Cellular Manufacturing Layout Design and Selection: A Case Study of Electronic Manufacturing Service Plant

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Abstract— **In this research, cellular manufacturing layout design based on Systematic Layout Planning (SLP) and selection of facilities layout design by Analytic Hierarchy Process (AHP) are applied to a case study of an Electronic Manufacturing Service (EMS) plant. Currently layout of this manufacturing plant is a process layout, which is not suitable due to the nature of an EMS that has high-volume and high-variety environment. Moreover, quick response and high flexibility are also needed. Then, cellular manufacturing layout design was determined for the selected group of products. SLP was used to analyzed and designed possible cellular layouts for the factory. In order to evaluate the best alternative layout, criteria for plant selection were determined. These performance measures were weighted by AHP. Then, the best cellular layout design was selected. This case study has shown the practical guideline for design and selection of the best EMS layout.**

***Index Terms*— layout design, SLP, AHP, layout selection, EMS**

I. Introduction

LAYOUT design and the flow of materials have a significant impact on performance of manufacturing system [1]. These can help to increase productivity, reduce work in process and inventory, short production lead time, streamlines the flow of materials, and reduce non value added activities from the production process of waiting and transportation, which make the factory meet customers' requirement quickly [2]. There are many types of layout design in manufacturing system such as process layout, product layout and cellular layout. A process layout is suitable for high degree of interdepartmental flow and little intradepartmental flow. It is proper for low-volume, high-variety environment. On the other hand, a product layout is used for high-volume, low-variety environment. A cellular layout is suggested for medium-volume and medium-variety environment [3]-[4]. This kind of layout is also appropriate for both automated and non automated manufacturing systems. It can be design based on Group Technology (GT) [5]. GT manufacturing offers several advantages which tend to improve productivity of a facility and reduce its operating costs, waiting time between process, machine setup time, distance and handling of work pieces, flow of materials between workstations. Several empirical studies confirmed these advantages [1],[2],[5],[6].

One of the effective methods for layout design was proposed by Muther which is called Muther's systematic layout planning (SLP) [4]. This method presents layout planning step that can be used sequentially to develop new layout or improve existing layout [4]. However, many layout design alternatives may be generated. Moreover, many kinds of performance measures may be needed for evaluation. Multicriteria decision making (MCDM) is needed for evaluation the best layout design based on selected criteria. This consideration is complicated, especially when there are many criteria. One of the most popular and effective method for MCDM making problem is Analytic Hierarchy Process (AHP), which has advantages in comparing alternatives based on pairwise comparison. Both qualitative and quantitative criteria can be determined by AHP. AHP has been successfully used in many applications such as supplier selection, system selection and plant location, etc. [1],[7]-[9]. So, AHP is selected to apply for layout selection of a case study.

In this research, a case study of an electronic manufacturing service (EMS), which currently uses process layout, is presented. EMS is a term used for companies that design, test, manufacture, distribute, and return/repair services for electronic components and original equipment manufacturers (OEMs). The business model for the EMS industry is to specialize in large economies of scale in manufacturing, raw materials procurement and pooling together resources, industrial design expertise as well as create added value services such as warranty and repairs [10]. There are varieties of orders under vast customers. These mean EMS company has many types of products to produce in different production routes and has large volume. So, the situation of existing plant is in a mess due to process layout. New layout for high-volume and high-variety environment is considered. Cellular layout is selected for implementation in one part of the current production plant due to the necessity of reduction of time, distance and flow within the manufacturing plant. Moreover, some of variety products can be grouped as group families. Then, SLP is applied for creating alternatives layout. Next, AHP is used

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to select the best layout design based on critical criteria.

This paper is divided into five sections. Section II gives an overview about SLP. Section III presents the AHP and related concepts. Next, the methodology that applied SLP for design layout alternatives and AHP to select the best alternatives layout are presented in section IV. Finally, conclusion is done in the last section.

