Chapter Nine

MODELING THE COST IMPLICATIONS OF ALTERNATIVE FACO STRATEGIES FOR JSF PRODUCTION

Analyzing the costs of any production task can be complex. In this case, the many scenarios that must be considered make the analysis even more difficult. To analyze different work splits, we have developed a cost model that can be used to examine the effects of the cost drivers under different scenarios. We have also identified and examined a number of other issues beyond those in the congressional language to complete a full and objective evaluation of the different scenarios.

Many factors, including labor efficiency, taxes, facilities requirements, environmental constraints, would affect the cost of having additional or alternative FACO sites for JSF production. It is difficult to predict the influence of all these cost effects. Some factors could increase the total production cost of using a second site—most notably, the need for redundant facilities, tooling, and equipment. Other factors may even decrease the total FACO cost for a multiple-site strategy compared with a single-site one. One such factor is the incentives to hire workers. These incentives may reduce the production cost at a second site. If the number of employees that could take advantage of these incentives were limited, it might make sense to move that portion of the work that would take advantage of the incentives to that second site. How these factors combine to result in a higher or lower FACO production cost is not obvious. We have no way of knowing whether a particular FACO strategy is more or less expensive without accounting for all the relevant factors in a consistent manner.
Cost influences may not be independent of one another, which complicates the accounting. Some influences on the FACO cost affect other factors. For example, environmental regulations may require additional facilities investments, such as a thermal oxidizer to reduce emissions of VOCs. These will in turn increase power usage, and thus overhead cost, at the site. Reflecting these linkages between factors is critical to an accurate determination of cost effects. The cost model that RAND has developed enables the quantitative assessment of the cost implications of different FACO strategies. In this chapter, we describe this model and the calculations made within it.

**COST ELEMENTS IN THE MODEL**

The RAND model was developed in Microsoft Excel and consists of nine different modules that correspond to discrete elements of cost. These elements, which are the major cost drivers for FACO activities, are production labor, indirect costs (overhead and G&A), investments (facilities, equipment, and tooling), taxes and credits, environmental and permitting costs, transportation, power, prime and supplier management support, and fee. Generally, each module calculates the appropriate cost for each fiscal year of production. Some costs, such as labor, are incurred over the entire production run (called recurring costs), while others, such as tooling and equipment, might be onetime costs or periodic (called nonrecurring costs). In this section, we describe the methodology and assumptions used to evaluate each cost element.

**Production Labor**

Labor is one of the largest cost components for FACO. The labor associated with FACO activities consists of two distinct types: “touch” and “support.” Touch labor is the direct work in the production of the aircraft, including such activities as structural mate, testing, and flight operations. Support labor is direct labor that facili-

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1For the FACO activity of the JSF program, we assume that actual costs are incurred two years after the government fiscal year in which the funds are appropriated (the gap between order and delivery).
tates FACO touch work, including engineering, quality, material inventory, and the like. For all these elements, we used the work breakdown structure (WBS) employed by Lockheed Martin for FACO activities and modeled each as a separate component of the overall production labor. The WBS is as follows:

- **Direct Labor**
  - Fuselage structural mate
  - Subsystem mate
  - Final assembly and test
  - Flight operations
  - Manloads/incomplete task logs
  - Final finishes
- **Support Labor**
  - Manufacturing engineering
  - Tool engineering
  - Tool manufacturing
  - Quality
  - Engineering
  - Material inventory

For each of the above components of production labor, we calculate the number of hours of work on a yearly basis at each site. (This calculation is complicated by the need to consider learning effects, which are described below.) These hours are then multiplied by a direct labor rate to determine the direct labor cost. Not all components have the same direct rate. Some components are more expensive on a per-hour basis than others. For example, the hourly direct rates for engineering are higher than those for structural mate.

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2This category includes residual work that must be accomplished post delivery at the FACO location on purchased subassemblies before they can be incorporated into final assembly.
Unit Learning Curve. The number of work hours per aircraft assembled is not static. It has long been understood that manufacturers become more efficient at producing identical items over time. This observation is the “learning effect.”\(^3\) We cannot determine the hours worked each year by simply multiplying the production rate by a fixed number of hours per aircraft.

