiah, M. I. Khairi, A. Abdullah, M.N. Baharin, and A. Airfin. "Time complexity analysis of the genetic algorithm clustering method", In Proc. 9th WSEAS Inter. Conf. on signal processing, robotics and automation. pp-171-176.