II. Muther's Systematic Layout Planning (SLP)

A. *Muther's Systematic Layout Planning (SLP)*

Systematic Layout Planning (SLP) was developed by Richard Muther in 1973 with 2 major purposes; high frequency and logical relationship. There are 6 main procedures as follows [4],[11],[12]:

1. Making Relationship Chart and from-to chart: In this procedure, relationship of each pair of activities is determined and evaluated in relationship chart. A material flow analysis is done in from-to chart.
2. Relationships Diagram: It is a diagram which symbols of proximity for all activities in the layout are shown how activities in each area are related to others.
3. Space Requirements and space available: Resulted from measuring the space of manufacturing process, machinery, and other manufacturing equipments of current manufacturing plant and analyzing space required.
4. Space Relationship diagram: Utilized as a guideline for design alternative layouts.
5. Alternative layouts Evaluation: Developed alternatives are evaluated based on specific criteria of each manufacturing plant.
6. Layout Selection and Installation: This final procedure is to select and to implement the most prefer alternative.

For GT layout three major steps are required. They are [13]:

i) Formation of part families and machine cell.

ii) Arrangement of the machines or work stations within each cell.

iii) Determining the configuration of cells on the facility floor.

B. *Tools for Layout Design*

There are many useful tools which can be used for analysis product, process and schedule of the current manufacturing layout. After determining a product from the part drawing then, processes and a schedule of that part are determined. This processes and schedule information can be collected and gathered by the following tools.

Operation Process Chart: It is a chart which shows the overall understanding of the flow within the facility. It is suitable for a study of main operations for any products which are in a manufacturing plant.

Flow Process Chart: The operation process chart can be complemented with transportations, storage and delays. Such a chart is referred to a flow process chart.

Flow Diagram: It is a diagram shown a direction of work flow according to the process step.

Relationship Chart: This chart shows the relationship of each pair of activities. It is a helpful tool for positioning activities in layout planning.

These tools are used for collecting the necessary data of the case study.

III. Analytic Hierarchy process (AHP)

Analytic Hierarchy Process is a process developed by Thomas Saaty [14]. It used for measuring decision-making level for each criterion and rearranging alternatives priority. The process requires the decision makers to develop a hierarchical structure for the factors which are explicit in the given problem and to provide judgments about the relative importance of each of these factors, specify a preference for each decision alternative with respect to each factor. It provides a prioritized ranking order indicating the overall preference for each of the decision alternatives. An advantage of the AHP over other multi-criteria decision making methods is that the AHP is designed to incorporate tangible as well as non-tangible factors especially where the subjective judgments of different individuals constitute an important part of the decision process [15].

A. *AHP Methodology*

Step 1: Specify target. The goal, criterion, sub-criterion, and alternative were provided in this step.

Step 2: Specify the significance weight of evaluation criterion. This step pairwise comparison using a scale of relative importance is conducted. The judgments are entered using the scale of AHP as given in Table I [12].

TABLE I
Relative Importance of Factor

Relative importance	Description
1	Equal importance
2	Weekly more importance
3	Moderate importance
4	Compromise between the above value
5	Strongly importance
6	Compromise between the above value
7	Very strong importance
8	Compromise between the above value
9	Extreme importance

Step 3: Compare the candidate alternatives pairwise with respect to how much better in satisfying each of the factors.

The critical issues of AHP are robustness and consistency. The robustness can be verified by sensitivity analysis of the weights. The problem is how sensitive the weights given by eigenvector. The eigenvector are used to compute the relative ranking of the being evaluated criteria. It is desirable that the weights do not fluctuate widely with small changes in judgment [7]. Expert Choice package program is used for sensitivity analysis of pairwise comparison. Another critical issue is consistency. The consistency means that if criteria x equal importance with criteria y, then the matrix is $a_{xy}= 1 = a_{yx}$, and the criteria y absolutely more importance than criteria z, so the matrix is $a_{yz} = 9$; $a_{zy} = 1/9$. Then, the criteria x must absolutely more importance than criteria z, so that the matrix is $a_{xz} = 9$; $a_{zx} = 1/9$. Unfortunately, the decision maker is often not able to express consistent preferences in case of several criteria. Then, the Saaty's method measures the inconsistency of the pairwise comparison matrix and set a consistency threshold, which should not be exceeded [16].

The consistency index (CI) is given by CI = $(\lambda_{max} - n)/(n-1)$, when λ_{max} is the maximum eigenvalue and n is number of criteria, then the consistency ratio (CR) is calculated by forming the ratio of CI and random index (RI). The RI is representing the consistency of a randomly generated pair-wise comparison matrix that derived as average random consistency index as shown in Table II. If CR ≤ 0.1, then the pair-wise comparison is considered to be consistent enough.

But, if CR ≥ 0.1, then the pair-wise comparison matrix should be improved.

