Introduction

Designing a manufacturing facility layout may become a significantly complex undertaking, depending on the number of factors affecting the performance of the facility, as well as the variability of relevant data required to conduct a sound, logical, and systematic study. This complexity, however, can be reduced somewhat by breaking down the overall project into sections or tasks which will be more easily managed. In this textbook, the factory layout and material handling design project is divided into six sections. Following a well-defined approach the information from these sections, once completed, will be synthesized and integrated into a final layout.

The purpose of the first section is to gain a fundamental understanding of the product or products which will be manufactured at the plant. Without a detailed knowledge of a product and its components, any further work will be shadowed by uncertainty concerning the feasibility or desirability of a proposed layout. Four information components provide the essential knowledge required in Section I: production drawings, assembly drawing, parts list, and assembly flowchart. Production drawings document the shape and dimensions of those specific parts to be manufactured. These drawings shed light on actual manufacturing operations required. Assembly drawings show the relative position of the individual parts in the final assembly. The parts list indicates which parts are purchased or manufactured, and summarizes the quantity of each part in the final product. It may also includes special remarks relevant to a specific part (for example, weight, material, or special fabrication processes). The assembly flowchart documents how the individual parts are linked together as subassemblies, and how the subassemblies and major assemblies become the final product. Inspections are also usually indicated in this chart.

Once the essential information on the product is obtained from Section I, it must be decided how to actually manufacture each part chosen for fabrication. The purpose of Section II is to document the corresponding operational sequence required to manufacture each part. The document summarizing this information is known as a production route sheet. For each operation listed on all route sheets -one sheet for each part or subassembly- specific machine types, brands, models, and capacities need to be determined and indicated. Additionally, where appropriate, the specific type of material required and the corresponding quantity needed in each operation must be documented. Evidently, machine and material requirements are dependent upon a pre-determined capacity at which the plant is expected to operate.
After having decided what product or products will be manufactured and which operational sequences will be required, Section III focuses on how the parts and materials will be moved within the plant. The required material handling system can be identified with the aid of layout planning charts and material requirements tables. Layout planning charts document fabrication operations, moves between manufacturing departments or to individual workplaces, storage operations and inspections. For fabrication operations (either treating or assembling operations), these charts also summarize relevant information, such as standard times, machine types and quantities, manpower requirements, and material handling equipment. Since the layout planning charts force a detailed analysis of every move of each individual part, the task of selecting material handling systems that will effect a good material flow throughout the plant is made easier.

As decisions concerning machines, materials, and handling systems are made, the associated costs are also computed to aid in estimating the total operation cost of the proposed plant. An important variable cost not yet considered is the personnel cost. Specifically, the purpose of Section IV is to identify the type of personnel required along with the corresponding cost. It should be remembered that production personnel (mostly machine operators and assembly workers) is only a portion of the total plant staffing requirement. Indirect costs, such as those associated with management and office personnel, can be established on the basis of an organization chart. Support personnel, such as janitors and nurses, should also be included. Once the staffing requirements are completed, expected salary determinations can be made. The total personnel cost can be computed after considerations are made for benefits besides the salaries.

Once Sections I through IV are successfully accomplished, there is enough information to begin developing an actual layout of the plant. This is the most important phase of the entire planning function, since the layout determines the following critical elements of the overall facility design: (a) how much space will be allocated to each planning department; (b) relevant material flow or closeness relationships between different departments; (c) location of manufacturing equipment and personnel. This is also the stage where all final details, such as restroom, office equipment, shipping and receiving areas, etc., are established. As a check to determine the suitability of the proposed layout, a material flow overlay should be made to trace the path of the individual parts throughout the plant. Any major problems with the material flow will be highlighted by this chart.

The physical arrangement of workstations and the determination of the associated material flow overlay will bring the layout process to a conclusion. This process provides an effective picture that shows what the plant will be like and can be used to communicate a wide variety of manufacturing information. At this point, both the total annual cost of the plant and the per unit cost can be calculated in order to provide significant input for the decision of building or not the plant.

