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Maximum Maintainability of Complex Systems via Modulation Based on DSM and Module Layout Case Study: Laser Range Finder

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KEYWORDS

Maintainability,
Modulation,
Layout,
DSM: Design Structure Matrix,
Multi Objective Problem,
MOPSO: Multi Objective Particle Swarm Optimization,
Laser Range Finder(LRF)

ABSTRACT

Layout design of complex systems in detailed engineering phase is a costly and difficult job which usually entails dealing with multiple conflicting objectives. The present paper aims to investigate the effect of four objective functions have been considered simultaneously in this research. The present paper aims to investigate the effects of modularity and the layout of subsystems and parts of a complex system on its maintainability. For this purpose, four objective functions have been considered simultaneously: I) maximizing the level of accordance between system design and optimum modularity design, II) maximizing the level of accessibility and the maintenance space required, III) maximizing the providing of distance requirement and IV) minimizing the layout space. The first objective function has been put forward for the first time in the present paper and in it, the optimum system modularity design was determined using the Design Structure Matrix (DSM) technique. The second objective function is combined with the concept of Level of Repair Analysis (LoRA), thus, a new objective function is developed. Simultaneous optimization of the above-mentioned objective functions has not been considered in previous studies. The multi objective problem which has been put forward was applied on a laser range finder containing 17 subsystems. As the resulting model is NP-Hard and entails quantifications of some qualitative data, a near optimal solution method is suitable to tackle it. Hence, in order to obtain the non-dominated solutions, a multi-objective particle swarm optimization (MOPSO) algorithm is used.

1. Introduction[1]

Maintainability is a factor of engineering design of systems which leads to, in the implementation and operation phase of the system, the measures and activities concerning maintenance and repairs taking place consuming less time and lower life cycle costs [1].

For cases where the stability and endurance of the system is intended by the designers,

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increasing the maintainability is of more importance than production costs and the system is to be designed in such a way as to be of higher maintainability and easier maintenance [2].

In order to increase system maintainability, engineering design has very important role in modular and layout design.

Usually, there are two different groups that working on layout design and increasing maintainability design.

Because there is little interaction between the two design teams, design problems often appear late in the design cycle. Conflicting goals in designing the layout and design to enhance maintainability as well, it makes it difficult.

In this article we have tried to use the expression of contradictory objectives simultaneously in four objective function, layout design objectives and design provide to enhance maintainability.

In order to elevate system maintainability, engineering design, including modular and layout design, which play a very vital role. The simultaneous design of these cases can lead to significant reduction in time and cost consumption through the design phase. In table 1, the design factors for maintainability are depicted.

Tab1. Maintainability factors in Design Phase

No.	Design Phase	Design for maintainability factors	source
1	Conceptual Design	Maintainability allocation	[3]
2		changeability	[4,3,1]
3		standardization	[1,4,5]
4		Modular design	[1,3,4,5]
5		Accessibility	[5,6]
6		Safety Requirement	[4,5,6]
7		Simplicity	[5,6]
8		Ergonomics	[5,6]
9		Identify Failure locations	[1]
10	Detail Design	Detection and test Requirement	[6]
11		Reform and the replacement of costly components	[7]
12		DSM Technique	[8,9]
13		Test and evaluation plan	[3]
14		Reduce storage and depot considerations	[3]
15		Level of repair analysis	[7]
16		Ensuring the implementation of the maintainability objectives	[10]
17		Physical design, configuration and layout scheme	[1,6,11]

A great number of studies have been conducted on assessment and improvement of maintainability in complex systems[1,3,4,12]. Also, numerous studies have focused on modular design and different type of system layout [11,13,14]. However, the issue concerning how modular design and system layout can affect system maintainability has been often less focused on Design the optimal system partitioning study by DSM techniques and web-based application was determined.

After optimization of maintainability, space requirements and minimal installation space modules using multi-objective particle swarm optimization and MATLAB 10 was given.

Objective function value for all the responses obtained from the Pareto front by system designers was assessed and the most appropriate response to the selection of the optimal layout and design were determined.

The performance of the final solution chosen by professionals with experience in electro optic industry and similar systems with efficient layout systems was approved.

In table 2, the previous studies regarding maintainability, modular and layout design and their shortcomings have been outlined.

