# A Decision Modeling Approach for Redesigning and Selection for Manufacturing Layout: A Case study of Metal Manufacturing Company

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**Abstract:** Proper selection of layout design is very important in any manufacturing company. With the right layout design, productivity can increase, lead time can be shortened, non-value added operations can be minimized, and the flow of materials can be streamlined. A company can also save money if the right design was chosen before the start of the first production. The traditional way of generating a process layout alternative is by applying the Systematic Layout Planning (SLP) which can result to multiple alternatives. One way to determine the best alternative is to compute the total transportation distance for each alternative. The alternative with the smallest total transportation distance is selected as the best alternative. However, the problem with the traditional methods is that it considers only quantitative criteria such as the transportation distance. Criteria which are difficult to quantify such as flexibility and ease of maintenance must also be considered in the selection of optimal manufacturing layout. In this study, the Analytic Hierarchy Process (AHP) is thus applied in the selection of the best manufacturing layout that integrates both quantitative and qualitative criteria in the decision structure. AHP is a theory of relative measurement that provides the objective mathematics to model the complexity of the decision problem and process the value judgment of individual or a group in decision making. To illustrate the method, a case study was conducted in a metal manufacturing company using a hierarchical decision model. The criteria selected were productivity, initial investment, flexibility, and ease of maintenance. Data required were collected, and layout alternatives were generated using SLP. Productivity and cost for each alternative were also computed. Finally, AHP was applied to determine the priority weights and the best layout alternative.

**Key Words:** facility layout; systematic layout planning; analytic hierarchy process

# 1. INTRODUCTION

Facility layout refers to the arrangement of activities, processes, departments, workstations, storage areas, aisles, and common areas within an existing or proposed facility. The basic objective of the layout decision is to ensure a smooth flow of work, material, people, and information through the system (Russel and Taylor, 2011). Every manufacturing organization exerts effort to make facility more efficient. The locations and arrangements of the departments and work centers contribute in a large measure to the manner in which a facility is operating (Sule, 2009). One factor that influences the layout design is the material handling cost which is estimated to represents anywhere from 15% to 70% of total manufacturing cost (Tompkins, 2010). Improving the arrangement of departments and machines directly contributes to the reduction of material handling cost and improvement of overall efficiency. Manufacturing layout requires large capital investment and long-term planning horizon and costs cannot be avoided if modification of an existing layout is necessary.

The traditional approaches to facility layout are the engineering design problem approach and the Systematic Layout Planning (SLP). Engineering design problem approach is based on the time-tested engineering problem-solving approach. In this approach construction algorithm such as modified spanning tree and graph theoretic algorithms is needed to generate layout. SLP involves simple step-by-step procedure to facility design and this is the reason why it is still being use after more than 30 years. In this approach, the position of departments is based on adjacency relationship and alternatives are generated by "eyeballing" and trial-and-error. This is the reason why several alternatives can be generated (Heragu, 2008).

The problem with the traditional methods is that the generation and evaluation of alternatives is based on transportation distance. The input to the modified spanning and graph theoretic algorithms are flow and distance data while the generated layout using SLP are evaluated based on transportation distance derived also from flow and distance. The main basis of selection of the most effective layout for both approaches is transportation distance. However, in real situation there are other factors or criteria that should be included in the selection process to meet other objectives. A mathematical model formulated to solve a layout problem can be inaccurate because of limiting assumptions and difficulty in including some factors. Thus, a multicriteria decision making approach such as the Analytic Hierarchy Process (AHP) is more appropriate in the evaluation of alternative layout designs.

AHP is a basic approach to decision making is designed to cope with both the rational and the intuitive to select the best from a number of alternatives evaluated with respect to several criteria. AHP decomposes the problem into a hierarchical structure and derives ratio-scale priority weights from pairwise comparative judgment matrices (Promentilla et al., 2014). In this process, the decision maker carries out simple pairwise comparison judgments which are then used to develop overall priorities for ranking the alternatives. The AHP both allows for inconsistency in the judgments and provides a means to improve consistency (Saaty and Vargas, 2012).

This study aims to demonstrate the application of AHP in the selection of the best alternative layout design. A case study in a metal manufacturing company is presented.

