Multi-criteria spine layout design of a mixed production line considering additional processes required for a new product

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Abstract. This research is based on a case study of an automotive company with a mixed production line system facing on redesigning layout due to an additional new product in the current facilities for cost improvement. The objective of this research is twofold (i) to fulfil space required for additional machines and (ii) to redesign layout which is the best layout for producing the current and new products. Heuristic approach combining construction and improvement algorithms is used for redesigning a manufacturing mixed production line layout, and this results in four alternative layouts. The four alternative layouts are evaluated comprehensively by using MCDM (Multi Criteria Decision Making) and the multi criteria considered are material handling cost, total re-layout cost, takt time process, numbers of shutdown period for relocation and comply with management policy related with safety. The best layout is the layout fulfilling required space, 1,120 m² for new processes, and meet with the five criteria considered.

1. Introduction

In the technology era, customer has many options to choose the goods according to what they want. Manufacturing operation is forced to quickly response on customer demand changes while improving competitiveness and profitability to survive. Efficient and effective systems are required to operate production with high quality, less inventory and low cost product [1]. Manufacturing strategy to be able to produce variety of product with flexible operation in volume and variant, requires dynamic changes of flow process and layout design [2]. According to Tompkins[3], a good facility layout contributes up to 50% of manufacturing operating cost by optimize material handling system, which is called Facility Layout Problem (FLP). FLPs have been studied since 1960s with various research and methodology to get new alternative layout with more efficiency by considering interaction between materials and facilities in order to contribute to cost reduction [4][5].

A manufacturing layout design is a systematic physical arrangement of facilities which consist of workstations, machines, equipment, storage, warehouse and other common areas which are essential for production or delivery goods and services. Numerous articles have been made to evaluate alternative solutions of layout by using material handling cost criteria as an objective for designing layouts [6][7]. However, in the actual practice, a layout designer has to take into consideration various criteria to decide the best solution layout, such as material handling cost, distance of operator movement, takt time, safety factor, etc. In this study, a layout for a mixed production line is considered. This production line dealing with welding processes produces a various model of automotive products in the same production line. Currently, the existing layout needs to be reconfigured as the company is expanding its business to produce a new type of the product in the current production line. In order to level up a competitive
advantage of the product, the current layout which was designed using a spine layout is maintained but it needs more spaces for several new machines to be added due to an additional new product that required to do welding processes. The company wants to maximize the utilization of existing facilities without a building expansion to produce the additional new product.

In this paper, we do relayout for the mixed production line using multi-criteria consisting of quantitative and qualitative criteria (i.e. material handling cost, total re-layout cost, takt time of process, number of shutdown and management policy). Redesigning the mixed production line layout based on a spine layout using multi-criteria can be viewed as the contribution of this paper. The paper is organized as follows. Literature review will be described in Section 2 and the case study of a relayout problem considered is presented in Section 3, Section 4 deals with designing alternative layouts for the production line, and finding the best layout using Analytical Hierarchy Process (AHP) technique considering some criteria is presented in Section 5. Finally, we give some important findings in Section 6.

2. Literature Review

2.1. Spine layout design
Spine layout is a form of layout that consists of one main line and there are several machine cells that are placed on one or both sides as shown in figure 1 [8]. The spine layout concept was introduced by Tompkins which efficiently combines two necessary qualities of layout, modularity and flexibility. This layout is particularly well suited for implementing flexible manufacturing systems [3]. Manufacturing facilities with spine layout are able to produce several types of product in the same production line with medium volume, such as automotive companies, semiconductors and others. In general, the layout design consists of determining practical and efficient locations for all departments in a factory, which can be classified into process layout or product layout. In the spine layout, all materials are transferred along the spine in such a way that the smallest total travel is obtained [1].

![Figure 1. Spine layout configuration.](image)

The advantages of spine layout such as reducing the size of aisle, less WIP (work in process) because the products can be directly supplied to the main line [3]. Spine layout with the shortest main path, will have the smallest value of material handling cost. It is important to consider total system of transfer material from one machine to another machine when designing a layout and also tradeoff between the material handling costs and the investment costs. The layout which has the smallest material handling costs may require substantial investment costs. For this reason, an effort is needed to find a net spine layout, which is a spine layout that has a small material handling costs and a cheaper investment cost [9].