Tab.2. Related studies regarding maintainability, modular and layout design

No	year	Auther	Title	shortcomings
1	2004	Grignon P.M And Fadel G.M	A GA based configuration design optimization method[15]	Maintainability is intended with two factor : simplicity of removable and components stated.
2	2009	Dhamodharan R Et al	A genetic algorithm and queuing theory based methodology for facilities layout problem[16]	Presented model is designed for work in process facilities.
3	2010	Zhao F. Et al	A human–computer cooperative particle swarm optimization based immune algorithm for layout design[25]	Modular design factor that is the significant increase in system maintainability, is not considered.
4	2011	Dong H. Et al	Bi-level approach to vehicle component layout with shape morphing[17]	Accessibility is intended the only factor of maintainability in the arrangement of components as the objective function.
5	2014	Nam K. Et al	Optimal module layout for a generic offshore LNG liquefaction process of LNG-FPSO[18]	The objective function in this paper Noted to Minimizing the total cost of layout design.
6	2014	Lou X Et al	Layout problem of multi-component systems arising for improving maintainability[5]	Modular design factor that is the significant increase in system maintainability, is not considered. Providing component accessibility and maintenance space regardless of the level of repair.
7	2015	Moatari A Et al	Integrating occupational health and safety in facility layout planning[19]	mathematical modeling to the issue is not provided.
8	2015	Kobayashia M. et al	Optimal design of component layout and fastening method for the facilitation of reuse and recycle[20]	The only factor taken into consideration in optimizing the layout problem with maintainability is disassemblability .

9	2015	Lou X Et al	Maintainability-based Facility Layout Optimum Design of Ship Cabin[37]	Modular design factor that is the significant increase in system maintainability, is not considered.
10	2015	Zheng G.b Et al	Conceptual layout design of CFETR Hot Cell Facility[11]	Modular design factor that is the significant increase in system maintainability, is not considered.

2. Problem Modeling

Modularity and layout design of a system in an optimum way, affecting the design factors for maintainability, results in boosting the maintainability of the system. Optimum system modularity, by affecting accessibility increase, simplification, ergonomics, identification of failure places, and by using DSM technique, increases system maintainability.

The modular and layout design impact on maintainability factors is specified in Fig. 1.

Figure1.Impact of layout and modular design on maintainability factors

2-1. Modularity

One of the most important design factors for maintainability is modularity. System modularity has been considered by several sources to be vital to system maintainability due to the fact that, through system simplification, it paves the way for having a better understanding of the system in order to take maintenance measures and improve system ergonomics. [5, 26-28]

In the following section, the authors are going to investigate how system modularity via the DSM technique can reduce time consumption in the diagnostics time factor in the equation above.

2-1-1. DSM: Design Structure Matrix

Designates a specific kind of layout and architecture for system partitioning in such a way that modules possess maximum internal interrelations and minimum external interrelations [9]. This technique determines optimum system modularity via the algorithm presented by [34].

Let us assuming that the system we intend to modulate possesses n subsystems.

$$\text{Subsystems} = \{S_1, S_2, \dots, S_n\} \qquad (1)$$

The n×n design structure matrix is formed as seen in figure 2. In the resulting design structure matrix, engineers must put a mark in the respective row and column for any relation existing between parts or subsystems in such a way that if the subsystem of S_i is the prerequisite of S_j, as seen in figure 3, a * is marked in the column S_i and row S_j [35].

Also, it is possible, in complicated cases with respect to the importance, the effect, the number of interactions and the power of the relations existing between the subsystems, to use several digits and colors for display.

	S_1	S_2	…	S_i	…	S_j	…	S_{n-1}	S_n
S_1	▨								
S_2		▨							
…									
S_i				▨					
…									
S_j				*		▨			
						▨			
…									
S_{n-1}								▨	
S_n									▨

Fig.2. Formation design structure matrix

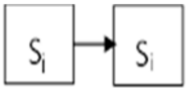


Fig.3. Sj Prerequisite Si

The relations between parts can be of the mechanical type or the type involving transactions of data flows, materials, or information [37, 8].

Communication in the design structure matrix can be modeled as follows:

$$r_{ji} = \begin{cases} 1 \\ 0 \end{cases} \qquad (2)$$

In this case, we can write:

$$r = \sum_{i=1}^{n} \sum_{j=1}^{n} r_{ji} \qquad (3)$$

In equation 3, r, show sum of all connections between all components in system in the design structure matrix.

Modularity have significant impact on the system maintainability. This can be explained by the relationship presented by [8]:

$$T_{total} = T_{diagnosis} + T_{repair} + T_{test} \qquad (4)$$

The maintainability index in equation 4 is equal to the sum of the times for diagnostics, repair time and finally the time required for subsystem or component testing and integrating and restarting the system.

The diagnostics time in a system which categorizes the layouts of subsystems and parts in certain particles using DSM technique is lower than that of a system designed without this technique. The probability of diagnosing in these two cases can be compared with a logic similar to the one used in a fault tree analysis.

If the system is designed without modularity, failure can occur from each of the n parts or subsystems or from the r relations between them. Therefore, failure can occur in, n+r cases. If failure occurs in several subsystems or relations simultaneously, in such a system, determining the failure place becomes more difficult as the system becomes more complicated.

On the other hand, a system modulated via the DSM technique possesses m modules where $m \leq n$.

According to the argument above, equality occurs when the partitioning algorithm, due to the existing relations, categorizes all parts and subsystems as one module.