To reflect experience-based gains in efficiency, we use the unit learning curve that represents the production hours per aircraft as a power function of cumulative production. The equation takes the general form:

\[
T(n) = T(1) \times n^{\ln(\text{slope}) \over \ln(2)}.
\]

The variable \(n\) is the cumulative number of units produced. \(T(n)\) is the number of hours for the \(n\)th unit. \(T(1)\) is the number of hours for the first unit. The variable \(\text{slope}\) is the improvement rate and represents the quantity by which the number of hours gets multiplied each time the production unit number doubles. For example, a slope of 0.95 implies that the unit hours decrease by 5 percent for each doubling of quantity. Therefore, if unit one takes 1.000 hours, unit two takes 0.950 hours and unit four takes 0.903 hours.\(^4,5\)

To determine the number of hours each of the 12 components of FACO labor requires, at a minimum, the calculation of 12 learning curves. However, the RAND model incorporates more complexity. Two additional aspects to production labor for JSF FACO need to be addressed (and were incorporated into the cost model) to reflect the unique nature of this study and of the program: the possibility that

\(^3\)Asher, 1956.

\(^4\)The insight that hours required to perform manufacturing functions decline at a set rate as the production units successively double was a foundation of formal cost estimation (Asher, 1956).

\(^5\)It should be noted that Lockheed Martin uses a compound learning curve that changes slope at three points in the production. Its curve mimics an “s”-shaped improvement curve. We have used constant slope curves for our analysis, in line with what the JSF Program Office and the OSD CAIG have done. A comparison analysis using a learning curve like Lockheed Martin’s and a simple single slope curve reveals that the difference in labor hours is only about +/- 3 percent. The difference depends on the point at which a second source is introduced.
learning can transfer between sites and the fact that what is being produced is not one single aircraft, but three variants of a single aircraft with a high level of commonality.

**Transferable Learning.** The efficiency improvement that the unit learning curve reflects results from a combination of factors, including improvements in production methods and experience gained by the workers. All FACO scenarios under examination rely on a single contractor (Lockheed Martin) controlling configuration and methods. Therefore, some, although not all, of the efficiency improvement could plausibly transfer between the various FACO sites. More likely to be transferable are larger-scale engineering improvements or process improvements, including new methods, simplifications of work methods, and tooling improvements. This type of change in the way work is done can be captured in documentation or even shared by engineers traveling between locations. Another kind of learning is generally not so easily transferred—that involved in the work done by touch labor, such as mechanics working on the factory floor. This learning would include start-up or training expertise required for a task, manual dexterity ("learning by doing"), and undocumented tricks or shortcuts that workers might not even be able to articulate.

In the cost model, we have incorporated the flexibility to model learning transfers of different levels between sites. To do so, we split the learning curve for a particular component of labor into two sets of curves, a universal one (for all sites) and a site-specific one. The universal curve is based on the units produced at all sites, whereas the site-specific curves are based on the unit production exclusively at one particular site. The revised learning curve has the form:

$$T(n_i) = T(1) \left\{ \gamma \frac{\ln(n_{all})}{\ln^{[2]}} + (1-\gamma) \frac{\ln(n_i)}{\ln^{[2]}} \right\}, \quad (2a)$$

where $i$ is an index of location, $n_{all}$ is the cumulative number of units produced at all locations, $n_i$ is the cumulative number of units produced at location $i$, $T(n_i)$ is the number of hours for unit $n_i$, and $T(1)$ is the number of hours for the first unit, assumed to be location-independent.
The constant $\gamma$ is the fraction of learning that is transferable. For example, say a site has produced 23 units of 54 total units. If that site produces the next new unit, $n_{all}$ is 55 and $n_i$ is 24. Note that we assume the universal and site-specific slopes to be identical. We make this assumption because, with the Lockheed Martin management team controlling production, we have no reason to believe that any one site will be able to “learn” more effectively than another, given that the skills required across sites will be the same and that the engineers involved will be able to interact with their counterparts at other sites.$^{6,7}$ This implies that formula 2a converges to formula 1 when $\gamma$ is 1 or one site does all the production (i.e., $n_{all} = n_i$).