# 2. METHODOLOGY

## *2.1 Decision structure*

There are several specific objectives of layout design such as to provide enough productive capacity, minimize material handling costs, allow high labor, machine and space utilization, reduce production time, provide for volume and product flexibility, provide safe working conditions, allow ease of supervision, and allow ease of maintenance. The importance of each objective can be different from one manufacturing plant to another. This is the reason why the set of criteria to meet the objectives also varies. The case study is a metal manufacturing company located in the Philippines which manufactures and sells different kinds of bolo knives used in farming, gardening, and logging. The criteria in selecting the most effective layout are identified by discussions with the top management. The four criteria that were identified are productivity, initial investment, flexibility, and ease of maintenance as shown in Figure 1.

Productivity (PR) is the ratio of output over input. Productivity can be increased by minimizing the non-value added (NVA) operations such as transportation. The transportation distance directly affects the material handling cost. To minimize distance and reduce lead time, the departments with the highest interdepartmental workflow should be place closer to each other. Finding the right place can help minimize non-value added operations.

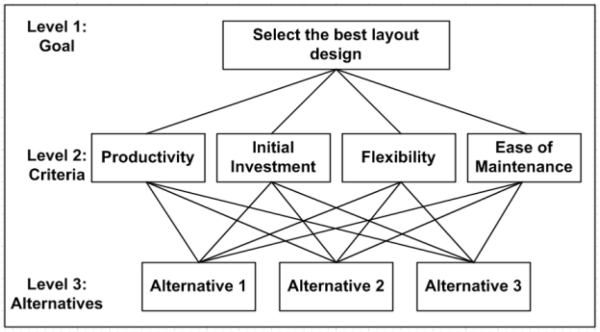


Fig. 1. Hierarchy of selection

In implementing a new layout, initial investment (II) such as installation cost cannot be avoided. Since several machines are relocated, there is a need to redesign electrical wirings for lightings and outlets. This involves material and labor costs.

Flexibility (FL) is the ability to address demand and product variations. If there is a need to expand, the production area can still accommodate additional machines. The presence of multiple paths between work stations also contributes to flexibility of a facility layout.

To minimize machine breakdown, periodic maintenance of machines should be conducted. It involves activities such as cleaning, repair and replacement of worn machine parts. Layout that allows ease of maintenance (EM) helps in reducing lead time and increase productivity.

## *2.2 Generation of Layout Alternatives*

In generating alternative layouts, the relationship chart, interdepartmental work flow, space requirements, limitations set by the company, layout pattern, and the existing layout are considered. The relationship chart shows the adjacency relationships for each department pair using closeness ratings which indicates the importance of locating department pairs next to each other (Muther, 1973). The interdepartmental work flow indicates the level or extent of interaction between department pairs. The frequency of trips between departments is a measure of interdepartmental work flow. Fig. 2. and Table 1 show the relationship chart and interdepartmental work flow, respectively. The company does not allow demolition of concrete walls. It only allows the relocation of machines. The present layout of the company is a process layout which is appropriate since this type of layout can handle demand and product variations. The current layout is labelled as Alternative 1. Fig. 3 shows the current layout and the flow of operations at the production area. The raw material storage (RMS), cutting section (CS), and final product storage and office (FPSO) area are fixed while forging section (FS), grinding section (GS), and finishing section (FNS) can be interchanged. Since there are 3 sections that can be interchanged, a total of 6 alternatives can be generated. However, based on the relationship chart, process sequence, and limitations set by the company, the number of alternatives was reduced to 2. The generated alternative layouts are labelled as Alternative 2 and Alternative 3.