TABLE II
RANDOM INDEX

Number of criteria	Random index
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

IV. METHODOLOGY

A. Data Collection

The case study factory is an EMS industry which provides design, test, manufacture, distribute, return/repair services and assemblies for electronic components and original equipment manufacturers (OEMs). There are variety of products and demands which depend on customer demand, material, manufacturing process, and product life cycle. Fundamental data of the factory such as product data, manufacturing process data, flow process (routing), layout pattern, manufacturing facilities and relationship between each process are collected. The current factory layout can be shown in Fig. 1. Regarding to the results from the fundamental data, the product group, called "Charm" is selected to study, due to increasing of its demand. Two subgroups of products (P1-P8) can be formed by process flow analysis (PFA). The 1st group contains P1, P2, P3, P7, and P8 and the 2nd group contains P4, P5, and P6. Currently, the layout of the factory is a process layout. There are 17 major manufacturing processes for these two groups as shown in Table III. Relationship chart can be shown as in Fig. 2. Space for each process departments are shown in Table IV.

TABLE III
PROCESSES OF PRODUCTS IN THE SCOPE OF THE STUDY

Product Name / Process	P1	P2	P3	P4	P5	P6	P7	P8
1. Part preparation	1	1	1	1	1	1	1	1
2. SMT	1	1	1	1	1	1	1	1
3. AOI	1	1	1	1	1	1	1	1
4. 2nd	1	1	1	1	1	1	1	1
5. ICT	1	1	1	1	1	1	1	1
6. Masking	1	1	1	1	1	1	1	1
7. Coating	1	1	1	1	1	1	1	1
8. Unmasking	1	1	1	1	1	1	1	1
9. De-panel	1	1	1	1	1	1	1	1
10. Laser marking	1	1	1	1	1	1	1	1
11. TLA	1	1	1	1	1	1	1	1
12. Welding	1	1	1	1	1	1	1	1
13. FCT	1	1	1	1	1	1	1	1
14. Hipot test				1	1	1		
15. Thermal test	1	1	1	1	1	1	1	1
16. QA	1	1	1	1	1	1	1	1
17. Packing	1	1	1	1	1	1	1	1

The performance measures are determined by discussions with the company's management and by general layout guidelines. Criteria which are generally considered in layout design are flexibility involves variety and future to expansion, accessibility in material handling and operator paths, maintenance involves require space and tool movement, net present value and quality in production and product [1][7][17]. Criteria for the EMS industry that has been evaluated are "material handling", "layout characteristic", "cost" and "flexibility".

"Material handling" is an important topic of the overall facilities design, that providing "right sequence". It can help eliminate non value added operation, and reduce variance of delivery time between elements. Work simplification can be provided and efficiency of material flow can also be increased [4].

"Layout characteristics" are styles or features of plant layout that can be visual. It is can be said that the plant layout is good or not with the visualization distance and a unity of production processes.

"Cost" is a very important criterion for top management decision. It is often be a most critical one. It includes of an initial investment and operating cost.