2.2. General purpose of redesign layout
Placement of facilities in right position can have a significant impact on productivity and production costs. Layout design of a manufacturing facility is integrated between physical equipment with the material flow system [10]. According to Tompkins, an appropriate placement of facilities can contribute to productivity improvement and able to reduce costs until 50% of total operating costs.

Some reasons why manufacturing has to do redesign layout as follows [11]:
- To produce new product, because old product is not meet with market demand
- Design changes in existing product significantly that impact to operation
- Capacity expansion
• To improve production operation in term of safety and quality
• To enhance productivity by reduce hard-work or motions
• New facility for special new market
• To reduce operation expenses

3. A Case Study
An automotive company (called Company A) applies mixed production line system, which produces several types of products in the same production line to fulfil customer needs. Company A is developing business by producing a new product in the current facilities to optimize investment costs.

3.1. Problem formulation
In the welding production division of a car body where the facilities were arranged using a spine layout, needs free space about 1,048 m² for additional machines and other equipment which are required to produce a new product in the current facilities. Company A sets a challenge target to utilize existing building as much as possible and there will be no additional new building. The welding division has to reconfigure the current layout to get the free space and redesign a new layout due to additional equipment for an additional new product with the lowest material handling cost, re-layout cost, and fulfilled other criteria (described in the next section). By maintaining the spine layout and the mixed production line system, this research is expected to be able to provide several alternative solutions in redesigning the layout, and to select the best layout by considering multi criteria consisting both quantitative and qualitative criteria.

Figure 2. Spine layout of Welding process.

3.2. Takt time condition
Based on the forecast production plan of Company A, takt time conditions for each department can be seen in table 1. The volume ratio of product 1 is only about 25% compared to the ratios for products 2 and 3, or only 10% compared to the total volume. The takt time of Product 1 is 20.4 minutes meaning that it needs to supply the product to the main line in every 20.4 minutes, note that the takt time in main line is 2.0 minutes.

Table 1. Takt time by product

| Product | Volume/day | Volume/hour | Takt time (min) |
|---------|------------|-------------|-----------------|
| 1       | 43         | 3           | 20.4 Eff 97%    |
| 2       | 173        | 11          | 5.1             |
| 3       | 217        | 13          | 4.1             |
| Main line | 433     | 27          | 2.0             |
Some adjacent sub-processes would be possible to be merged through job balancing for a productivity improvement, and the takt time of combined sub process are as shown in table 2. The takt time of the combined sub process between sub processes of products 2 and 3 is 2.3 minutes which is closer to the takt time of the main line which is 2.0 minutes.

Table 2. Takt time for combined product

| Product | Volume/day | Takt time (min) | Eff 97% |
|---------|------------|-----------------|---------|
| 1 & 2   | 216        | 4.1             |         |
| 2 & 3   | 390        | 2.3             |         |
| 1 & 3   | 260        | 3.4             |         |

The sub-process of products 2 and 3 will be more efficient if it is located closer to the main line, because it requires faster delivery speed than sub-process of product 1. With a position adjacent to the main process line as the next process, product outputs 2 and 3 can be directly sent to the side of the main process line without having to use shipping equipment such as towing-cars, AGV, and other logistics transportation. As for sending product output 1 to the main process line can be done with the help of logistical equipment because the shipping requirements are slower than product 2 and 3.

4. Design Layout
To achieve the objective of this research, we develop methodology as follows:

4.1. Develop alternative for space-lacking
Before constructing the layout for the existing and new products, we need to develop several alternative layouts in order to solve a lack of space in the current facilities. The considerations in selecting alternative solutions to get more spaces for new processes, as follows:

- Process of part preparation needs to be removed to the logistics department, and the space can be optimized for the assembly process.
- Department can be removed to upper floor with following criteria:
  - Not a critical process
  - Have no manual process by operator
  - Have no parts and in-line stock

Based on the above considerations, there are two alternative solutions as follows:
  - Alternative 1. Finish Good stock moves to upper floor.
Finish good stock is a storage for good product that ready to be transferred to the next process without any process. The main equipment is skid conveyor with free space about 1,120m$^2$ from this alternative.

