Chapter 6
Manufacturing

6.1 Elements

There are many aspects of an effective manufacturing operation. The products that will be manufactured must be defined. In many cases some components will be manufactured internally, while other components in the bill of materials will be outsourced. Outsource partners must be selected and qualified. The manufacturing process must be designed for internally manufactured components and the integration of all product components.

The process flow must be laid out so that unit operations can be visualized and optimized. Understanding the impact of each process step is critical to accurately define the unit cost. It is not always obvious where the true cost of manufacturing is generated from. The process-flow analysis helps identify the cost drivers. As an example, in the manufacture of optical fiber, increasing the drawing speed by a factor of 3 only decreased the manufacturing cost by 3% since the drawing operation accounted for 7% of the manufacturing cost, while the primary contributions to cost are associated with preforms and testing.

Capacity for current and scale-up needs is clearly tied to the sales forecast. To achieve the forecast, equipment needs based on capacity requirements must include the time to acquire the equipment as well as to set it up and debug it. It is not uncommon for specialized equipment to have lead times for delivery in excess of six months. Manpower needs can have similar time-delay issues associated with hiring and training skilled staff. As capacity requirements increase, equipment and manpower can be better used in expanded shifts. The shift can take many forms, such as the manufacturing shift extending from 8 hours to 12 hours, two complete 8-hour shifts, three 8-hour shifts, or rotating shifts that enable full coverage of the 168-hour week.

Manufacturing engineering has several functions. First, it provides the bridge between product development and product suitability for manufacturing. Second, it provides the necessary engineering to go from prototype to full product and subsequent scale-ups. Third, it impacts product and process variability to improve yield. Last, manufacturing engineering has a strong focus on cost reduction.

Process documentation is an important aspect of monitoring and controlling the manufacturing process. It provides a means to track the product manufacturing, including the material and processes used. Process documentation is a major component of ISO certification.

6.2 Manufacturing Cost

The objective of any commercial manufacturing operation is to build products that have a profitable sale. In early manufacturing, the fabrication costs may exceed the sales price, but order costs must move in the direction of profitability to achieve a sustainable operation. Manufacturing cost should be 45–60% of the selling price to maintain a sustainable profitability. Ganesh Gopalakrishnan points out that optoelectronics manufacturing for the telecommunications industry is falling short of this target with manufacturing costs hovering around 70%, which is problematic for sustaining and growing a manufacturing business.[1] Table 6.1 outlines the cost components associated with manufacturing.

The manufacturing cost is defined as the cost of goods sold (COGS), as shown in the following equation:

$$\text{COGS} = \text{Materials} + \text{Direct Labor} + \text{Factory Overhead}$$

The factory overhead can be one to three times the amount of direct labor. When the labor cost includes the overhead, it is referred to as fully burdened.

6.3 Outsourcing versus Internal Manufacturing

In start-ups there is a tendency to manufacture as many components as possible to protect a proprietary position. Usually, that is not a good approach. It is more efficient to manufacture those components that are associated with core technologies and outsource the manufacturing of noncore components.

Table 6.1 Manufacturing cost components.

Direct	• Material used to directly build the product (bill of materials) • Direct labor

Overhead	• Supervision
	• Manufacturing support
	  ◦ Shipping
	  ◦ Inventory control
	  ◦ Quality control
	• Manufacturing engineering
	• Facility engineering
	• Consumables (indirect materials)
	• Physical plant
	• Physical plant improvements
	• Facility and equipment amortization and depreciation
	• Insurance
	• Utilities

The outsourcing approach allows limited resources to be focused on the core components that provide product differentiation, while outsourcing noncore components eliminates time and the cost of developing "me too" competencies. This implies lower capital and manpower investment, as well as time-compression.

The disadvantages of outsourcing include vendor markup and vendor reliability. It is important to select vendors that can meet cost targets, deliver on time, and scale-up as needed. Vendor quality should be certified to both ensure quality and minimize the cost of incoming inspection.

