Title: Case Study: Automobile Final Assembly Plant

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Abstract: This case study requires the student to consider the problems and issues involved in the design of a final assembly plant in the automotive industry. Data and information are presented by which the student must determine: (1) the number of workstations required on the line, (2) the types of conveyor systems and/or other material handling systems required to move the products through the workstations, (3) the length of the flow path of a car as it is being assembled, (4) the amount of time a car spends in the plant during assembly, and (5) the floor space requirements for the plant.

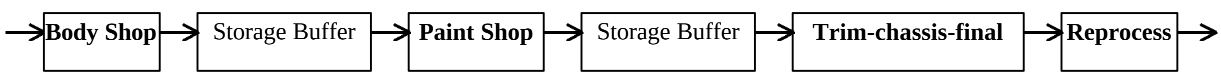
Case Problem: Automobile Final Assembly Plant:

This case problem deals with the analysis of workstation, material handling, and floor space requirements for a proposed automobile final assembly plant. The plant will have a product-flow layout, capable of producing 60 automobiles per hour for 10 hours per day (one 10-hour shift, including overtime), five days per week (a total of 150,000 cars per year). Only assembly will be done in the plant - no parts manufacturing. All components will be delivered from outside suppliers. The plant will be built as a one-story structure, including office space for management, technical, and other staff.

Work Organization in the Plant

Automobile final assembly plants are usually divided into three major departments: (1) body shop, (2) paint shop, and (3) trim-chassis-final. This plant will be organized accordingly. The three departments must all be contained within one building, but the paint shop must be physically separated from the others because of cleanliness, processing, and ventilation problems associated with spray-painting technology. In addition, there will be a fourth department, (4) reprocess, to fix those cars needing repair as they exit trim-chassis-final. Storage buffers with substantial capacities will be installed between the body shop and the paint shop, and between the paint shop and trim-chassis-final. A summary of the work flow is illustrated in Figure 1.

Figure 1 - Major departments and work flow in an automobile final assembly plant.



About a thousand spot-welds are made in the body shop. To begin the assembly, the individual sheetmetal parts, consisting of the floorpans and side panels, are loosely fastened together by human workers. The car body then moves through a series of spot-welding operations, both robotic and manual, to add more parts and permanently assemble the body.

After the sheetmetal body is completed, it then moves into a temporary storage area that serves as a buffer in case of significant downtime delays in either the body shop or the paint shop that follows. From the temporary storage area, the car bodies move into the paint shop, where a series of processes are performed to paint the car body.

The painted car bodies are then transported from the paint shop to another temporary storage area to permit thorough curing and drying of the paint, and to permit proper sequencing of the components that will be added in trim-chassis-final. Cars are produced from customer orders with specific combinations of parts, and the proper parts must arrive at the respective workstations at the same time as the corresponding car bodies.

The car bodies then move to the trim-chassis-final department, where the remaining parts and subassemblies are assembled into the body. These include the engine and transmission, dashboard, seats, tires, and so on. When all of the trim and chassis work have been completed, the cars are ready to be driven off the line. However, in some cases, there are quality problems that must be repaired on the completed automobile. This repair is accomplished in the reprocess department, which is located after the end of the line in trim-chassis-final. It consists of a large open area with stalls in which repairs are made on cars that have quality problems or missing components. There is no conveyor line in the reprocess department since even cars needing rework can usually be driven after completion in trim-chassis-final.

Labor Hours

It takes 20 hours of direct labor to complete the average automobile to be assembled in the proposed plant. The division of labor hours between the three sections of the plant is given in Table 1.

Table 1 - Labor hours in the four departments of the final assembly plant.

Department	Work organization	Labor hours	Variation in hours
Body shop	Manual assembly; then Robogate, followed by robotic and manual welding stations.	2.0 hr	Minor variations
Paint shop	Automated dip tanks, then robotic and manual stations. Repair loop after painting.	3.0 hr	No variation
Trim-chassis-final	All manual stations.	14.0 hr	Range = 12 to 16 hours, uniform distribution
Reprocess	All direct labor.	1.0 hr	Range = 0 to 3 hours, normal distribution with $\sigma = 0.35$ hour.
Subtotal		20.0 hr	

Most of the direct labor is in the trim-chassis-final area. This is typical because the body shop and paint shop are highly automated; the assembly work in trim-chassis-final is difficult to automate. Maneuvering back seats into position, and attaching dashboard assemblies, for example, are difficult for a robot to perform. These operations require a certain sense-of-touch and other skills that only humans possess.