Assuming that $\{r_1, r_2, \dots, r_m\}$ are the relations existing in modules 1 to m and the number of subsystems or parts of the i^{th} module is equal to m_i

, then when such a system goes out of access, failure may have resulted from each of the m modules or from the relations between the modules or from the relations between the modules . So the number of connections between modules is obtained equation 5.

$$v = r - \sum_{i=1}^{m} r_i \quad (5)$$

In system downtime, in the first phase, the failure may be of any one of m modules or v communication between modules .So in the first phase of diagnosis, there is, m + v modes for event failure. In the second phase of detection error location, in the worst case, if the failure occurred on the kth module, with the largest sum of components and communication, total failure modes equal:

$$f_{total} = m + v + m_k + r_k \quad (6)$$

To prove:

$$T_{diagnosis,Modular\ System} \leq T_{diagnosis,NO\ Modular\ System} \quad (7)$$

Just to prove:

$$m + v + m_k + r_k < n + r \quad (8)$$

According to Equation 5, we have:

$$r = v + \sum_{i=1}^{m} r_i \quad (9)$$

By substituting in equation 8, we have:

$$m + v + m_k + r_k < n + v + \sum_{i=1}^{m} r_i$$

$$m + m_k + r_k < n + \sum_{i=1}^{m} r_i \quad (10)$$

On the other hand, we have:

$$n \geq m + m_k \ , \ \sum_{i=1}^{m} r_i > r_k \quad (11)$$

So proved the unequal 8 and then unequal 7.

Therefore, the more system modularity is based on an efficient scientific method, the more useful a role it will play in providing a higher level of maintainability in the system. The objective function of system maintainability is directly related to the level the system follows the partitioning designated by the DSM technique. In order to perform the level of accordance modeling we can write:

$$P_i = \begin{cases} 0 & \\ 1 & \text{, otherwise} \end{cases} \quad (12)$$

In the same way as we have for communication between components:

$$P_j = \begin{cases} 0 & \\ 1 & \text{, otherwise} \end{cases} \quad (13)$$

Therefore, the modularity index, in relation with optimum system modularity via DSM technique, is as follows:

$$I_p = \sum_{i=1}^{n} \alpha_i \times P_i + \sum_{j=1}^{r} \beta_j \times P_j \quad (14)$$

Where α_i is the level of importance for subsystem accordance and β_j is the level of importance for the relations existing between the subsystems with the optimum modularity design presented by the DSM technique.

In order to provide a higher level of maintainability, we seek to minimize the above equation.

2.2. Increasing the level of accessibility and the required maintenance space with respect to level of repair analysis

Level of repair analysis is conducted in a system with the purpose of reducing the economic costs of maintenance and repairs. Level of repair analysis investigates the following:

Determining and identifying the system components which are repairable and the ones which are not. If repair is possible for a system component, the place for conducting repairs on that component, in case failure occurs, is determined.

three general places for conducting repairs have been mentioned [7, 33]:

- Components which, for repair purposes, do not need to be separated from the system and, in case of need for repairs, are repaired online.
- Components which, is case of facing failure, must be disassembled from the system and repairs actions are to take place in the same site where the system is located
- Cases where the faulty component must be transported to a site other than that of the system

Therefore, in the layout issue, level of repair analysis is to take place first and then accessibility and the required maintenance space are to be maximized in accordance because, if the faulty component is of the 2nd or 3rd cases of the level of repair, only proper accessibility for the component is to be provided due to the fact that repairs will take place off the system.

Therefore, in his section, the equation proposed by [5, 37,38] is combined with the concept of level of repair analysis and developed. For this purpose, the decision variable d_i is defined as follows:

$$d_i = \begin{cases} 0 & \\ 1 & \text{, otherwise} \end{cases} \qquad (15)$$

In this case, the system maintainability index, in relation with accessibility and the required net space, with respect to the level of repair analysis for the system, will be as follows:

$$I_m = \sum_{i=1}^{n} \mu_i \left(A_i + (1 - d_i)\lambda\, M_i\right) \qquad (16)$$

Where in:

μ_i : Maintenance frequency for the ith component

A_i : Accessibility for the ith component

λ : Importance of accessibility against to the operating maintenance space factor

M_i : Maintenance space for the ith component

In order to provide a higher level of maintainability, we seek to minimize the equation 16.

2.3. Considering distance requirements

The maximum level of providing distance requirements existing between the components, including the near and far requirements, is of the other factors to be considered when designing the system layout. In [5,37], the objective function of minimizing the dissatisfaction of distance requirements has been explained as follows:

$$I_D = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \cdot d_{s,ij}$$

In order to provide a higher level of maintainability, we seek to minimize equation 17.