As previously indicated, this is a design course where the knowledge learned in a number of engineering courses, especially those in the area of industrial engineering, can and should be integrated to develop an effective and efficient plant layout. This project
can be accomplished by groups of three to four students. It is intended to be a factory design simulation exercise that includes all significant phases a real-life process. Students are expected to apply some analytical techniques and computerized procedures discussed in the course to enhance their decision-making process and justify some of the most challenging courses of actions.

**Computerized Format Files**

The sample formats for each section’s result are shown in the appendices (please refers to the table of contents for the respected format). However, the formats files can also be downloaded from the 416 web page.

**Project Overview**

In the first session of the laboratory design project, each group of students disassemble the device for which a facility layout is going to be designed. All parts are identified and enlisted in the parts list provided by file s1pl.doc. Most of the parts are manufactured and a few of them will be purchased.

The route sheets for the parts to be manufactured in the facility are prepared and documented in the s2rs.doc template. These sheets contain the standard times needed for each manufacturing operation or process to be performed. These standard times enable us to estimate the machine requirements, which will be documented using the s2mrt.doc template. The necessary equipment will be purchased after carefully reviewing possible vendors. The costs for the machinery will be tabulated using the s2mct.doc template. The materials required for the fabrication of various parts are documented in the s2mmr.doc template.

Layout planning charts are detailed documents that contain essential information on various steps followed in the manufacturing or assembling of parts. These charts are prepared using the s3lpc.doc template. Layout planning charts identify material handling requirements and costs documented in the s3mht.doc template.

The factory direct and indirect personnel along with the associated salary information will be documented using the s4prc.doc template.

The Plant Layout Summary template (summary.doc) is designed for documenting all cost components of the project. This summary is useful in analyzing total annual costs, unit costs, and profit margins.

**Project Report**

A report documenting all procedures and findings must be written using a word processor, such as MS Word 6.0. A template document and templates for all required tables will be provided in computer files that can be easily accessed by the students. These templates have been designed using MS Word 6.0 and can be efficiently modified by the students to include specific relevant information on their application.
The report must include a title page (see the document template), a summary sheet, an introduction section, and additional sections to document the specific achievements of each of the six sections of the factory layout design project. A final section of the report should be devoted to an overview of work done, conclusions, and recommendations. Sample calculations as well as additional relevant material should be placed in an appendix. After each section of the project is finalized, the report should be submitted for grading and recommendations on how to improve it.

**Section I: Product Analysis**

<table>
<thead>
<tr>
<th>Production drawings</th>
<th>Assembly drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts list</td>
<td>Assembly flow charts</td>
</tr>
</tbody>
</table>

The design project begins with the collection of information that will serve as the foundation for any future analysis in the factory layout design process. The specific purpose of this section of the project is to provide adequate answers to the following four questions: (1) What product will be manufactured? (2) What parts does the product have? (3) Where are these parts obtained from? (4) How are the parts going to be used to manufacture the product? The required relevant information will be classified as production drawings for individual parts, an assembly drawing for the product, the corresponding parts list, and an assembly flowchart.

The production drawings provide essential information about the shape, dimensions, materials, and other relevant manufacturing-related aspects on those parts to be produced. This information can often be used to provide some details that help in the selection of the manufacturing processes and operations that will be required. The assembly drawing shows an exploded view of the product. It helps to visualize how the individual parts are put together in the final assembly.

The parts list provides a summary of all the parts needed for an assembly. It shows manufactured parts as well as those purchased, along with the required quantity of each part in the final product. The list also includes special remarks, if any, relevant to specific parts.

The assembly flowchart serves as a graphic representation of how to assemble the entire product. The chart shows how the individual parts become linked in sub-assemblies and major assemblies as the final product is put together. Inspections are usually shown in this chart.

As the above data is obtained, a broader understanding of the product develops. This information serves as a knowledge base for the layout designer and can be used to effectively proceed into the initial stages of the desired plant design.
**Production Drawings**

There is no realistic way to design the layout of a plant without knowing the product in detail. As a growing number of factors enters into the decision-making process to determine the specific operational sequences required to manufacture each individual plant, the production drawings become a more and more invaluable tool to the layout designer. Besides detailing the physical dimensions of the parts, these drawings also give information on materials, tolerances, and surface finishes.