Alternative 2. Respot moves to upper floor & relocate transfer lane of chassis.

Respot process consist of 4 units robot for left-hand side process and other 4 units robot for right-hand side process. Those robots perform for welding spot of joint main body part with high accuracy level requirement. Transfer lane of chassis is the preparation area for transferring chassis parts to assembly shop. Transfer lane of frame is out of welding body process but in the same building. The exit door for transferring to the assembly shop is adjacent to the welding body process. We get 1,100m$^2$ free space from this alternative.

4.2. Construct initial layout
After getting alternative solutions for the lack of space, the next step is to create an initial layout by applying construction algorithm based on spine layout with maintaining facilities closer to the next process. Some scenarios are developed to get the alternative solutions such as:

- **Scenario 0**: arrange department randomly
- **Scenario A**: sequence of process
- **Scenario B**: clustering based on takt time

**Table 3. Scenario for initial layout design**

| Scenario   | Alternative 1 | Alternative 2 |
|------------|---------------|---------------|
|            | Finish Good Stock move to 2nd floor | Respot move to 2nd floor & relocate transfer lane of chassis |
| Scenario 0 | Arrange department randomly |                        |
| Scenario A | Arrange department based on sequence of process |                        |
| Scenario B | Arrange department based on takt time |                        |

Scenario 0 (an initial layout where departments arranged randomly) is required for a comparison only and to understand the importance of developing a good initial layout. Scenario A is considered since a sequence of process is required for a body maker and other assembly part processes for an efficient manufacturing. It is also to minimize equipment relocation in the current layout where the sequence of process already exists [12]. For scenario B, in order to maintain smooth continuous flow in main line, the takt time of in all sub processes which is determined by the market, needs to be synchronized with main line. Placement of sub process with considering takt time gives some advantages to minimize work in process (WIP). Sub processes with faster takt time should be arranged closer to the next process to perform direct supply to the main line to reduce stock. While sub processes with slower takt time is clustered and delivered product to next process then the sub-processes are supported by supplying equipment such as AGV, towing-car, roller-conveyor, and other equipment [13].

4.3. CRAFT technique
After designing the initial layout by applying a construction algorithm, the initial layout will be adjusted with the improvement algorithm by using CRAFT software. This software is a computer-based layout algorithm that was developed by Armor & Buffa in 1963 for factory layout design. CRAFT helps to improve existing layout or initial layout which is more suitable for rectangular facilities, by exchange among department and compute material handling cost [11]. CRAFT exchanges departments that have similarity of space in the same location. For example, department no.1 exchange position with department no.3, department no.11 exchange position with department no.17 and so on. This iteration will be continued until we get lowest material handling cost (MHC) [1].
CRAFT software has not yet been equipped with adequate restrictions, necessary to check every iteration obtained during exchanging the position of department. For example sub process which produce left-hand component should not be moved to right side of main line and vice versa. Through this step, we will get 1 scenario 0 as comparison only, and 4 alternative configurations from created scenario: configuration 1-A, 1-B, 2-A and 2-B as shown in table 4.

**Table 4. Alternative configurations as output of CRAFT**

| Item                  | Scenario 0 | Alternative 1 | Alternative 2 |
|-----------------------|------------|---------------|---------------|
|                       | Configuration 1-A | Configuration 1-B | Configuration 2-A | Configuration 2-B |
| Free Space m²         | 1,120      | ←              | 1,100         | ←              |
| MHC                   | 7,034      | 6,760         | 6,685         | 8,472          | 8,434 |
| Σ Iteration           | 4          | 10            | 13            | 5              | 3     |
| Σ Moved Dept          | 15         | 17            | 17            | 19             | 19    |
| Total *relayout* cost (Bio IDR) | -         | 54.8          | 54.8          | 85.6           | 85.6 |

5. Finding Best Layout

5.1. Multi-criteria layout problems and decision-making technique

In general, layout problems use material handling cost value as a criterion for evaluating layout. Layout improvement is usually done by minimizing the value of material handling cost [14]. However, there are some potential problems arise related to qualitative criteria, such as environment noise, safety issue, facilities that must be far from sparks and dust. For example, painting process must be separated from welding process because the risk of fire and dust [15]. The qualitative criteria cannot be captured through a quantitative approach only. For this reason, a multi criteria or MCDM (Multi Criteria Decision Making) approach is required to evaluate alternative layouts to decide the best layout [7].