There will be variations in these labor hour values from car to car because of differences in models and options. For a plant that produces several different models, some models will require a larger total direct labor time, others less time. Measures of this variability are provided in Table 1 for each department. This plant will produce two-door and four-door sedans. The four-door models require more time than the two-door models. Options have a significant effect on total direct labor time. Cars loaded with options (e.g., special radio, air conditioning, moon-roof, etc.) take significantly longer to assemble than cars with the standard equipment. The labor hour data in Table 1 are intended to represent the expected average automobile that will be produced in the plant, and these figures should be used for planning purposes.

In addition to direct labor hours, there are also indirect and overhead hours for the plant. The indirect category includes the foremen and supervisors, maintenance and repair personnel, material handling, and other support people. Overhead includes plant management and professional personnel (engineering, accounting, etc.).

Number of Workstations in the Final Assembly Plant

The total direct labor hours must be allocated among workstations located along the line of flow of the cars moving through the factory. With a production rate of 60 cars per hour or one car per minute, this means that the work accomplished at each station must be completed in one minute or less. (The cycle time is the reciprocal of the production rate.)

The total number of workstations in the plant will be influenced by certain factors and by differences in the work performed in the three sections. The following factors must be taken into account in the planning and design computations:

- ***Line balancing*** - It is impossible to allocate exactly one minute of work to each station, because of variations in work element times at the different workstations. Some workers will have work requiring less than one minute. In addition, different automobile models require different total times, and this aggravates the line balancing problem. Options on the cars (air conditioners, special radios, sunroofs, etc.) also complicate the line balancing problem. Balance delay values are given for each of the three major departments.
- ***Manning levels*** - In most cases, more than one worker can be assigned to each station where manual assembly operations are performed. For example, one worker might be performing an operation on one side of the car, while another worker is doing similar work on the opposite side. This reduces the number of manual workstations required on the line. Manning levels are presented for each department.
- ***Level of automation*** - Some workstations are automated using industrial robots and other automated machines. These stations do not add direct labor hours to the car, but they add to the number of workstations on the line. The automated stations are more numerous in the body shop and paint shop than in trim-chassis-final. Details are given for each department in which automation is a factor in the planning process.
- ***Delay sections*** - Some additional stations and sections of conveyor must be allocated to accommodate special (non-workstation) sections of the line such as drying ovens, inventory banks, switches in the conveyor system, and so forth. These stations do not have workers assigned to them. The needs for these areas are described in the case problem. Switches in the conveyor system might be used, for example, to provide repair loops in the regular line.

Material Handling System

Various types of material transport equipment will be used in different sections of the plant. Some areas require continuously moving transport, while others require synchronous transport (also called intermittent transport). For example, continuous transport is required in the trim-chassis-final area, while synchronous transport is required for accurate location in the spotwelding line. Also, there will be some portions of the flow path that are overhead, while other portions are on-the-floor. The overhead portions may be used for in-process storage and movement between the three plant sections. These different material handling systems must be integrated so as to achieve smooth flow of the product from one section of the plant to the next.

Throughout the plant, the car bodies are moved on work carriers. Standard work carriers have been designed to hold the different body styles. All of the transport systems (intermittent and continuous, overhead and on-the-floor) can accommodate the standard work carrier, up to the location in trim-chassis-final where the wheels are added to the car. At this point the cars are removed from the work carriers, and a chain-in-floor conveyor system is used to move the cars from this point to the end of the assembly line. The chain-in-floor system does not utilize work carriers. Instead, the cars roll on their own wheels. The wheels are added to the car approximately 10 workstations from the end of the line.

A special overhead conveyor system must be provided to move the standard work carriers back to the beginning of the body shop line so that they can be re-used. This conveyor length should not be included in the total flow path length, because the return conveyor length depends on the shape of the plant and where the starting points and ending points of the flow path are located.

