Productivity improvement of a manufacturing facility using systematic layout planning

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Abstract: Implementation of lean manufacturing principles and believing in continuous improvement are the tools which help industries to sustain global competition. With the escalation in population, the demand for technology is increased more than ever. This leads to the steady increase in production rates of existing models and even introduction of new product models. These factors often result in “layout modification” of manufacturing industries. Plant layout improves resource utilization and provides means for application of lean tools such as 5S, seven wastes, kanban, Just In Time (JIT), etc. These tools not only contribute in reducing cost but also benefit the organization by improving product quality. This paper provides a comprehensive comparison of different approaches used in layout design. The study also simplifies the application of systematic layout planning (SLP) in the development of new layout. SLP is a technique used for layout development and material flow improvement. A case study of layout design using SLP is presented for a multinational company which manufactures a product with high variety. The results include four possible rearrangements of production departments. These layout alternatives are evaluated on basis of improved accessibility and material flow efficiency criteria.

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Muhammad Fahad (In Photo) is a PhD scholar and an associate professor at the Department of Industrial and Manufacturing Engineering, NED University of Engineering & Technology, Pakistan. He completed his post-graduation in Manufacturing Management and PhD in Additive Manufacturing from Loughborough University, United Kingdom. His main research areas include Additive Manufacturing, Lean Manufacturing, Value Stream Mapping and Operations Management. He has supervised several lean manufacturing implementation projects in local/multinational industries.

Syed Asad Ali Naqvi, Muhammad Atir, Muhammad Zubair and Muhammad Musharaf Shehzad are recent graduates (2015) from Industrial and Manufacturing Engineering, NED University. The core interests of the group are related to productivity improvement projects in manufacturing firms by using lean methodologies such as Waste assessment, 5S, Kaizen, Kanban, Just in time, six sigma and Energy management.

PUBLIC INTEREST STATEMENT
Facilities layout is the arrangement of machines, workstations and logistics. With the development in automation technology, small and medium enterprise (SME) now use a combination of both automated and manual skills to manufacture a customize product. The automation machines in SME are generally used for machining, welding and painting the product. The facility studied in this paper characterizes these automated machines as “pre-fabrication”. The parts are then transported to assembly line using suitable material handling equipment. Hence, a well-designed plant layout ensures efficient utilization of these resources. Factors such as increase in product demand, cost effective manufacturing and competitive pressure for improved quality are resolved by layout design. The selection of appropriate layout is a difficult decision because of complex relation between production departments. This paper helps enterprises by using a simplified approach for layout design and selection. The results show improvement in production rates, economic savings along with future impact in reducing greenhouse gas emission.
Thus, the economic benefits achieved by overall integration of facility are highlighted. The results illustrate the impact of layout design on elimination of waste and the economic benefits achieved by reducing overall material flow and lead time.

**Subjects:** Lean Manufacturing; Operations Management; Production Systems

**Keywords:** lean manufacturing; SLP; wastes; Kaizen; layout

1. Introduction

Lean Manufacturing is a philosophy that maximizes efficiency, reduces costs, improves product quality, and also takes an important look how people work in a factory (Ohno, 1988). Lean production is “lean” because it uses less of everything; half the human effort in the factory and half the manufacturing space (Womack, Jones, & Roos, 1990). Factories that become lean can double output without enlarging their facilities or adding workers. Lean factories have one-tenth as much as work-in-process inventory (WIP) because material flows continuously during production from raw stock to the customer’s dock (Standard & Davis, 1999).

Some of the common tools utilized for implementing lean are (Ali, Jaweed, & Fahad, 2015; Ohno, 1988):

- Seven Wastes: wastes are the profits that the company can earn and lean is a revolution that earns that profit. As per Taiichi Ohno, wastes may comprise motion, waiting time, over production, over processing, defects, transportation and inventory. Eliminating waste is the primary focus of lean manufacturing.
- Kaizen: philosophy of continuous improvement of working practices
- Just In Time: reducing the in-process inventory and associated costs
- 5S: methodology for work place organization
- Kanban: visual signal of customer demands