6.4 Process Flow

A process flowchart with a graphic representation of the major steps in a manufacturing process is helpful to understanding the complete process flow of manufacturing. The flowchart identifies the critical stages of a process and shows relationships between different process steps. It can help identify problem areas such as bottlenecks or inefficient work flow, and provide a basis for optimization. An understanding of the steps in the process and each associated cost provides an accurate basis for estimating manufacturing cost and identifying cost drivers.

Figure 6.1 is an example of a process flowchart. The hypothetical product is composed of five components. Two components are outsourced, and three components are fabricated internally. The outsourced components go through an incoming inspection. The internally fabricated parts have an incoming inspection for the purchased material prior to fabrication and test. The resulting components go to a subassembly step where the three components are integrated

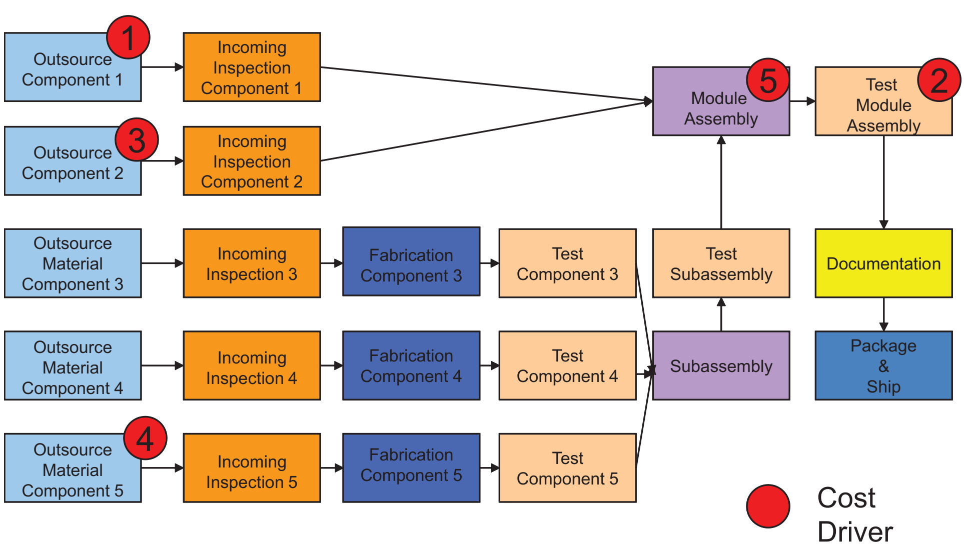

Figure 6.1 Process flowchart: a hypothetical example.

and subsequently tested. The final integration occurs when the outsourced components and the internal subassembly merge to form the module assembly. The module is tested, and all documentation generated throughout the assembly process is compiled to allow traceability to any step in the process. The product is then packaged for shipping. As the cost detail emerges, the cost drivers are identified. These are the process steps that have the highest contribution to the product cost.

6.5 Cost Model

The manufacturing cost model is based on the process flow. The cost of each process step is determined by estimating the direct labor cost, the material cost, and the yield. Also, the machine time is determined for each process step so that capacity can be predicted.

The cost model provides an estimate of total manufacturing cost through a summation of costs for each unit operation. Cost drivers can be identified to enable cost-reduction engineering efforts to focus on the areas that will have the greatest impact. The model provides an estimate of capacity utilization. It provides a means of forecasting the need for increased manpower, capital equipment, or expanded shifts.

The cost model has many assumptions, especially in very early development stages. However, as the amount of data increases, the cost and capacity estimates become more accurate.

Table 6.2 is the cost model based on the process flowchart. For each process step, the model tracks cumulative material cost, machine time hours, direct labor hours (fully burdened), direct labor cost, yield, process step cost, incremental cost, incremental cost percentage, and cost rank. The machine time is the actual time it takes the process equipment to complete the process step. The direct labor time is the actual time it takes to complete the process step and is sometimes referred to as touch time. Often the direct labor time and machine time differ, especially when automated or semi-automated equipment is employed.