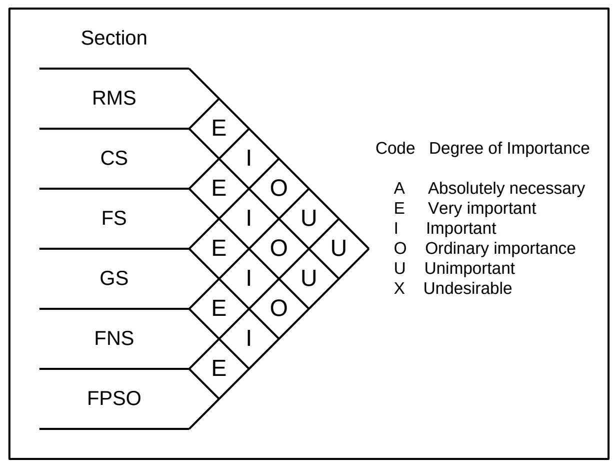


Fig. 2. Relationship chart

Table 1. Interdepartmental work flow for 1 batch (20 pieces) of bolos

| Section | RMS | CS | FS | GS | FNS | FPSO |
|---|---|---|---|---|---|---|
| RMS | - | 4 | 0 | 0 | 0 | 0 |
| CS | | - | 2 | 0 | 0 | 0 |
| FS | | | - | 7 | 0 | 0 |
| GS | | | | - | 2 | 0 |
| FNS | | | | | - | 2 |
| FPSO | | | | | | - |

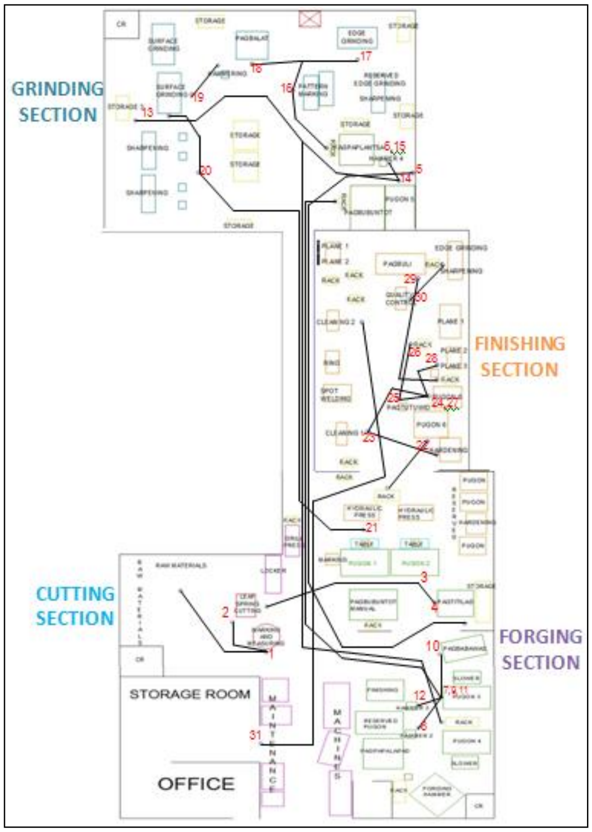


Fig. 3. Alternative 1

The relationship chart and sequence of the process were the basis of generating Alternatives 2 and 3. For Alternative 2, the grinding section and finishing sections were interchanged with the current layout as basis. Fig. 4 shows Alternative 2 layout. For Alternative 3, the grinding section became forging section, finishing section became grinding section, and forging section became finishing section. Fig. 5 shows Alternative 3. In order to measure the distance the string diagram was used. In this approach, "thread" is used to trace the path or movements of worker and materials during the production of 1 batch (20 units) of bolo on the scaled alternative layouts as shown in figures 3 to 5. The total distance travelled per batch for Alternatives 1, 2, and 3 are 1,086 meters, 713 meters, and 574 meters, respectively. The reduction in distance leads to reduction in both non-value added operations and throughput time.

## *2.3 Evaluation of priority weights*

The eigenvector method proposed by Saaty (1980) is used to derive the importance weights of criteria from pairwise comparisons of criteria with respect to the goal. The criteria were evaluated by the supervisor of the production area based on his experience and knowledge. The supervisor is also one of the decision makers and already with the company for at least 23 years. To derive the comparison matrix, every two criteria were compared at each time with respect to the goal using the fundamental scale (Saaty, 1987). This scale ranges from 1/9 for "least valued than," to 1 for "equal," to 9 for "absolutely more important than" covering the entire spectrum of comparison (Vaidya et al., 2006). It allows numeric scale calibration for the measurement of performances. Inconsistency may occur because the comparisons are based on subjective judgements. To ensure that inconsistency issues are properly addressed, consistency ratio (CR) is computed. A CR greater than 0.1 means that there is a need to review and revise the pairwise comparisons. This consistency verification is one of the strengths of AHP. Table 2 shows the pairwise comparison matrix including the computed eigenvector and consistency ratio.