The assembly drawing, while not showing how the product is put together, does show the relationship among the parts. It will be useful later on when decisions are made about specific ways to assemble the final product.

At this stage of the project, each team -consisting of three to four students- should have a mechanical device disassembled. The decision must be made, and verified by the instructor, as to which parts will be manufactured, and which parts will be purchased. Only 20 parts need to be considered individually, with all other parts regarded as a kit. Each team must manufacture 12 parts and purchase 8 parts. Once this decision has been made, each team is required to make detailed sketches of the parts to be manufactured, with each team member drawing an equal number of parts on AutoCAD. The sketches must show all the dimensions with accuracy within one thousandth of an inch. These sketches may not be to scale, but must be proportional. Plot these drawings on regular letter size paper (8.5”x11”).

**Parts List and Identification System**

The parts list not only does indicate which parts are to be manufactured or purchased, but it also provides the quantity needed, types and quantities of materials required, and special manufacturing-relevant remarks for each specific part. Each part is listed along with an identification code, which can be useful in tracking the parts to expedite the process of finding more detailed information on any part. The cataloging, storing, and manufacturing routings (machining sequences) information can be enhanced through the use of this coding system.

The parts list is essentially a table with a heading including the name of the product and one row for each part. Typically, a parts list table has the following content on each row: part identification code, part name, quantity, material, weight, and the indication that the part is either manufactured or purchased. The identification system must be designed and fully explained. File s1pl.doc contains the format of the parts list.

**Assembly Flowchart**

The assembly flowchart provides a graphical representation of how to assemble the entire product. It helps to visualize the flow of components entering into a product and shows the logical sequence of assemblies, sub-assemblies, and inspection stations. In this chart each assembly stations are usually denoted by circles labeled sequentially as A1, A2, A3, ... Similarly, sub-assembly stations are denoted by smaller circles with labels SA1, SA2, SA3, ... Inspection stations are represented by squares labeled I1, I2, I3, ...
The basic function of an assembly flowchart is to show the sequence of operations and inspections in an assembly process. One of the parts must be chosen and designated as the base part. The base part should be the one which would logically be picked up first, and to which all other parts are sequentially attached. The assembly chart graphically depicts the sequence of assembly operations and inspections from start to finish, including packaging and shipping. Included on the assembly chart is the company name and product, each individual part name and number. The assembly flow chart can be drawn on 10"x16 " paper using AutoCAD.

Section II: Parts Manufacturing

Manufacturing route sheets
Machine requirement table and costs
Material requirements table and costs
Machine drawings

The design of a manufacturing facility can be viewed as a logical progression of steps. After the initial planning of what parts are to be produced in the plant, the production drawings and the assembly flowchart are studied in detail to determine how to best produce the parts. In this section of the facility layout project specific manufacturing processes and operations must be identified in an efficient sequence to produce each part. These sequences are documented in route sheets.

The layout designer needs to determine the specific type and capacity of every machine required for conducting the operations listed in the route sheets. Once the machine requirements are consolidated by type, specific machine brands and models are selected from the market that best suits the plant’s expected needs.

The material requirements for the plant can subsequently be assessed by using information from both production sketches and production routings. In this assessment any losses due to scrap should be included, since the cost of the scrap contributes, sometimes significantly, to the overall cost of the product. Usually the material requirements and associated per-unit material cost are expressed on a weight basis.

Both the machine and material requirements are contingent upon the capacity at which the plant expects to operate. These data along with a good approximation of the future cost involved will bring the plant layout one step closer to reality.