To further explain how the model is designed and works, consider Component 3. The material cost for Component 3 is \$10, the machine time is zero, the direct labor time and cost are zero, and the yield is 100% with an incremental cost of \$10 or 2.3% of the total cost. When Component 3 goes through the incoming inspection and the yielded labor cost is added, it now has a cost of \$19.32 with an incremental cost of \$9.32. At the Component 3 fabrication process step, the cost of the previous two steps involving Component 3 are included in the cumulative material cost column, which shows \$19.32. Adding the yielded labor cost, Component 3 now has a cost of \$26.06 with an incremental cost of \$6.76. When all of the incremental component costs (Components 3, 4, and 5) are added, the cumulative cost for the three components prior to subassembly fabrication is \$123.73. The tracking is continued for each process step so that the total manufacturing cost is determined. For the model, the total cost of the packaged and shipped product is \$434.42. The yielded machine time to build the product is 2.21 hours, and the direct labor hours are 3.05 hours. For the analysis, the fully burdened hourly rate was assumed to be \$50/hour. The analysis identified the cost driver rank. Only the top five drivers are indicated.

To generate a profit, the cost to manufacture, often referred to as the cost of goods sold (COGS), should not be more than 65–70% of the selling price. In early manufacture, the cost may even exceed the selling price but must be quickly reduced to be an acceptable product. In an idealized business case, the COGS is 45–60%, leading to a gross margin (the difference between the selling price and the COGS) of 40–55%. There are cases in which the gross margins are higher, but as products mature and competition increases, very high gross margins are difficult to maintain. Understanding manufacturing costs and cost drivers is critical to maintaining high-gross-margin profitable products.

Figure 6.2 shows a good example of manufacturing costs for the Kindle Fire.[2] The COGS is about 72% of the selling price. As indicated before, this is on the borderline of a profitable product. In addition, a product of this type will be under a lot of pressure for price reduction, creating a greater need for cost reduction. Since the primary purpose of the Kindle Fire is to sell content, low profit margins might be acceptable. For most photonic products, this level of margins is not sustainable for a long-life product.

The cost of the Apple iPhone shown in Fig. 6.3 is an example of a high profit margin product with a manufacturing cost of about 30%.[3] This cost level of manufacturing allows for significant price erosion anticipated in the consumer marketplace. Unlike Kindle, the iPhone is not a primary means to sell content and must have a reasonable profit margin to remain viable based on the product itself.

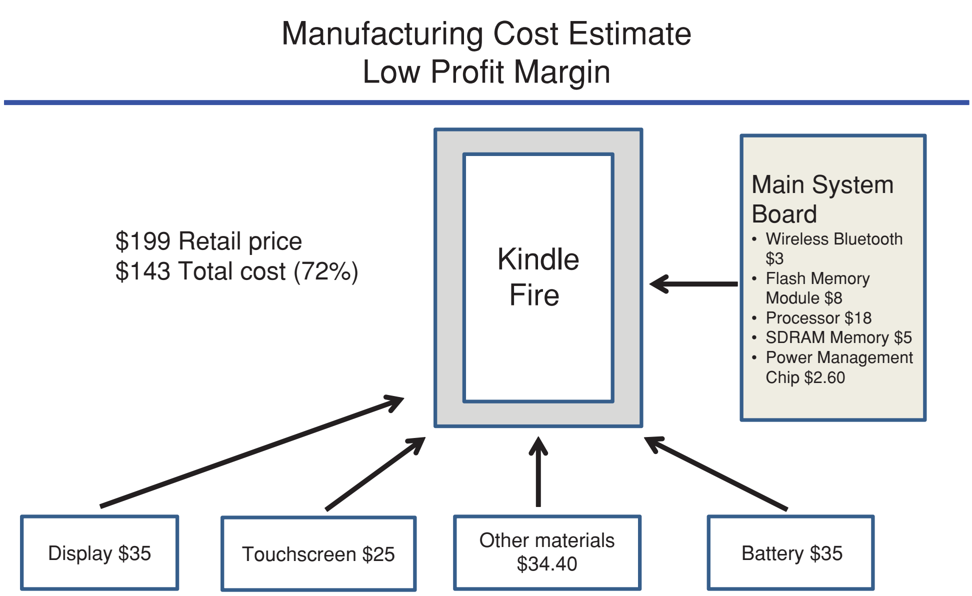

Figure 6.2 Kindle Fire manufacturing cost.[2]