Facility layout is the arrangement of operations, machinery and spaces and the correlation between them (Hales, 1984). It is the study of spatial allocation, for instance architecture space planning, manufacturing layout, offices layout and very-large-scale integration (VLSI) layout (Tam & Li, 1991). The plant design is often directly related with production control and product quality (Vollmann & Buffa, 1966). Well-organized machine or department arrangements and suitable transportation paths create an efficient plant (Bock, 2007). Plant layout analysis generally incorporates a study of the production line process flow charts, material flow diagrams, product routings, processing times, development of from-to charts, relationship diagrams between different departments in the facility and the cost of material movement (Francis, McGinnis, & White, 1992). Systematic Layout Planning (SLP) is a prominent procedural approach and is widely used in layout design for various small and medium enterprises (Gilbert, 2004). Some recent work explore new areas in the application of layout planning such as hospitals and food industry (Helber, Böhme, Oucherif, Lagershausen, & Kasper, 2014; Lin, Liu, Wang, & Liu, 2015; Ojaghi, Khademi, Yusof, Renani, & Bin Syed Hassan, 2015; Wanniarachchi, Gopura, & Punchihewa, 2016).

This paper illustrates the use of SLP as a simplified approach for layout design. Since, the selected facility manufactures a customize product (switch gear) thus, the layout alternatives are evaluated on basis of better integration of facility. The economic benefits of the selected layout are also estimated. The rest of this paper is organized as follows, Section 2 provides a comparison between algorithmic and procedural approach and gives brief overview of factors considered during layout design. Section 3 explains the methodology and simplifies the criteria of layout alternative selection. In Section 4, an example of a facility is presented to apply the simplified SLP approach in real case. The final section discusses the concluding remarks and the application of the work in future research areas.
2. Literature review

Facility layout design has major influence on plant productivity. The purpose of layout design is to find the most effective facility arrangement and minimize the material handling. It has remained an active research area during recent decades (Allegri, 1984; Meller & Gau, 1996; Tarkesh, Atighechchian, & Nookabadi, 2009). Previous studies have shown that material handling cost has significant impact on plant’s operating cost. According to American Society of Mechanical Engineers, Material handling is defined the art and science dealing with the movement, packaging and storing of substances in a form. The equipment used in material handling influences the productivity of manufacturing (Jiamruangjarus & Naenna, 2016). It is estimated that material flow cost contributes from 30 to 70% of the total manufacturing cost, subject to the type of industry (Dongre & Mohite, 2015; Immer, 1953; Matson, Mellichamp, & Swaminathan, 1992). The operation cost during manufacturing can be reduced from 15 to 30% by well-organized material handling (Sule, 1994; Tuzkaya, Gülsün, Kahraman, & Özgen, 2010). Thus, it is critical that the location of machines/workstations should be arranged in a way that reduces the distance travelled by personnel or material handling (Heragu, 1992). Most literature for layout design problem falls into two major categories, algorithmic and procedural approaches. Table 1 compares both these approaches.

Layout generation and evaluation is often considered as time consuming and difficult task. This is because of two reasons. First, the extensive data collection process at the initial stage. Second, the multiple objective nature i.e. the best layout is selected after a trade-off between a combination of actual production requirements (Lin & Sharp, 1999a, 1999b). Examples include overall integration of all functions, minimum material movement, smooth work flow, effective space utilization, employee satisfaction, safety, flexibility, etc. (Rooot & Rakshit, 1993). The prioritization of the facility layout objectives decides the suitable approach to pursue (Aleisa & Lin, 2005). It is significant to evaluate long-term effects of modification before any change in facility layout. The new layout should justify the expense occurred during the rearrangement of machines/departments (Sule, 1994). Vollmann and Buffa (1966) investigated critically the assumptions involved in modification of layout. When following procedural approach these implications play a vital role in determining the best alternative.