Where w_{ij} is the importance weight of distance requirement between component i and component j, and $d_{s,ij}$ denotes the degree of dissatisfaction with the distance between component i and component j. Let d_{ij} be the distance between component i and component j. If the separation requirement between component i and component j is that component i should stay away from component j with distance greater than $D_{r,ij}$, $d_{s,ij}$ can be obtained as :

$$d_{s,ij} = \begin{cases} \dfrac{D_{r,ij}}{d_{ij}} & d_j \le D_{r,ij} \\ 1 & d_{ij} \ge D_{r,ij} \end{cases}$$

If the closeness requirement between component i and component j is that component i should close to component j with distance less than $d_{r,ij}$, $d_{s,ij}$ can be obtained as :

$$d_{s,ij} = \begin{cases} \dfrac{d_{ij}}{d_{r,ij}} & d_{ij} \ge d_{r,ij} \\ 1 & d_{ij} \ge d_{r,ij} \end{cases}$$

2.4. Layout space

Layout space is the space taken by system, which is an important design criterion of complex system. The minimization of layout space should be taken into account to enhance the efficiency of space. [5]

Maximum space that We have , is a Cube with dimensions 30 x 30 x 45 centimeter .

3. Constraints

The constraints of the layout design for maintainability can be divided into two classes: geometric constraints and functional constraints.

The geometric constraints are the essential constraints in the layout design, containing the interference constraints and the boundary constraints.

These constraints require no overlap between any two components, and all components should be contained within the layout space.

The functional constraints, such as mechanical functional constraints and layout knowledge constrains, also should be taken into account in the layout design. These constraints limit the orientation, layout region or relative position of some components, usually translated by geometric constraints (angle, distance, coincidence, etc). In general, the functional constraints of different components are not the same. [5,27,39]

4. Case study

The multi objective problem which has been put forward was applied on a laser range finder containing 17 subsystems and the modularity and optimum layout was determined using a Multi Objective Particle Swarm Optimization (MOPSO) algorithm. With respect to the kind of system under analysis, the weight of the modularity objective function, in relation with system maintainability, was calculated far above the other objective functions. For this reason, the optimum modular architecture of the system, was first determined via the design structure matrix and the 17 existing subsystems in the system under analysis were categorized into 6 final modules. For the purpose of partitioning the system via the DSM technique, the web application presented in [34] was used. The relations existing between the 17 subsystems of the laser range finder were identified as presented in figure 4 and 5 by the system designers.

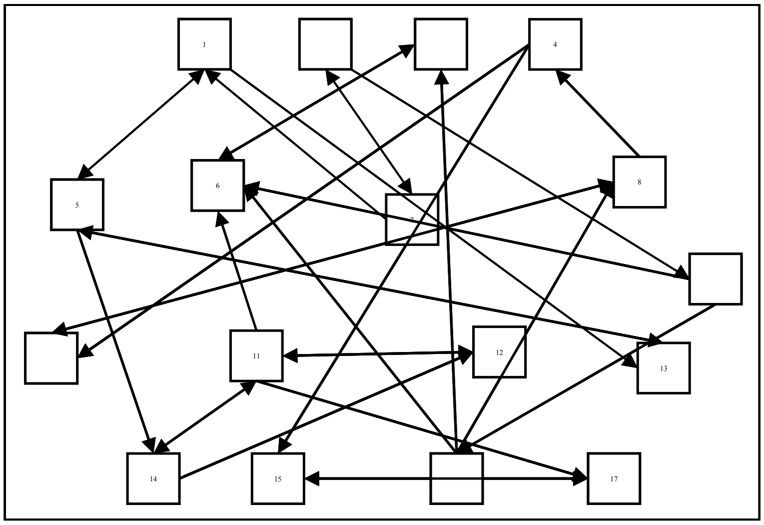
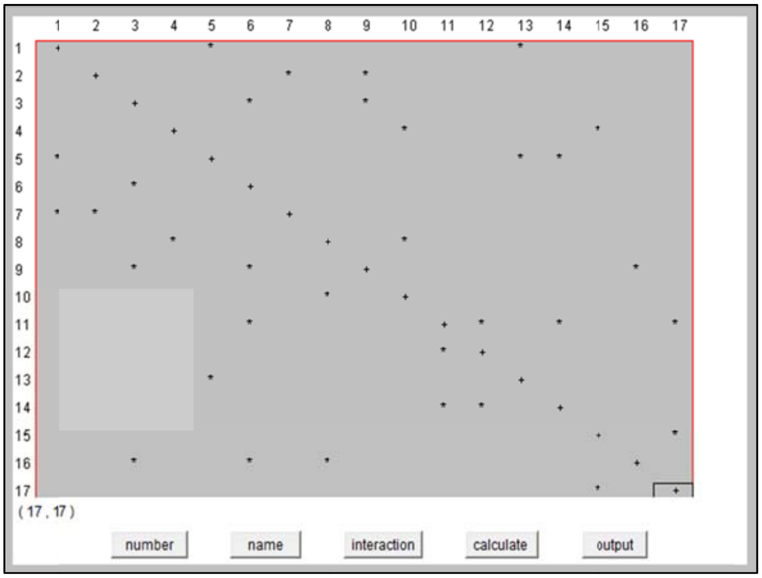