Analytical Hierarchy Process (AHP) was developed by Saaty [16]. This method is a model of decision making to choose the best solution from the complex criteria. This decision support model has break down multi-criteria problems or complex criteria into a hierarchy. AHP method has been expanded with various alternative models, such as resources allocation, choosing a portfolio model, etc.

![Figure 4. Hierarchy diagram on selecting the best layout](image-url)

For best layout decision making, the steps in AHP as follows [16]:

Step 1. Determine the objectives, criteria and alternatives of a hierarchical structure
Step 2. Make a pairwise comparison based on expert judgment
Step 3. Determine the criteria weights
Step 4. Consistency check by calculating Consistency Index and Consistency Ratio
Step 5. Make overall priorities prior to decision making

Four alternative configurations/layouts will be evaluated based on multi criteria both qualitative criteria and quantitative criteria. Multi criteria in this study are summarized based on exclusive literature and expert judgement, described as follows.

Material handling cost (C1) represents effectiveness of layout, which is obtained by CRAFT when improving initial layout. The smallest number is the best.
Total re-layout cost (C2) should be minimized that include all cost for work site rearrangement including demolish cost, re-installation, floor construction, and other required cost.
Takt time of process (C3) is considered to evaluate supply system to next process.
Number of shutdown (C4) that required days for relocation of machines and equipment to arrange the layout. This factor is considered to minimize loses of production day.

Management policy: safety (C5) of worker is important for the alternative layout. New layout should make better environment and comfort to increase member motivation.

Table 5. Matrix of multi criteria and alternative layouts

| Criteria                          | Alternative 1 | Alternative 2 |
|----------------------------------|---------------|---------------|
|                                  | Configuration 1-A | Configuration 1-B | Configuration 2-A | Configuration 2-B |
| C1. Material handling cost (MHC) | 6,760          | 6,685          | 8,472            | 8,434            |
| C2. Total re-layout cost (Bio IDR) | 54.8           | 54.8           | 85.6             | 85.6             |
| C3. Takt time of process         | Insufficient supply part | Sufficient supply part | Insufficient supply part | Sufficient supply part |
| C4. Number of shutdowns          | 10 days        | 10 days        | 25 days          | 25 days          |
| C5. Management Policy: Safety    | Yes            | Yes            | Not enough support | Not enough support |

Evaluation of each alternative layout based on the above multi criteria is summarized in table 5, where alternative 2 with scenario 2-A and 2-B has bigger amount of MHC and total re-layout cost because we need to relocate 8 units robot to 2nd floor. It also takes longer day of shutdown for construction.

Then, Analytical Hierarchy Process (AHP) method is used to select the best alternative layout configuration based on multi criteria. By following steps of AHP for a decision-making process as discussed, we get the total value of each alternative layout shown in table 6. Alternative configuration 1-B gets the highest score that is 1.0, compared with the scores of other alternatives. It means that alternative 1-B has a dominant score in all criteria, and hence selected as the best layout.

Table 6. Total value for decision making by AHP method

| Alternative | Alternative 1 | Alternative 2 |
|-------------|---------------|---------------|
|             | Configuration 1-A | Configuration 1-B | Configuration 2-A | Configuration 2-B |
| Total Value | 0.888          | 1.00          | 0.536           | 0.624           |
The best layout is selected from this study as shown in figure 5, with spine-sub processes located on the right and left side of the main line. Figure 5 is image of process configuration based on output of CRAFT after improved initial layout based on scenario 1-B.

Refer to figure 5, process flow will be started from point ☒ for sub-processes to Under Body Final line then move to Main Body line with sub-processes of all product are on the right and left side of main process. Then move to Respot process at point ☑ with 8 units robot without any sub process. All job in Respot process is done by robots with high accuracy level requirement. The process flow will continue to point ☐ Shell Body line whereby sub-processes of products 2 and 3 have faster takt time, located on the right and left side of the main process, while sub-processes of product 1 are located in one location, which has slower than that of sub-process of products 2 and 3. Output of this process will be stored in Finish Good stock at upper floor by overhead transfer [17].