| Table 1. Procedural and algorithmic approach |
|---------------------------------------------|
| **Procedural approach**                      | **Algorithmic approach**                      |
| **Approach**                                 |                                               |
| It is classically defined as a component approach (design process is divided into several steps) (Bock, 2007) | It usually simplifies both design constraints and targets into an objective function, which is then solved mathematically (Yang & Kuo, 2003) |
| **Data Requirements**                        |                                               |
| During the design process, procedural approaches consider both qualitative and quantitative objectives (Padillo, Weyersdorf, & Reshef, 1997). Qualitative data depends on operation requirements including communication need between departments, equipment used for material handling, etc. | Algorithmic approaches usually only involve quantitative input data. Quantitative data comprises production rates, lead times, material routing, etc. Design solutions are simply assessed with comparison to objective function values (Yang & Peters, 1997) |
| **Major studies**                            |                                               |
| The methods of Apple (1977), Reed (1961) and Muther (1973) are highlighted among procedural approaches | Most of the existing literature is based on algorithmic approaches (Heragu, 1997). Meller and Gau (1996) classified ninety-one (91) layout models and algorithms |
| **Limitations**                              |                                               |
| Before applying procedural approach extensive experience from designer is required, due to a number of subjective decisions (Bock, 2007) | Advanced mathematical modelling techniques are prerequisites used to develop algorithmic approaches (Tompkins et al., 2003) |
| Layout alternatives obtained from procedural approach are evaluated and compared by various procedures on basis of multiple objective criteria (Sharma & Singhal, 2016; Tompkins et al., 2003) | Modifications are often required in algorithmic outputs to assure design is practical. These include department shapes, utilities supply, material handling systems, ergonomics concerns, work-in-process storage, space utilization, etc. (Yang, Su, & Hsu, 2000) |
The critical objective of layout is to minimize the material handling costs. Two basic sets of constraints in designing a layout are: (1) department space and total floor area requirements and (2) operation boundaries, that is the departments placed within the facility should not overlap, and some departments must be isolated or have a specific position (Meller & Gau, 1996). New layout selection should consider long-term factors such as expandability and flexibility. Expandability is the ability to accommodate future expansions with least cost. Flexibility implies that layouts should be able to adapt future changes in product mix, variation in demand, and upgradation of technology. Both these factors emphasize that layout is not a one-time decision; it should be able to accommodate modifications when needed (Vollmann & Buffa, 1966).

3. Methodology
The benefit of using procedural approach in facility layout problem is that it involves both quantitative and qualitative factors. Thus, for developing plant layout SLP is used. It provides step-by-step guidelines for plant design from input data to evaluation of plant layout. The downside of SLP is that it requires thorough initial research on existing flows, procedures and activities of the facility (Trein & Amaral, 2001). For a detailed discussion and explanation of the technique, readers are suggested reference (Muther, 1973). According to Tortorella and Fogliatto (2008), SLP has three macro steps: (i) analysis, (ii) research and (iii) selection. Thus, SLP is often modified w.r.t system requirement and adaptability (De Carlo, Arleo, Borgia, & Tucci, 2013; Flessas, Rizzarelli, Tortorella, Fettermann, & Marodin, 2015; Lin et al., 2015; Wanniarachchi et al., 2016).

This paper differs with other researches in two ways: (i) it uses simplified criteria for layout alternative selection and (ii) it attempts to estimate the economic benefits of a well-designed layout by comparing previous and proposed state of the facility in terms of production parameters. The research can be further illustrated by projecting the economic and environmental benefits throughout plant life cycle. The approach used in this paper for simplifying SLP is explained in Table 2.

| Table 2. Proposed method |
|---------------------------|
| **Data collection** | **Tools used** | **Detailed approach** |
| (1) Determine plant capacity | PQOIST approach | Use monthly production data for certain period (6 month) |
| (2) Analysis of operations | Work and method study tools | Identify waste using flow process chart and use manufacturer’s catalogues for spatial requirement of machine |
| (3) Materials flow | From-to chart | By multiple factory tours |
| (4) Relationship between depts | Mileage chart with grade criteria | Include the needs for communication and logistics flow between departments |
| (5) Spatial requirement | Space relationship diagram | Identify total area for each department including aisles and ergonomics |
| (6) Layout alternatives | Simulate for material flow | Characteristics of each layout are evaluated on basis of material flow |
| (7) Selected layout | Convert block into factory layout | Machines and transportation path are placed to transform plant layout |
4. Analysis of switch gear manufacturing facility
This study is related to a medium-scale manufacturing facility which is planning to modify its existing layout for improved productivity. The facility manufactures switch gear which is a customized product and is used to regulate (control) voltage and current. The switch gear facility occupies 87.891 × 60.627 m². Some major components of switch gear are galvanized steel frame, copper bars, CTs (current transformer), bus bars and general items which include mechanical components, etc. Each switch gear consists of four sub-assemblies. These sub-assemblies are manufactured by different departments and then assembled at main assembly line. The sub-assemblies include pre-fabrication, copper shop, vacuum circuit breaker (VCB) and wiring shop.