Route Sheets

The format for the route sheets is available in file s2rs.doc. Each sheet shows the sequence of fabrication and assembly operations required to manufacture a particular part. The route sheet for the base part includes the entire assembly process. However, the sheets for the other parts do not need to show the entire assembly process because, typically, parts are taken to storage facilities after being manufactured and are later retrieved to form sub-assemblies.
Route sheets are important because they contain critical information required to perform further analyses, such as the determination of machine and material requirements. Typically, route sheets contain the following information:

- Part name and number
- Drawing number and lot size
- Operation number
- Operation description
- Jigs, fixtures or tools required for operation
- Machine type
- Standard time and machine capacity/hour
- Material requirements (type and quantity)

**Machine Requirements and Costs**

This information is summarized in a table which lists the total number of machines required, by type, to manufacture each part. Specific machine brands and models are indicated, along with their costs and space requirements.

The total cost of the machines represents the initial capital investment, while the annual cost reflects the depreciation of the machines over a specified multi-year period. The expected salvage value of all machines is usually expressed as a percent of the initial cost. In the calculation of the total cost per machine all shipping and handling charges, installation fees, and all other costs associated with making the machine operational must be included.

**Machine Requirements**

The format for the machine requirements table is available in file `s2mrt.doc`. This format is designed for detailing and summarizing the number of machines required by part number and operation number. Machine requirements will be calculated on the basis of an availability percent, a specified number of set-ups per day along with the corresponding set-up times, required production volume, the length of the daily production period, and the standard time of the machining operation.

The availability percent indicates the fraction of a production period during which the machine is up for working on a particular part of the given product. In the absence of a more accurate figure, it can be assumed that machines will be available to do work 90% of the time, with the remaining 10% of the time being required for maintenance and repair works. In the layout design project, each group will assume that one daily set-up taking 0.20 hours will be required per machine. Additionally, if not specified otherwise, the plant will be assumed to operate during eight hours on each work day.

The fractional number of machines needed can be calculated using the expression given below:
\[ N = \frac{Pt}{(H-s) p} \]

where the following notation has been used:

- \( N \) = number of machines
- \( P \) = daily production volume
- \( t \) = standard time
- \( H \) = available time
- \( s \) = set-up time per day
- \( p \) = availability factor (as a decimal fraction)

As a sample calculation, it is assumed that the production rate is 1600 pieces per day and that the standard time of a particular machining operation is estimated to be 0.015 hours per piece. Using the above formula, the fractional number of machines is computed as \( N = 1600 \times 0.015 / ((8 - 0.20) \times 0.90) = 3.41 \). If an integer number is required, \( N = 4 \) machines must be purchased.

**Machine Costs**

The general format of the machine cost table is provided in file `s2mct.doc`. This format allows the listing of each machine along with a short description, the number of identical machines required, space requirement per machine, purchase cost per machine, and the total cost of identical machines. The overall annual depreciation cost for all machinery will be computed using the straight-line depreciation technique, although other techniques will be acceptable. If not specified otherwise, it will be assumed that the service life of the manufacturing equipment is 15 years and the corresponding salvage value is 10% of the purchase cost. As a sample calculation, if the total machine cost is $1,200,000, the annual depreciation cost will be estimated as \( (1,200,000 - 120,000) / 15 = \$72,000 \).

**Material Requirements**

The format of the material requirements table is provided in file `s2mmr.doc`. The table shows the amount and type of each material used to manufacture each part. Material requirements and material costs are given on a weight basis. The total amount of each type of material should include the corresponding scrapped quantity. As an example, material requirements for parts cut from sheet stock must allow for the blank size and the quantity scrapped. Whenever appropriate, purchased items are given on a cost per unit basis.

**Machine Drawings**

Layers are an important and necessary component of AutoCAD drawing. Machine drawings must be plotted using a 1/4"=1' scale and should include the following layers:

- Layer #1: Outline of machine
Section III: Layout Planning

After determining in Sections I and II what products will be manufactured and how they will be manufactured, respectively, emphasis must be now placed on how to efficiently move parts and materials within the plant. Material handling is basic to all manufacturing processes. Raw materials must be delivered to the proper places where they will be processed and the final products must be stored and then distributed to the customers. This is a function that cannot be avoided, but can always be improved.

The specific purpose of this section is to generate three types of documents: layout planning charts, material handling requirements, and material handling costs.