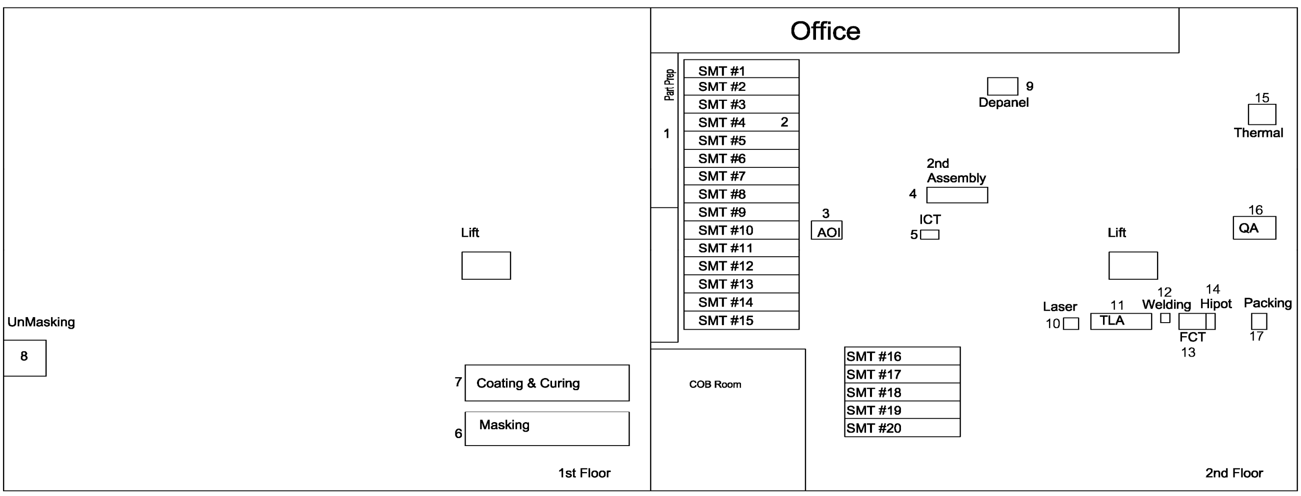

Fig. 1. The existing layout for case study

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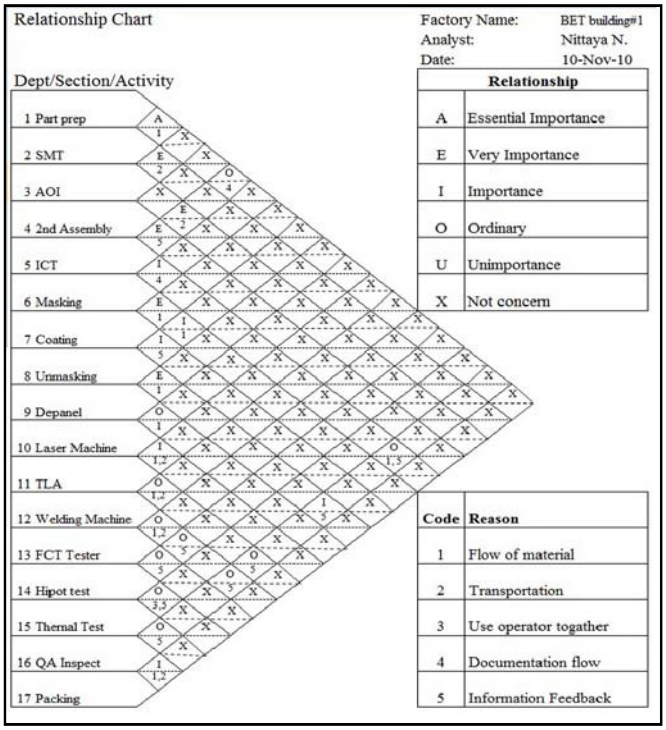

Fig. 2. The relationship chart

TABLE IV
SPACE OF CURRENT LAYOUT, TOTAL 127.87 M^2

Process	Size (m^2)
1. Part preparation	3.24
2. Surface Mount Technology: SMT	32.88
3. Auto Optical Inspection: AOI	7.34
4. 2nd Assembly: 2nd	3.12
5. In Circuit Test: ICT	15.08
6. Masking	2.82
7. Coating	7.76
8. Unmasking	2.82
9. De-panel	3.10
10. Laser marking	3.02
11. Top Level Assembly: TLA	15.68
12. Welding	1.32
13. Functional Test: FCT	3.60
14. Hipot test	1.62
15. Thermal test	19.52
16. QA inspection: QA	2.19
17. Packing	2.76

Flexibility of plant layout is also a crucial criterion for EMS plant because of the nature of EMS which has to produce many types of products. Moreover, changes of product design often occur.

B. Layout Alternatives Generation

Alternative layouts are generated based on the existing layout and some significant limitations that executives need to pay attention. Twenty four types of block layouts are generated. However, there are limitations that some designs may not appropriate. These limitations are availability of space, utilities support, work environment, affect on other products and investment cost. So, factory layout designs can be possibly performed in 3 patterns as shown in Fig. 3. - Fig. 5. In layout 1 (Fig. 3), QA process of existing layout (process number 16) has been move from existing place to arrange in a production line. Two production lines are constructed for two product groups in layout 2 (Fig. 4). In layout 3, two cells of the two product groups have been moved to the second floor. The operational sequences of parts in each group are indicated using different styles of numbers. The 1st product group uses Roman numerals and the 2nd product group uses Arabic numerals.

C. AHP for Evaluation

AHP is a theory of measurement for dealing with quantifiable and intangible criteria, which has been applied to numerous areas. It can be solved by Expert Choice Package Program. In this research, it is applied to select the best plant layout design with 4 criteria those are "material handling", "layout characteristics", "cost" and "flexibility".

"Material handling" involves three sub-criteria based on number of operator and needed area, use of new system and use of old system.