Fig.4.Connections between subsystems in Laser Range Finder

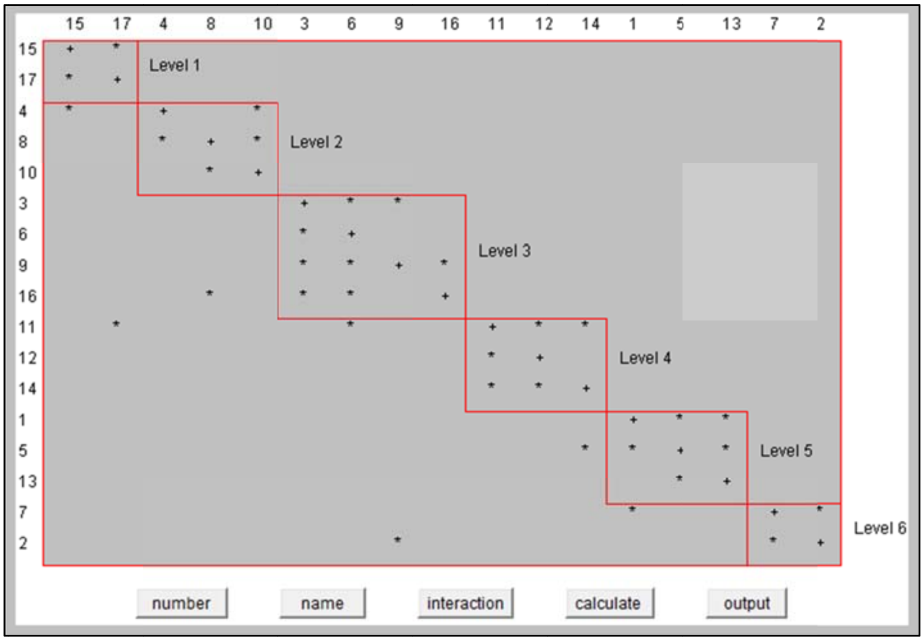


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	+				*								*				
2		+					*		*								
3			+			*			*								
4				+						*					*		
5	*				+								*	*			
6			*			+											
7	*	*					+										
8				*				+		*							
9			*			*			+							*	
10								*		+							
11						*					+	*		*			*
12											*	+					
13					*								+				
14											*	*		+			
15															+		*
16			*			*		*								+	
17															*		+

(17 , 17)

Fig.5.Connections between subsystems in the design structure matrix

Rearrangement of the rows and columns of the initial design structure matrix is depicted in figure 6 and 7.



	15	17	4	8	10	3	6	9	16	11	12	14	1	5	13	7	2
15	+	*															
17	*	+															
4	*		+		*												
8			*	+	*												
10				*	+												
3						+	*	*									
6						*	+										
9						*	*	+	*								
16				*		*	*		+								
11		*					*			+	*	*					
12										*	+						
14										*	*	+					
1													+	*	*		
5												*	*	+	*		
13														*	+		
7													*			+	*
2								*								*	+

Fig.6.Determination of the optimal system modular design by design structure matrix

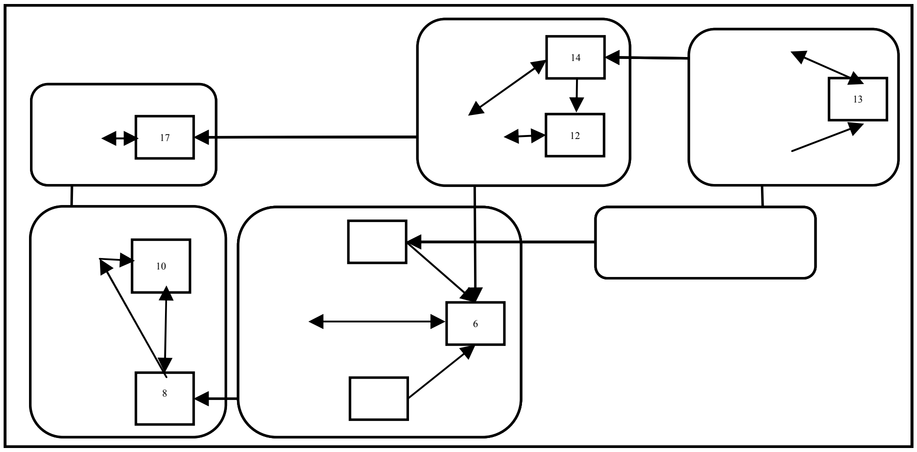


Fig.7.Determination of the optimal system modular design of Laser Range Finder

Layout of the 6 final modules was optimized, with respect to the three remaining objective functions, using the multi-objective particle swarm optimization method.

In this stage, the layout of each of the subsystems in the specified module is firsthand carried out for each module separately with respect to the weight of the 3 objective functions of minimizing the module space, maximizing the observation of distance requirement between the subsystems, and maximizing accessibility and the required maintenance space for conducting repair activities considering the level of repair analysis for the components. These stages can repeated for the 6 specified modules as the highest level of subsystems whose combination makes up the whole system.