The layout planning charts allow an integrated analysis of every operation, move, storage, and inspection that take places in the process of transforming raw materials into components of the product to be manufactured. Once the material handling requirements have been established, specific equipment and accessories need to be identified. At this time, the cost due to material handling can be determined. The specific material handling systems and associated costs can be summarized in tabular form along with a total material handling cost figure.

Layout Planning Charts

One of the most important tools the designer uses in defining the material handling requirements of a plant is the layout planning chart, available in file \texttt{s3lpc.doc}. This charts documents the sequence of operations performed on a particular part. In this sequence the following operations are considered:

- Fabrication (F)
- Move (M)
- Storage (S)
- Inspection (I)

Along with each operation, the chart specifies the time per piece required for the action, the machine type and required number of machines, the manpower requirement, and the material handling requirements.
By analyzing each operation in the sequence documented on a layout planning chart, the designer is forced to determine how often a type of operation (F, M, S, I) takes place, the most effective type of facility required by the operation, and the associated manpower requirements. In particular, the information on type of moves, frequency of moves, origins and destinations of moves, quantities being moved, and time required by each move, is essential to decide what is the most effective and efficient material handling system, as well as to balance machine utilization and manpower.

**Material Handling Requirements and Costs**

One of the most important decisions made during the design of a plant is the selection of material handling systems to effect a good material flow throughout the plant. The layout planning charts are useful in determining what methods might best be used. Typical material handling equipment can be classified as conveyors, hoists/cranes, and industrial trucks.

A preliminary sketch of the proposed layout often helps to understand specific requirements of the material handling system. For example, it helps to better visualize machine interactions and provides a basis for later on selecting the specific type of equipment needed, its size, its capability, etc.

The cost of the individual components of the material handling system are itemized in the material handling requirements and costs table, available in file s3mht.doc. The total cost of each piece of equipment should include shipping and handling charges, installation fees, and all other costs required to make the equipment operational. The table also shows the annual cost (depreciation) of each piece of material handling equipment. The material handling cost per unit of product is determined by dividing the total resulting from the consolidation of all equipment annual costs by the annual production volume. If not otherwise specified, in this project it will be assumed that the service life of the material handling equipment is ten years, and the salvage value is 10% of the purchase cost.

As an illustration of the computation of the material handling cost per unit, a tow line will be considered. It is assumed that the required length is 900 feet. Moreover, the cost per foot is $21, and the installation cost per foot is 40% of the purchase cost. As can be verified, this results in a cost equal to $26,460. The salvage value can be estimated as 10% of the purchase cost, $18,900. On the basis of this, the annual cost is calculated as $(26,460-1,890)/10 = $2,457$. If, after proceeding in this manner, the total cost for all equipment is $113,046, the corresponding material handling cost per year will be equal $(113,046-40,166)/10 = $7,288$. Moreover, if the annual production volume is 260,000 units, the corresponding cost per unit will be $7,288/260,000 = $0.028$. 


Section IV: Personnel Planning

The purpose of this section of the project is to estimate personnel requirements, personnel costs, and to calculate the cost per unit for the first operating year.

By using the layout planning charts developed in Section III, the number of people directly necessary to produce the required units of finished product each week can be determined. The production personnel, however, is only a portion of the plant's total staffing requirements. It is recommended to use the organizational chart of the company to aid in the determination of indirect (management and office) personnel needed. This includes the plant manager, supervisors, engineers, accountants, maintenance staff, sales persons, etc.

As various stages of the plant design are completed, the corresponding cost components are identified and quantified. Still, questions concerning the profitability of a product cannot be answered until the entire cost per unit has been calculated. The cost per unit for the first operating year is based upon material, material handling equipment, machine requirements, and personnel costs.

Personnel Requirements and Costs

The personnel requirement costs table is provided in file s4prc.doc. The exact number of people required to achieve the desired production level as determined in Section II must be established at this stage of the project. All personnel requirements documented in the layout planning charts of Section III are consolidated by type. It is noted that this total does not include any indirect labor, such as supervision, engineering, personnel management, payroll and accounting, medical services, sanitation, maintenance, etc. The costs (salaries) for all personnel should be estimated based on current day wages, cost-of-living, and inflation rate.