"Layout characteristics" are influenced by distance between station, visibility and unity of production line.

"Cost" involves investment cost and operating cost.

"Flexibility" involves accessibility and maintenance and ability to modify with new product improvement (NPI).

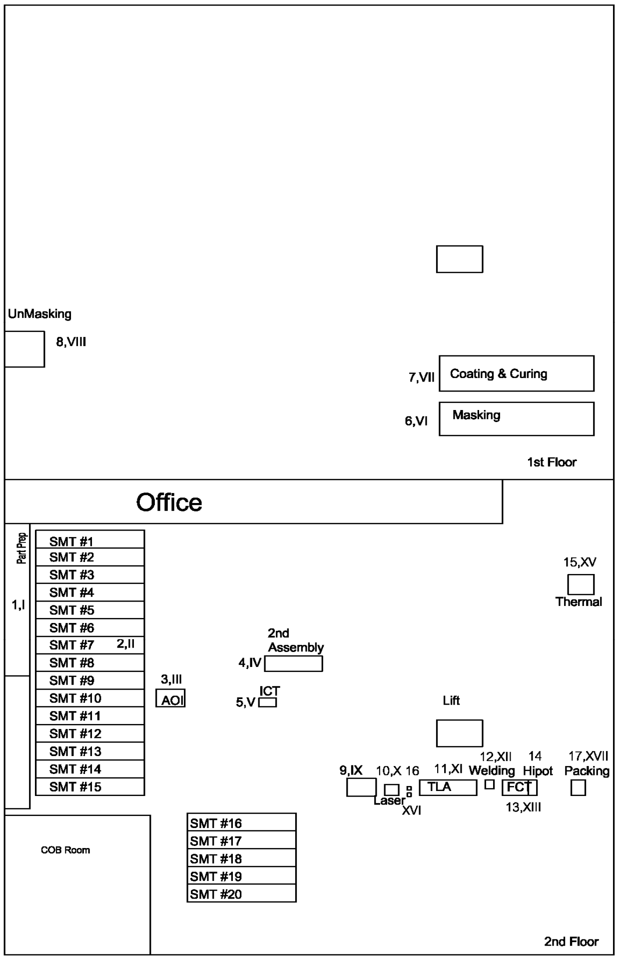

Fig. 3. Alternative layout 1

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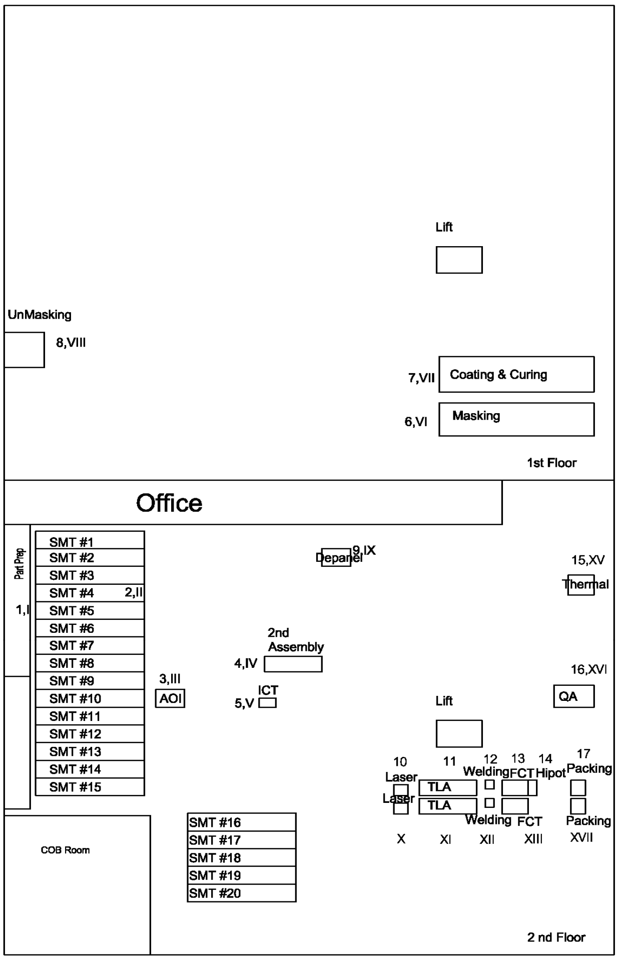