Pre-fabrication includes nibbling and bending machines and weld, grind and paint shop. The facility has two nibbling and three bending machines. Thus, pre-fabrication operate on batch production for effective sheet utilization. Based on operational requirements it is considered as deafening area and it is preferred to place it away from other departments. The second sub-assembly is prepared by copper shop. It comprises two machines; copper bend and copper cut. VCB shop contains jigs/fixtures against which components are assembled to make VCB. Wiring shop produces instrument box. This shop is responsible for circuit making and wiring. The facility has one main store which receives and inspects the incoming parts. Kitting Area is a small store which holds the raw material required for the weekly production of wiring shop and assembly line. Copper bars and steel sheets are stored in racks inside their shops. Finally, customer area is the heritage of switch gear facility. It is a place which is dedicated to hold the latest and previous switch gear models from where customer select and place its order.

4.1. Step 1: PQRST analysis
Step 1 begins with PQRST analysis for the overall production activities. This includes P (product), Q (quantity), R (routing), S (supporting) and T (time). The facility manufactures two types of switch gears i.e. MV (medium voltage ranges between 630 and 2,500 A) and LV (low voltage ranges between 25 and 40 kA). Both products have several types and variants. MV has more than 15 categories which differ in physical size, structure (geometry), along with functional design (interior) and components.

In this phase 6 months data was collected. The lead time of a switch gear varies between 3 and 5 days. The operation time is 22 h approximately. Thus, the existing layout dimensions, equipment, utilities, number of workers and machinery involved were plotted using CAD software. The 3D layout contains all distinguishing features of plant including pillars, floor coating, workstation, machine area, tables, logistics, etc. as labelled in Figure 1. There are total nine functional areas in the facility which are mentioned in Table 3.

4.2. Step 2: activity relationships analysis
For determining activity relationship, outline process chart was constructed by observing the actual line for weeks in random shifts. Activity charts for individual departments (inside shop flow) were also investigated which are not presented here.

4.3. Step 3: flow of materials analysis
This step involves the analysis of flow of materials throughout the production. In this step from-to chart is constructed which represents the flow intensity and interaction between different production departments as explained in Table 4. The numbers in from-to chart matrix indicate flow intensity (trips) required for manufacturing one switch gear. From-to chart is also transformed in flow diagram as shown in Figure 2.

4.4. Step 4: relationship diagram
Relationship diagram establishes relative positioning decision among the functional areas. Even though from-to chart acts as basis for department orientation but material flow is not necessarily the only reason. For this purpose mileage chart is constructed. A number(s) entered below each
relationship give reasons for assigning the code. Thus, flow diagram is converted into relationship
diagram as shown in Figure 3. It offers an overview of the closeness relationship along with practical
constraints and act as priority for design alternatives.
4.5. Step 5: space requirements/available analysis

These steps decide the amount of floor space assigned to each department. This decision is critical to design problem due to expensive floor space and plays vital role in future expansion. In step 5 respective function and area of each department is calculated as explained in Table 5. The switch gear facility is divided into five major departments. These departments work simultaneously and are dependent on each other. It is noted that this floor space area not only comprises the machinery and operation space but also includes the required support activities space such as maintenance.
human–machine interaction and material handling equipment. Figure 4 depicts space relationship diagram through mapping each department size in accordance with material flow.

4.6. Steps 6: layout alternatives practical constraints
These steps convert the relationship chart into block layout. For switch gear facility following constraints are incorporated:

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**Figure 4. Space relationship diagram.**

**Figure 5. Layout alternative.**

- a) Alternative i
- b) Alternative ii
- c) Alternative iii
- d) Alternative iv
Grinding and paint shop should remain isolated from facility and office area. This is because of the hazardous nature of chemical used in these shops.

The sub-assemblies VCB and testing field location should remain in close proximity.

Wiring shop should be placed adjacent to pre-fabrication.

After applying the constraints on mileage chart, new layout alternatives are developed as shown in Figure 5.

### 4.7. Step 7: evaluation

Layout alternatives are evaluated as explained in Table 6. The criteria comprise two aspects:

(a) No. of departments adjacent to logistic centre: this is a part of Kaizen philosophy and is important for implementation of lean tools including on-line inspection (jidoka), kanban and JIT.