In Shell Body line, sub-processes of product 2 and 3 are located closer to the main line, which able to supply the output of process directly to the main line without any logistics transportation such as towing-car, etc. Since sub-processes of product 1 are not close to the main line, the output of process will be transferred by using towing-car, AGV, and other logistics equipment. By this configuration, we get benefit to minimize WIP or inventory as well as reduce space.

6. Conclusion
Based on the case study of this research, we conclude that the lack of space (i.e. 1,048 m²) for additional processes needed for the new products can be fulfilled by relocating the finish good stock facility to the upper floor. This alternative requires a smaller construction cost and has the smallest risk related to safety because there is no operator involved in this process. We obtained four alternative solutions of the layout using a construction algorithm with appropriate scenarios of the initial layout and the improvement algorithm by using CRAFT. Alternative 1–B is the best alternative based on the AHP result considering multi criteria discussed in Section 4. The material handling cost of the best alternative is 6,685, the total cost of relocation machines is 54.8 bio IDR and it takes about 10 days of shutdown for rearranging machines based on the best layout. The other important finding is that this best layout is the one that considers the placement of the machine based on the takt time of a process.
References

[1] Heragu S 2016 Facilities Design 4th edn (New York: CRC Press)
[2] Lujie C Jan O and Ou T 2014 Manufacturing facility location & sustainability: a literature review and research agenda Int. J. Prod. Econ. 149 pp 154-63
[3] Tompkins James A et al 2010 Facilities Planning 4th edn (New York: John Wiley & Sons Inc)
[4] Drira A Pierreval H and Hajri-Gabouj S 2007 Facility layout problems: a literature analysis Annu. Rev Cont. 31 (2) pp 255–67
[5] Shayyan E and Chittilappilly A 2004 Genetic algorithm for facilities layout problems based on slicing tree structure Int. J. Prod. Res. 42 pp 55–67
[6] Kovac G and Kot S 2017 Facility layout redesign for efficiency improvement and cost reduction J. Appl. Math. Comput. Mech. 2017 16 (1) pp 63-74
[7] Besbes M Affonso R Zholgadri M and Masmoudi F 2017 Multi-criteria decision making for the selection of a performant manual workshop layout: a case study IFAC PapersOnLine 50 (1) pp 12404–09
[8] Zuhdi A Taha Z Zawiyah S and Yap H 2013 Spine layout design for flexible manufacturing systems using a hybrid genetic algorithm and fuzzy-based level control model Proc Int. Conf. Intel. Manuf. Log. Sys. 9 pp 71 – 77
[9] Lavengin A Montreuil B and Lopel D 1994 Spine layout design Int. J. Prod. Res. 32 (2) pp 429–42
[10] Mital A Desai A Subramanian A and Mital A 2014 Product Development 2nd edn (Amsterdam: Elsevier) pp 509–22
[11] Prasad H N Rajyalakshmi G and Reddy Sreenivasulu 2014 A typical manufacturing plant layout design using CRAFT algorithm Proc. Eng. 97 pp 1808–14
[12] Yang T and Peters B 1997 A spine layout design method for semiconductor fabrication facilities containing automated material handling systems Int. J. Oper. Prod. Manage. 17 (5) pp 490–501
[13] Lahmar M and Benjaafar S 2005 Design of dynamic distributed layouts IIE Trans. 37 pp 303–18
[14] Raman D Nagalingam S and Lin G 2009 Towards measuring the effectiveness of facility layout Rob. Comput. Integr. Manuf. 25 pp 191–203
[15] Lin L C and Sharp G P 1999 Quantitative and qualitative indices for the plant layout evaluation problem Eur. J. Oper. Res. 116 pp 100–17
[16] Saaty T L 1990 How to make a decision: the analytic hierarchy process Eur. J. Oper. Res. 48 pp 9–26
[17] Ting J and Tanchoco J 2001 Optimal bidirectional spine layout for overhead material handling systems IEEE Trans. Semicond. Manuf. 14 (1) pp 57–64