The work carriers are 20 ft long and must be separated in their movement on the conveyor system by a distance of 5 ft. The cars themselves are each 16 ft long, and they must be separated by 9 ft. The car bodies are each 6 ft wide, and the work carriers are the same width.

Storage buffers are included at various locations in the sequence of work flow. They provide the automobile assembly plant with a way of dealing with a number of production problems that occur in final assembly. The following paragraphs describe the uses of these storage areas. Storage buffers should be included in the analysis, and space allocated accordingly. The following descriptions indicate their locations.

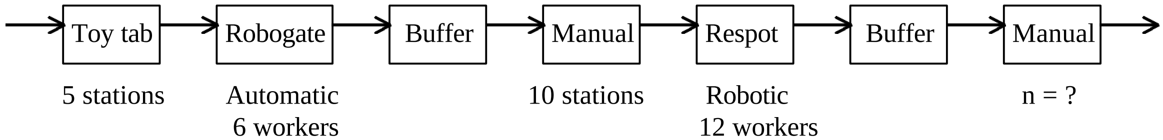
- Storage buffers must be located after automated sections of the welding line in the body shop, so that if one section breaks down, the upstream and/or downstream sections of the line can continue to operate. Details on the requirements of these storage areas are presented in the description of the body shop.
- Car bodies going from the body shop to the paint shop will have a 3/4-hour delay, in case of large downtimes in either the body shop or the paint shop.
- Painted car bodies going from the paint shop to trim-chassis-final will have a 3.5-hour delay. This is required to permit components and subassemblies in trim-chassis-final to be sequenced to be consistent with the car body sequence. Most of the items added in trim-chassis-final are shipped by suppliers near the plant according to a just-in-time discipline. The delay between paint shop and trim-chassis-final allows time for the plant inventory control personnel to organize the components (motors, dashboards, seats, etc.) for feeding to the appropriate stations in a sequence that agrees with the arrival of car bodies down the line.

The Body Shop

Nearly all of the sheetmetal body components in an automobile body are assembled by spot welding. There are approximately 4000 spot-welds on a typical car, about 1000 of which are accomplished in the body shop. The very first operations consist of manually fastening the side panels and floorpan together to form the initial body assembly. This is called "toy tabbing" because the fastening is accomplished by bending metal tabs on the sheetmetal parts. Each car body is then fed through a framing system which fixtures the body and performs a limited number of spot welds to hold the subassembly into this alignment. From the framing system the car bodies are transferred through a series of robotic stations which accomplish additional spot-welds. At subsequent stations in the body shop, the roof, hood, and other sheetmetal parts are added and spot-welded in place to complete the car body. To repair any blemishes, scratches, and rough spots, the bodies then move through a metal finishing section of the line where workers grind and wire-brush the imperfections out and smooth the sheetmetal surfaces.

The body shop is a highly automated department, the automation consisting of robotic spot welding stations at which approximately 800 of the 1000 spot welds in the body shop are performed. An overview of the work flow in the body shop is provided in Figure 2.

Figure 2 - Work flow in the body shop.



The assembly process begins with body side panels and floorpans being launched onto the front of the conveyor line. Toy tabbing is performed at five manual workstations to fasten together the body panels before they move into the framing system.

The framing system, called "Robogate", is 100 ft long and 30 ft wide. Robots and other automated devices are used to accomplish the initial spot welds to make the car body rigid. A total of 200 spot welds are performed in the Robogate. A crew of six workers attends to the Robogate, providing supplies, reprogramming if necessary, and performing maintenance and repairs as necessary. The cycle time of the Robogate is well within the required 1.0 min. production time requirement, even considering occasional downtime.

The Robogate is followed by a storage buffer with capacity of 12 car bodies. This is considered sufficient to maintain an overall production rate at 60 units/hour.

Next in the sequence are ten manual stations which add the remaining parts (roof, trunk, lid, etc.) except doors. No welding is performed at these stations.