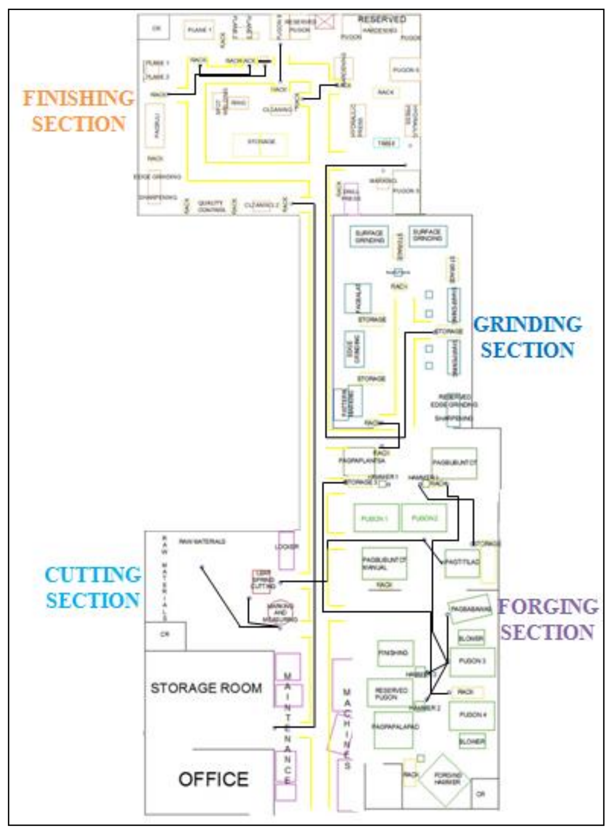


Fig. 4. Alternative 2

Table 2. Pairwise comparison matrix of the criteria

| | PR | II | FL | EM | Eigenvector |
|---|---|---|---|---|---|
| PR | 1 | 4 | 5 | 6 | 0.6042 |
| II | 1/4 | 1 | 2 | 3 | 0.2007 |
| FL | 1/5 | 1/2 | 1 | 2 | 0.1207 |
| EM | 1/6 | 1/3 | 1/2 | 1 | 0.0744 |

$\lambda_{max}$ = 4.0658 C.R. = 0.0246

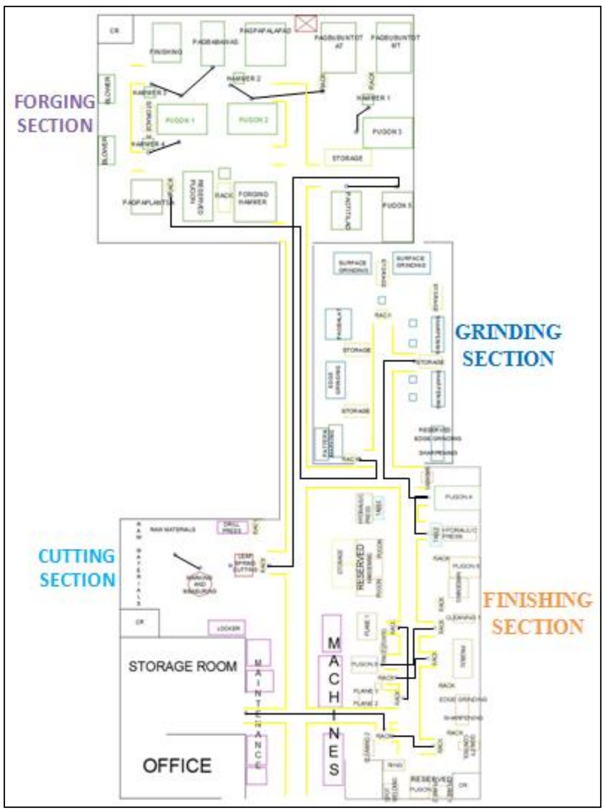


Fig. 5. Alternative 3

As for qualitative criteria such as ease of maintenance (EM) and flexibility (FL), preference weight of the alternatives was derived based on the value judgment of the decision maker. The comparison matrix of alternatives with respect to a criterion is derived in the same manner in obtaining the comparison matrix of the criteria. Verification of consistency is also done on this level. For the quantitative criteria such as productivity (PR) and initial investments (II), weights are derived from actual measurements and then normalized to derive the preference weights. Once all local preference weights are available, they are aggregated with a weighted sum in order to obtain the global priorities of the alternatives. Table 3 and 4 shows the example pairwise comparison of alternatives with respect to flexibility (FL) and ease of maintenance (EM), respectively.