Fig. 4. Alternative layout 2

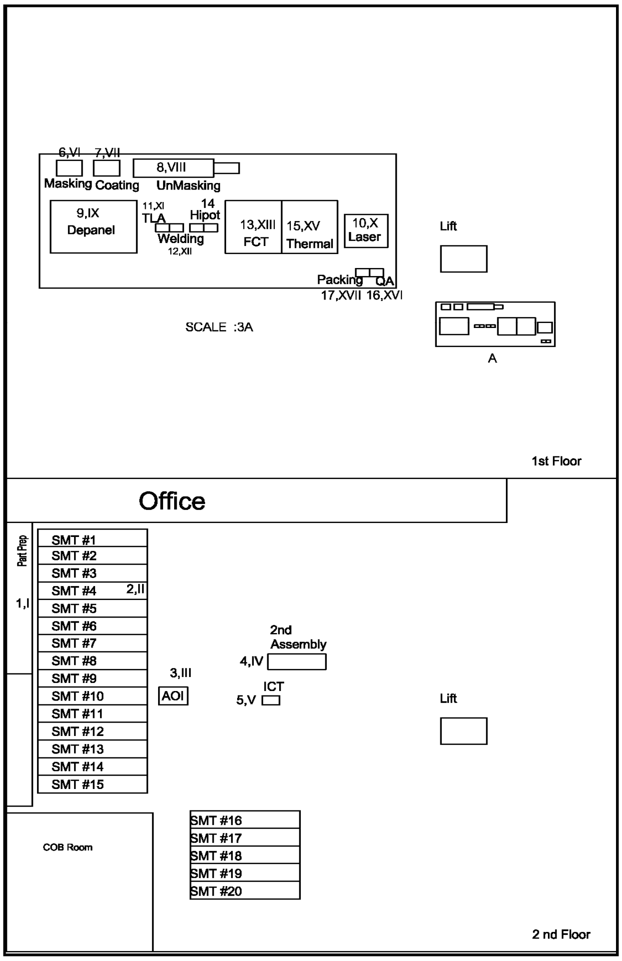

Fig. 5. Alternative layout 3

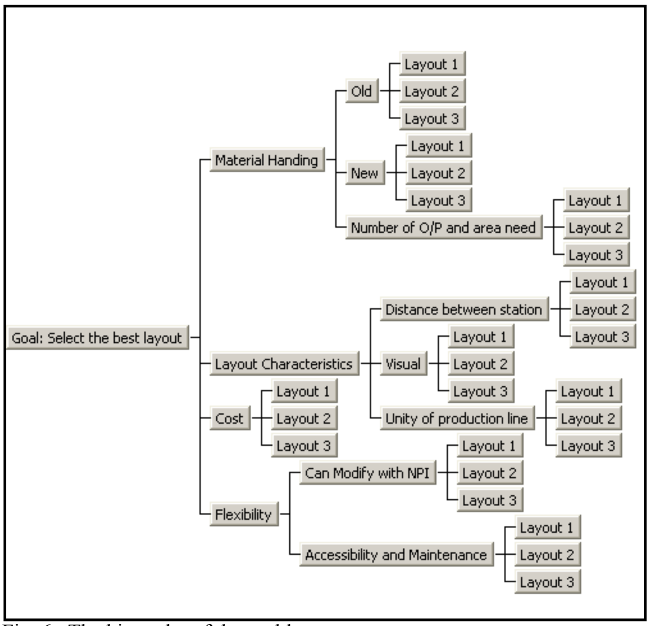

Fig. 6. The hierarchy of the problem.

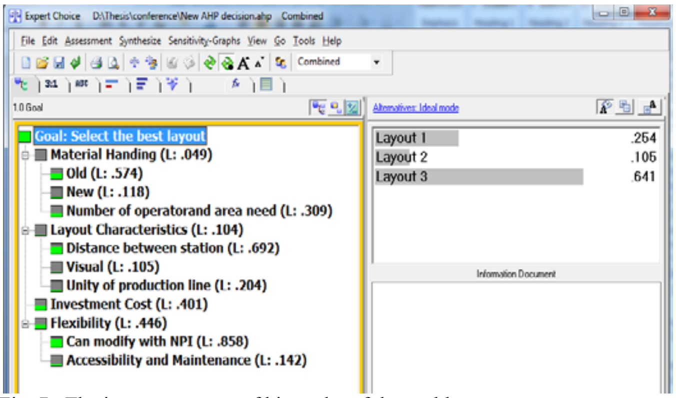

Fig. 7. The importance rate of hierarchy of the problem.