The ten manual stations are followed by an automated line consisting exclusively of spot welding robots; it is called the "respot" line. The respot line requires a crew of 12 workers to perform maintenance and repairs when breakdowns occur and to otherwise tend the line. The number of robotic welding stations on the line must be determined from the following. A total of 640 spot welds must be accomplished. Each station will have two robots, one on either side of the line. Repositioning time for each robot T_r = 9 sec. This is equal to the transfer time of the material handling system moving the car bodies between stations. Each robot must be programmed to perform a certain number of spot welds s. The value of s will be nearly the same for each robot. It takes 2 sec for the robot to perform each weld during its service time; thus, $T_s = 2s$, and $T_c = 9 + 2s$. For each station, frequency of failure = 0.0025 (1 breakdown every 400 cycles). A failure stops the line, and average downtime per occurrence = 5 minutes (300 sec). Based on this data, you must determine the number of robots required on the line to achieve the specified production rate.

The respot line is followed by a storage buffer with capacity of 12 car bodies, which is considered sufficient to maintain overall production rate at 60 units/hour.

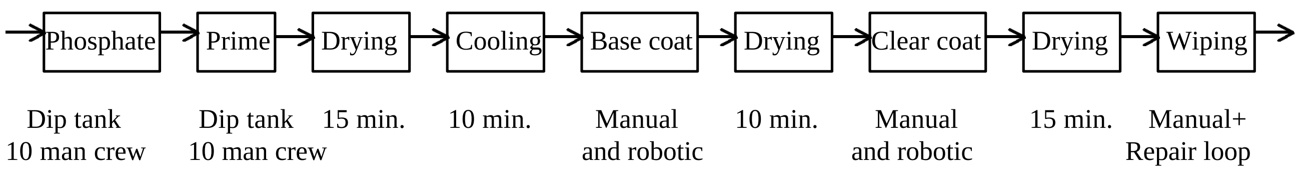
After the storage buffer following respot, a series of manual workstations are used to assemble the doors and other fixtures that must be on the car body prior to painting. This section of the line includes manual spot welding stations that complete 160 spot welds which cannot be accomplished by robots. The section also includes a metal finish section where the sheet metal is cleaned and repaired using grinding and wire-brushing. This step prepares the surfaces of the car body for painting. The manning level in the body shop for all manual stations will average 2.0, the balance delay in this department is expected to be 0.08, and line efficiency (proportion uptime) in the manual portions of the line = 100%. Repositioning time = 0.15 minute; however, this time is included in the total labor hours for this (and other) departments, so it need not be considered in the case problem.

Each station in this department is 25 ft in length and 30 ft wide (12 ft on either side of the line, allowing for the 6 ft width of the car body and carrier. The two storage buffers in this department need be only 12 ft wide which includes an allowance for safety and maintenance. These buffers are to be on-the-floor conveyors. Synchronous transport of car bodies must be used at all stations in this department, but not in the storage buffers. In the buffers, quick access to units in storage is required.

The Paint Shop

In the paint shop, a series of processing steps are performed to prepare and coat the car body surfaces. These steps are: (1) phosphate, (2) prime, (3) base coat, and (4) clear coat. The phosphate process chemically cleans the surface and prepares it to accept the paint coat. The priming operation adds the first coat of paint. Base coating is the coat that provides the color to the automobile car body. The clear coat is applied to enhance luster and complete the coating process. The paint shop is organized into four sections, corresponding to these steps. Between the sections, there are drying and cooling areas. Figure 3 presents the organization of work in the department.

Figure 3 - Work flow in the paint shop.



The phosphate operation is a fully automated dipping process in which the work carriers, with car bodies on board, are submerged in a large tank of chemical solution to prepare the body for painting. The dipping tank is 150 ft long and 15 ft wide. The car bodies are moved through the tanks by continuously moving conveyor. Immediately following phosphate is prime, with 100 ft of conveyor length (by 15 ft wide) separating the two sections. The prime operation also involves submersion of the body, but it uses an electrostatic process to increase the surface coverage of the coating. The prime tank is the same size as the phosphate tank and is also fully automated. Although automated, phosphate and prime each require a crew of 10 people for maintenance and monitoring. These crews are included in the direct labor hours per car allocated to the paint shop.