If the system was very complex, this process can repeated for several times in different level of system.

The problem of system modular design and system layout for maintainability is known as an NP-hard problem whose optimum and deterministic solution at a logical time is not possible. The particle swarm optimization (PSO) algorithm, which was initially presented by Eberhart and Kenedy in 1995 [40], has been made use of a lot in order to solve problems of layout design. MOPSO (multi-objective PSO), which is the developed form of PSO, is a meta-heuristic method which has been considered to be effective for solving large-scale problems of multi-objective optimization [28].

The problem was solved using the MATLAB 10software, with parameters including population size of 30 particles and a non-dominated answer bulk of 5000, on a computer with 4 GHs of CPU and 2 GBs of RAM in the time of 21 seconds.

PSO method defined velocity vector in equation 20, update particle Location in the Search space at any iteration of algorithm. The equations for updating speed and particle location in the search space have been determined in relations 20 and 21 [41,42].

$V_i\ (t+1) = \hat{w} * V_i\ (t) + c_1\ r_1\ (Pbest - X_i\ (t)) + c_2\ r_2\ (gbest - X_i\ (t))$

Where c_1 and c_2 are positive constants called learning factors. r_1 and r_2 are two different random numbers in the range [0,1], and $w\hat{}$ denotes the inertia weight. If a particle violates the velocity limits, set its velocity equal to the proper limit.

$X_i\ (t+1)=X_i\ (t)+V_i\ (t+1)$

Determining the problem parameters has been done as the relations 22 to 26 :

$\varphi_1=2.05$

$\varphi_2=2.05$

$\varphi=\varphi_1+\varphi_2$

$W\hat{} = 2 /((\varphi -2)+ \sqrt{} (\varphi^2 - 4* \varphi))$

$c_1=c_2=2$

Required information about laser range finder system listed in Table 3 to 5.

Tab.3. Dimensions and maintenance frequency of Modules

modules	X(cm)	Y(cm)	Z(cm)	(μ_i)
1	25	12	17	45%
2	15	15	17	27%
3	16	14	15	9%
4	15	12	14	9%
5	27	18	13	6%
6	14	15	12	3%

Tab.4. Maximum and minimum maintenance operating space Requirements

modules	D_{max}(cm)	D_{min}(cm)
1	15	7
2	15	7
3	4.5	3
4	11.5	7
5	4.5	3
6	3	1.5
modules	D_{max}(cm)	D_{min}(cm)

Tab.5. Distance Requirements

Modules	Closeness	Separation
1,3	5	
1,3		2
2,4	5	
2,4		2
1,5		15
2,5		15

Mathematical programming and the exact solution of this problem because of the definition of objectives in this issue is a matter of time.

It also determines the arrangement of modules in the three-dimensional space it was difficult.

At first, particle swarm optimization algorithms, such as genetic algorithms produce a set of possible answers and then at each iteration try to improve them.

Accordingly, without the need for mathematical programming, and not necessarily the optimal solution provides optimal.

Non-dominated distribution solution or the Pareto front is shown in Figure 8.

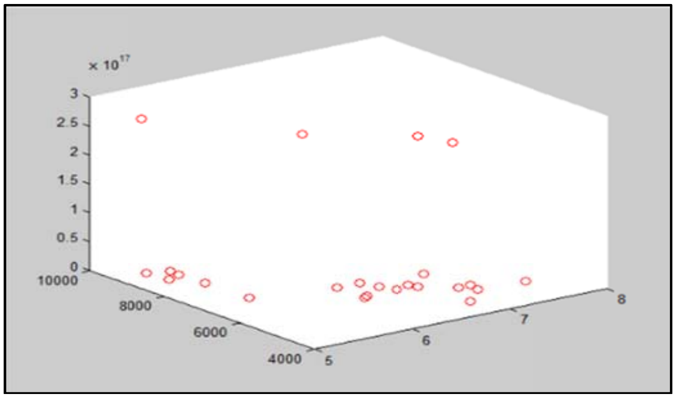


Fig.8.Distribution of non-dominated solution

As consider, fifteen questions can be seen in the Pareto front is obtained. Which includes a set of answers is that the three main functions listed in different levels have been optimized.

Table 6 the objective function value of maintainability, distance and space requirements in order to arrange columns I_L وI_D, I_M determined by the type of layout shows the Pareto front.

After Pareto results obtained in the industries studied, questions of violation of the requirement, system designers were eliminated.

Tab.6. Objective Function Values.