Table 3. Pairwise comparison matrix of alternatives with respect to flexibility (FL)

| Alternative | 1 | 2 | 3 | Eigenvector |
|---|---|---|---|---|
| 1 | 1 | 1/3 | 1/3 | 0.1396 |
| 2 | 3 | 1 | 2 | 0.5278 |
| 3 | 3 | 1/2 | 1 | 0.3325 |

$\lambda_{max}$ = 3.0536 C.R. = 0.0516

Table 4. Pairwise comparison matrix of alternatives with respect to ease of maintenance (EM)

| Alternative | 1 | 2 | 3 | Eigenvector |
|---|---|---|---|---|
| 1 | 1 | 1/4 | 1/6 | 0.0890 |
| 2 | 4 | 1 | 1/2 | 0.3234 |
| 3 | 6 | 2 | 1 | 0.5876 |

$\lambda_{max}$ = 3.0092 C.R. = 0.0088

## 3. RESULTS AND DISCUSSION

Table 5 summarizes the results of the preference weights of the alternatives with respect to each criterion.

Table 5. Preference weight for all alternatives

| Alternative | Criterion | | | |
|---|---|---|---|---|
| | PR (0.6042) | II (0.2007) | FL (.1207) | EM (.0744) |
| 1 | 0.2944 | 0.5143 | 0.1396 | 0.0890 |
| 2 | 0.3453 | 0.3479 | 0.5278 | 0.3234 |
| 3 | 0.3603 | 0.1378 | 0.3325 | 0.5876 |

In terms of productivity, Alternative 3 has the highest weight because it can produce the highest potential output. For the initial investment criterion, Alternative 1 got the highest preference simply because it requires no capital outflow. When it comes to flexibility, Alternative 2 got the highest preference weight because of greater free space for future expansion. Because of greater space for maintenance personnel which allows easier access to machines, Alternative 3 is the most preferred alternative when it comes to ease of maintenance. The final score of Alternative 1, Alternative 2, and Alternative 3 are 0.3046, 0.3662, and 0.3292, respectively. Therefore, the company should select Alternative 2 as the best layout design.

## 4. CONCLUSIONS

This paper demonstrated the application of AHP in the selection of manufacturing facility layout. It provides more comprehensive evaluation of alternatives because it allows the evaluation of both quantitative and qualitative criteria. It provides faster way of evaluation since quantifying hard to quantitative performance measures can be avoided. A real case study was conducted in metal manufacturing company to demonstrate the selection process. The quantitative criteria selected were productivity and initial investment while flexibility and ease of maintenance were the selected qualitative criteria. Data needed to generate alternatives] layouts using SLP were collected. Initially, there were six possible process layout alternatives. However, considering the limitations set by the company, space requirements, process sequence, interdepartmental work flow, and other factors, the number of alternatives was reduced to three. After generating alternatives, productivity and initial investment for each alternative were computed. The computed values served as basis of the decision maker in evaluating the quantitative criteria. The three alternatives were assessed based on the weighted criteria derived from AHP approach. Alternative 3 was selected as the best alternative. The case study illustrated the practical use of AHP in the selection of manufacturing layout design.

For further study, sensitivity analysis should be performed to determine the effect of weight changes in the selection of the best alternative. It is also recommended to include other managers as decision makers. Lastly, other tools such as computer simulation should be done to determine other performance measures that are also important to the company such as utilization and idle times when evaluating further the best layout.

## 5. ACKNOWLEDGMENTS

The authors would like to acknowledge Engr. Eriberto Hebron and Ross Hebron for allowing the authors to conduct study in the company and providing information. Special thanks to the management and staff of Hebron Brothers Metal Mfg. Co., Carmona, Cavite.

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