Following prime is an enclosed drying oven which must permit a total of 15 minutes drying time for each car body as it moves through. The drying oven is 15 ft wide. Another 10 minutes must be allowed for the bodies to cool before going into the base coat line. A width of 15 ft must be allowed for this transport system. The base coat line is a ventilated paint line consisting of a combination of robots and humans to perform the color base coat. Ten minutes are then provided for drying of the base coat before going into the clear coat line. Again, the required design width = 15 ft.

The clear coat line is the same space allocation as base coat. After clear coat, 15 minutes are allowed for drying. The paint drying areas in the plant are 15 ft wide. This is followed by a series of workstations in which the bodies are manually wiped, buffed, and inspected for painting flaws.

Defects are common in the paint shop. Those cars needing repair enter a repair area and are then merged back into the line before exiting the paint shop. This repair area = 10,000 sq ft. Painted cars with defects are simply taken off the regular line, repaired, and then placed back onto the line at vacancies where other vehicles have been removed for repair. These disruptions in the sequence create only minor problems in trim-chassis-final so long as the paint quality level remains high on average. The balance delay and other line factors in the paint shop include the effect of the expected workload in the repair loop.

Not counting phosphate and prime, the average balance delay is 0.10 and the average manning level = 1.5 on the paint shop workstations. Repositioning time = 0.20 minute. The balance delay and manning level include the effect of the robotic stations. The paint department should be planned for a line efficiency (proportion uptime) of 95%. Each station in this department is 25 ft long and 40 ft wide. The extra width is required for ventilation equipment and associated enclosures.

Trim-Chassis-Final

seats, dashboard, windows, and other trim are added. Radios and options such as air conditioning are also added here. Near the end of trim-chassis-final, the engine, transmission, and tires are mounted into the car.

This is the department in which the automobile is completed. Painted car bodies enter the department, and finished cars drive off the end of the line. Motors, wheels, transmissions, steering mechanisms, seats, dashboard, panels, and all of the other trim subassemblies and components are added in this section of the plant. The parts are delivered to the proper locations by overhead conveyors, forklifts, and other mechanized methods.

The department has no automation. The balance delay in this department = 0.15, repositioning time = 0.20 minute, and the average manning level = 3.5. This department should be planned for a line efficiency of 95%. The average station in this department is 25 ft in length and 50 ft in width (22 ft on either side of the conveyor).

Reprocess Department

The reprocess area is used to repair cars that suffer some quality defect or need additional work. Cars coming off the trim-chassis-final line that do not need reprocess are driven directly out of the plant to a large parking lot, from which they will be shipped by rail or truck to various distribution points.

Cars needing rework are driven or pushed to the reprocess area which occupies a total of 40,000 sq ft. The department will consist of a sufficient number of individual stalls to service the defective product. Although the reprocess department is needed, the goal of the company is to maintain a high quality level in the preceding departments so as to minimize the number of finished products needing reprocess.

Office Space

On the plant floor, an allowance of 3,000 sq ft must be provided in each of the three major departments for office space for supervisory, clerical, maintenance, and other factory support staff. No office space is provided in the reprocess department.

The plant must also have a front office for the management, technical, secretarial, and related staff. A total of 100,000 sq ft must be allowed for this office, to be located at the front of the plant. This space includes a cafeteria which is used by assembly workers and office staff.

Aisle, Dock, and Storage Space

An allowance of 35 percent must be added to the floor areas of each of the three departments for aisle space and rest room facilities. These allowances should be added to the total assembly space, not including office space.

In addition, receiving docks must be provided with limited space for temporary storage. A total of 30,000 sq ft must be provided for this purpose near the front of the body shop, for storing and preparing of the body panels prior to launching onto the body shop line. This space is not considered part of the body shop. Another 25,000 sq ft should be provided following trim-chassis-final and reprocess. This space serves as temporary storage for finished product and as overflow space for the reprocess department.

Assignment

The division manager has requested an analysis of the final assembly plant. The analysis should include material handling equipment recommendations for moving the cars through the assembly plant, the number of automated (robotic) and manual workstations required, and plant size. State any assumptions you make in your analysis. Assume no allowance for plant expansion, since any increase (or decrease) in production can be accommodated by increasing (or decreasing) the number of weekly hours of plant operation.