No.	I_L	I_D	I_M
1	6.1200	8260	$4.72*e^{17}$
2	7.0521	$5.32*e^{3}$	23.33
3	5.52	$7.0913*e^{3}$	7
4	6.83	5082	$4.7288*e^{17}$
5	6.83	$6.3775*e^{3}$	10.5
6	6.5003	6696	8.7500
7	5.94	$9.0738*e^{3}$	105
8	6.2825	$6.7375*e^{3}$	8.75
9	6.32	6048	52500
10	6.88	$4.7355*e^{3}$	105
11	5.4975	$8.2305*e^{3}$	7.5
12	6.34	$6.038*e^{3}$	105
13	5.4938	8925	7
14	5.52	$7.0913*e^{3}$	7
15	6.0238	$6.9694*e^{3}$	$4.7288*e^{17}$

While solutions with optimal value in each of the objective functions were held. Thus, the questions of 13, 9, 6, 4, 3 and 14 were considered in order to select the final solution. Layout design in any of the solutions mentioned in Figure 9 is specified.

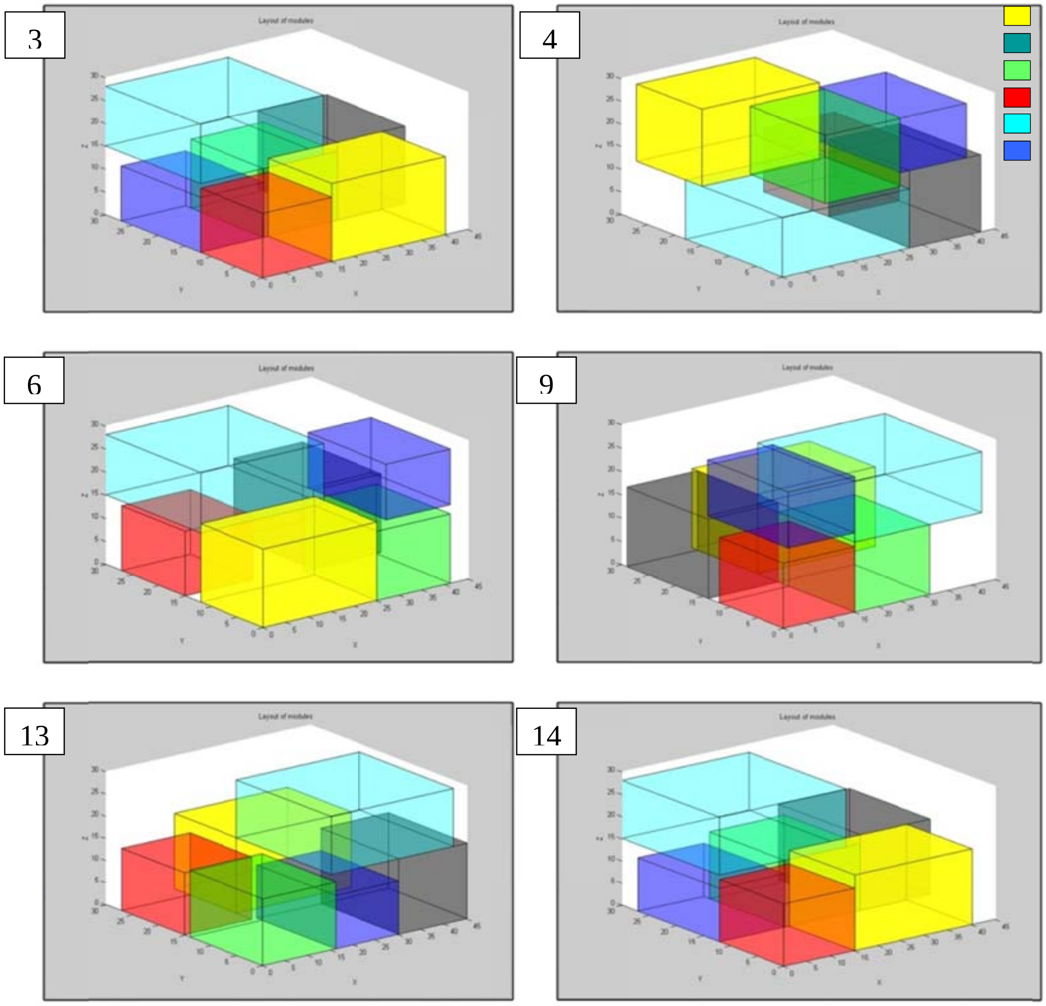
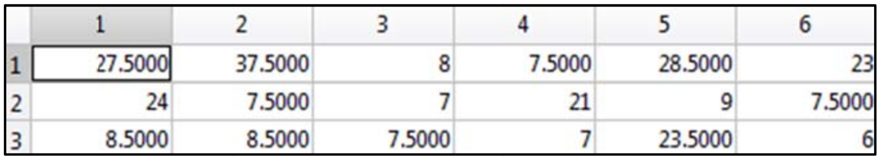


Fig.9.Layout design in the best solutions

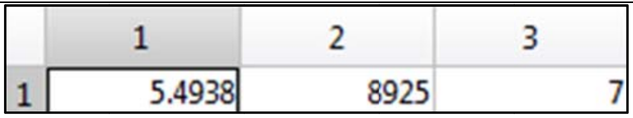
Solution No. 13 in Pareto solution set, due to the optimal amount of 3-objective and non-dominated Hemp distance between modules as the final solution was chosen by experts in electro optic-industrial system designer.