The hierarchy of the problem is shown in Fig. 6. Four experts who have intensive experience in layout design at the EMS plant evaluated these criteria. The weights of "material handling", "layout characteristics", "cost" and "flexibility" are shown in Fig. 7. Different weights are prepared based on pairwise comparison.

As a general rule, a consistency ratio (CR) of 0.1 or less is considered acceptable [16]. All of CR values are less than 0.1 as shown in Table VI. So, there is no evidence of inconsistency. As a result, layout 3 is the best alternative for this case study because it has the highest score as shown in Fig. 7.

TABLE VI
CONSISTENCY RATIO OF ALL CRITERIA

Criteria	CR
Overall	0.03
1. Material Handing	0.00
2. Layout Characteristics	0.02
3. Investment Cost	0.01
4. Flexibility	0.00

D. Sensitivity Analysis

A sensitivity analysis can be performed to see how sensitive the alternatives will change with the important of the criteria. As the priority of one of the criteria increases, the priorities of the remaining criteria must decrease

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proportionately, and the global priorities of the alternative

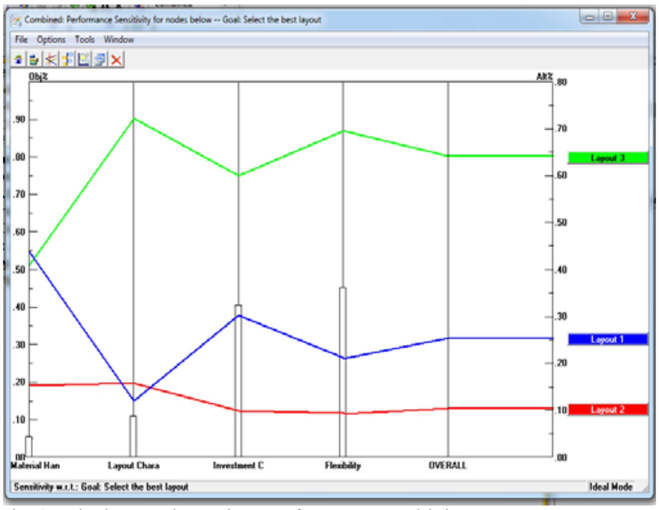

Fig. 8. The layout alternatives performance sensitivity

must be recalculated [18]. The Expert Choice program is used to conduct gradient sensitivity analysis according to each criterion.

For "material handling" criterion, layout 3 is selected with the weight equals to 0.049. Selection will be changed to layout 1, if weight of "material handling" is increased more than 0.93, which is very far from the current weight.

For "layout characteristics" criterion, layout 3 is also selected with the weight equal to 0.104. Selection will be changed to layout 1, if the weight is reduced lower than 0.01, which is very low.

For "investment" and "flexibility" criteria, layout 3 is the best alternative for all weight values.

Fig. 8 (performance sensitivity analysis) illustrates that the behavior of the alternative with respect to each other. From the overall analysis, layout 3 is the best alternative because it has high weight for almost all criteria.

So, it can be concluded that layout 3 is the best alternative. Moreover, the alternative is not sensitive with the changes of weights for all criteria.

V. Conclusion

This research addresses the facility layout design by SLP and evaluation based on AHP. Cellular manufacturing layout design was selected for a case study of EMS factory due to an inappropriateness of the existing layout. The nature of EMS factory should be served for high-volume, high-variety environment. However, currently the layout of this factory is a process layout. So, cellular manufacturing system, which suits for medium-volume, medium variety environment was adapted for the selected product groups to reduce processing time, waiting time, machine setup, time distance and handling of works. SLP was used for alternatives generation. Twenty four alternatives layout were determined. However, after considering limitations of the current factory three alternatives were evaluated by AHP. Four criteria were used in this case study; "material handling", "layout characteristics", cost, and flexibility. The result of the evaluation of this case study shown that layout 3 was the best layout based on evaluated weight of criteria. Sensitivity analysis has been performed to shown the effect of weight changes. It was shown that layout selection of this case study is not sensitive with changes of these criteria. This is the practical case study for plant layout design and selection that can be used as a guideline for other industries.

For further study, evaluation of the new layout should be done by computer simulation to confirm the effectiveness of the new layout before implementation.

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