Unit Costs

The labor cost per unit can be calculated by dividing the total labor cost per year by the annual production volume. This can then be added to the cost per unit of machines, materials, and material handling equipment, all of which have been previously determined. The cost per unit for the first operating year is a very useful piece of information, because it is the basis on which the selling price can be determined after adding the desired profit per unit. The cost per unit can also serve as an index that management can use to track the cost components of the product.

The following table provides an adequate way to summarize the components of the total per-unit cost. Hypothetical figures are shown in this table.

Unit Cost Summary
<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Annual Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machines</td>
<td>$0.36</td>
</tr>
<tr>
<td>Materials</td>
<td>$3.54</td>
</tr>
<tr>
<td>Material handling</td>
<td>$0.08</td>
</tr>
<tr>
<td>Personnel requirements</td>
<td></td>
</tr>
<tr>
<td>Management and office</td>
<td>$10.70</td>
</tr>
<tr>
<td>Factory direct</td>
<td>$10.23</td>
</tr>
<tr>
<td>Factory indirect</td>
<td>$5.60</td>
</tr>
<tr>
<td>Total cost per unit</td>
<td>$30.50</td>
</tr>
</tbody>
</table>

**Section V: Office Layout**

The purpose of this section is to determine how the offices should be arranged to efficiently accommodate the personnel identified in Section IV. Offices will be physically arranged according to the importance of personnel relationships.

After determining several alternatives to link workstations into offices, a recommended office layout must be generated using AutoCAD. An alternative office layout must be proposed by each member of the project team. Each drawing should be done using a 1/4”=1’ scale and should represent a 50’x60’ area (approximately). Note that small items do not need to be drawn at scale. The build-up wall should be 6” thick. The **minimum** items required for the office layout are:

- Offices
- Furnishings
- Door swing
- Conference room
- Reception area
- Restrooms
- Workroom with storage and copying capability
- Identification of equipment, areas, and offices
Section VI: Recommended Plant Layout

A substantial number of hours of planning and analysis go into the design of a manufacturing facility. One of the final stages before the construction phase is the development of a layout of the plant showing a material flow overlay. This allows the planner to see how the plant will actually look, and to make adjustments and last-minute changes before the plant is built.

Perhaps to a greater degree than any other engineering discipline, industrial engineering means the “reengineering” of the factory floor. Indeed, the development of an effective and efficient floor plan for the proposed facility is usually considered the most important step in the plant layout process. This is because the layout defines how much space area will be allocated, the physical relationships between different areas, and where each piece of equipment and each person will be located. This is a time consuming task since the optimal location for each department or each piece of equipment is often not readily apparent. Additionally, the size or shape requirements of the building might have to be taken into account.

Some of the details that have to be accounted for and have not been previously planned are desks and office equipment, first-aid, lunch facilities, and restrooms. The number of fire extinguishers and water fountains needed and their location must be chosen.
Appendix I: Section I

- General Format of Parts List
- Parts List Sample
- Part Drawing Sample
- Assembly Drawing Sample
- Assembly Flowchart Sample
Appendix II: Section II

- General Format of Route Sheet
- Route Sheet Sample
Appendix III: Section II

• General Format of Machine Requirements Table
• Machine Requirements Table Sample
Appendix IV: Section II

- General Format of Machine Costs Table
- Machine Costs Table Sample
- Machine Drawing Sample
Appendix V: Section II

- General Format of Material Requirements Table
- Material Requirements Table Sample
Appendix VI: Section III

- General Format of Layout Planning Chart
- Layout Planning Chart Sample
Appendix VII: Section III

- General Format of Material Handling Requirements and Costs Table
- Material Handling Requirements and Costs Table Sample
Appendix VIII: Section IV

• General Format of Personnel Costs Table
• Personnel Costs Table Sample
• Corporate Structure Sample
Appendix IX: Section V

• Office Layout Sample
Appendix X: Section VI

• Plant Layout Sample
Appendix XI: Plant Layout Summary Sample