Centers coordinate system modules, Laser Range Finder in three directions (x, y, z), the values of objective functions I_L, I_D, I_M and alignments in the final solution is shown in Figure 10 to 12.



	1	2	3	4	5	6
1	27.5000	37.5000	8	7.5000	28.5000	23
2	24	7.5000	7	21	9	7.5000
3	8.5000	8.5000	7.5000	7	23.5000	6

Fig.10.The Coordinates centers of 6 module in x, y, and z dimensions.



	1	2	3
1	5.4938	8925	7

Fig.11. Values of objective functions I_L, I_D, I_M.

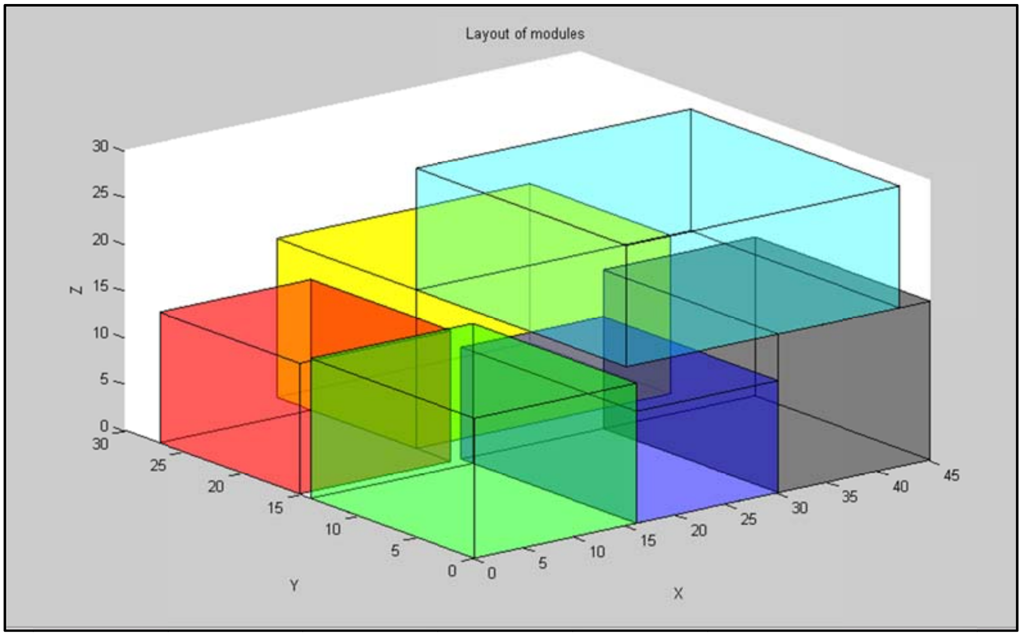


Fig.12. Optimal layout design of Modules 1 to 6.

Evaluation ultimate solution obtained from the use of meta-heuristic algorithm for multi-objective particle swarm optimization was performed in two categories.

The first solution obtained in electro optic-industry approved by system designers. The layout design similar to external systems that are appropriate in maintainability performance, the solution is obtained, questions confirmed the result.

5. Conclusions and suggestions

In the present paper, the problem of modular design and layout of complex systems for the purpose of elevating maintainability was presented through 4 objective functions. The objective function of maximizing the system accordance with the optimum modularity design, which is determined using the design structure matrix technique, was presented in the present paper. The objective function of increasing accessibility and the required maintenance space, with respect to the level of repair analysis, was developed. The objective functions of maximizing the providing of distance requirement and minimizing the layout space were used based on previous studies. The 4 above-mentioned objective functions were formulated in a multi-objective optimization problem.

Due to the fact that the presented problem is categorized among NP-hard problems, the meta-heuristic multi-objective particle swarm optimization algorithm (MOPSO) was used in order to solve the modeled multi-objective problem. The output obtained provides designers with practical information about similar systems and aids them in the simultaneous design of modularity, layout, and design for the purpose of maintainability. In this way, cost and time consumption in the designing phase of the system will be significantly more economical.

Laser range finder system as a case study with 17 subsystems was conducted. Due to the importance of modular design in this system, system modularity was embarked upon firsthand using the design structure matrix technique and then, through two stages of using the optimizing algorithm, subsystem and module layout was done with respect to the 3 other objective functions. The results obtained prove that the presented method for the simultaneous design of maintainability during system modularity and layout design is of influence.

It is suggested to use DSM features, for improved system modularity and compared with binary DSM used in this article.

Alternatively, to be solved multi-objective problem presented in this paper by other metaheuristic methods.

It is suggested in systems with more complexity, to identify the type of communication between system components, including the flow of materials or information, other features of the design structure matrix technique to use for partitioning the system.

Alternatively, in the design of complex systems, including the immune system and is designed for all requirements with regard to the stability and robustness of the system, in addition to the maintainability be considered.

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