(b) Overall material flow minimization: for productivity improvement and minimizing idle time (seven waste elimination), material flow is estimated for each alternative for production of one switch gear.

Therefore, layout alternative iv was selected and block layout was modified by placing actual shops and machines as shown in Figure 6.

**Table 6. Layout alternative evaluation**

| Switch gear layout | Number of adjacent departments | Overall material flow (m) | Remarks and problem highlights |
|--------------------|-------------------------------|---------------------------|--------------------------------|
| Alternative i      | 6                             | 115                       | Bending 3 and paint shop are far away from logistics |
| Alternative ii     | 7                             | 92                        | Paint shop and logistics are distant which will increase idle time |
| Alternative iii    | 8                             | 84                        | VCB and store are remote. This increase the material flow and accessibility |
| Alternative iv     | 9                             | 76                        | Maximum exposure to logistics results in improved material tracking |

Figure 6. New plant layout.
5. Results and discussion

Overall distance travelled (i.e. material flow) during manufacturing a single MV panel for the previous layout equals 115 m (approx.). Using lean tools major non-value adding activities were identified. The previous layout is improved by the rearrangement of pre-fabrication machines. The formation of logistic centre eliminates, delays and minimizes transport because of its central location. For better utilization of outside space CT centre is constructed. CT sorting, the activity which consumes the most of non-value added time is now minimized by implementing lean tool “5S” at CT centre. Thus, using SLP along-with lean tools overall material flow efficiency is improved significantly. The impact of this efficient material flow can be projected on various aspects. These include decreasing lead time, increasing production rate and cost reduction per MV panel. These estimates are calculated for each alternative as explained in Table 6 (Figure 7). Average walking speed is considered as 1.2 m/s or 4.0 ft/s (Manual on Uniform Traffic Control Devices for Streets & Highways, 2003).

The distinguishing features of new layout are stated below:

1. Logistics centre is introduced in future layout. It will be responsible for feeding individual stations timely by using a trolley system. After pre-fabrication it stores the steel sheets and copper, and along with CTs and GK (General Items) it will collect, hold and bring all necessary items to production line.

2. CT centre is an area where now all CTs are arranged on basis of three major functions that are current ratio, insulation and number of cores. After sorting the required CTs they can now be directly feed into the MV line.

3. The pre-fabrication machines (steel nibbling and bending) are re-arranged. This new formation increases the percentage of forward moves.

| Evaluated layout | Material flow (m/panel) | Lead time (h/panel) | Production rate (panel/yr) | Transport cost per panel ($) | Cost reduction per panel ($) | Cost savings per yr ($) |
|------------------|-------------------------|---------------------|----------------------------|-----------------------------|---------------------------|------------------------|
| Existing         | 125                     | 22                  | 218                        | 40                          | 0                         | 0                      |
| Alternative i    | 115                     | 20.24               | 237                        | 34                          | 6                         | 1,460                  |
| Alternative ii   | 76                      | 13.38               | 359                        | 15                          | 25                        | 9,050                  |
| Alternative iii  | 84                      | 14.78               | 325                        | 18                          | 22                        | 7,125                  |
| Alternative iv   | 92                      | 16.19               | 296                        | 22                          | 18                        | 5,437                  |
6. Conclusion

Layout enhancement of a production plant is a common problem. Although, the use of SLP provides sequential steps to develop layout; it is generally considered as slow and time consuming process. The case study of switch gear facility presented in this paper consumed six months to depict the existing state and propose the new layout. This study attempts to illustrate the use of modified SLP procedure and also uses a simplified approach in layout selection criteria. The new layout successfully increased the overall productivity of the facility. Results prove improvement in distance which ultimately reduces lead time and increases value addition. The proposed layout also emphasize on better integration of production departments of the facility (Table 7).

For future research, computer aided simulation software such as witness can be employed for a detailed “before and after” comparison. The simulation should illustrate real-time results of factors including capacity utilization, machine idle time, labour efficiency, etc. Since material flow has a direct influence on fuel (diesel) use. Thus, the findings of this study can also be used to examine the layout from a “green factory” perspective i.e. estimation of decrease in greenhouse gas emission throughout the plant life cycle.

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