The RAND FACO cost model implements equation 2a in a slightly modified form. The unit parameter $n$ for the universal part of the curve is actually the prior year’s last unit number (total) plus the site’s unit number for the current year. For example, say the prior year’s total cumulative production was 57 and that site $i$ had produced 22 of those units. Say this year’s total production is 20, of which 10 are produced at site $i$. For the 10th new unit site $i$ produces this year, $n_{all}$ would be 67 and $n_i$ would be 32. For the first unit produced at site $i$ the next year, $n_{all}$ would be 78 and $n_i$ would be 33. This modification reflects that universal learning would not be transferred instantaneously. We assume a delay of one year for improvements in production efficiencies to be transferred from site to site.

Determining a reasonable value for $\gamma$ (learning transfer) is problematic. Learning-curve analysis has been typically done at an aggregate level where the cause and effect of the efficiency improvements have not been isolated. Other authors have examined the ability to transfer learning under circumstances where a gap in production occurs.$^{8}$ These cases represent an extreme in the transfer of learning. That is, when production is restarted, all of the learning benefit from the workers’ efficiency will have disappeared. The efficiency gains from methods improvements should have been cap-

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$^6$This assumes the Northrop Grumman site will be closely tied in with its JSF partner, Lockheed Martin.

$^7$To explore how this assumption affects the cost results, we test the sensitivity of one alternative to different learning transfer percentages.

$^8$Andelhor, 1969; Birkler et al., 1993.
tured in the processes used to analyze and implement engineering changes. Therefore, a reasonable estimate for the value $\gamma$ can be determined from an analysis of restarted production. Recasting the data slightly from that reported in Birkler et al. (1993), we find that, on average, 64 percent (percent $Learning \ Retained = \frac{L_R}{L_L}$) of the overall learning (in hours) is retained for production labor, with a range of 30–88 percent. We use this average (and range) as a surrogate for $\gamma$ (the transferable portion). The remainder of learning will, therefore, be site-specific. The cost model does incorporate flexibility in implementing different assumptions about learning transfer, so further sensitivity analysis on all cases from zero to complete learning transfer can be tested.

**Commonality of Variants.** The original vision of the JSF program included the cost advantages of having three variants of a single aircraft meet the needs of the Air Force, Navy, and Marine Corps, rather than having each service pay for separate development and production programs. Commonality among the variants is expected to save significant design and production costs (and perhaps maintenance costs for the life of the aircraft). For the production costs specific to FACO, these benefits should also apply.

To represent the effect of the commonality among the three variants, each of the components of labor is determined in the model by a combination of a common and a unique learning curve. We treated “cousin” aspects of commonality as “common” because the assemblies are similar enough to allow for learning transfer among cousin parts. In particular, while cousin parts might have internal differences that affect cost during the fabrication or subassembly process, the interface properties of cousin assemblies and parts are extremely close or identical. Therefore, the shared learning among variants is expected to be high for FACO activities. (The JSF Program Office accepted this approach of treating common and cousin aspects similarly as appropriate for FACO activities.) The formulation of the common and unique learning equation is analogous to equation 2a.

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9 Common parts are exactly the same among variants. Unique parts are completely different—the STOVL lift fan is one example. Cousin parts are similar in shape and size but may vary slightly. Thicker spars for increased strength on the CV offer one example.
The equation for one variant (if all production were produced at one site) would be,

\[
T_j(n_j) = T_j(1)\left(\frac{\ln(\text{slope})}{\ln(2)} \theta_j n_j + (1-\theta_j) n_{all}\right),
\]

where \( j \) is an index of the variant, \( n_{all} \) is the cumulative production of all variants, \( n_j \) is the cumulative number of variant \( j \) units produced, \( T_j(n_j) \) is the number of hours for unit \( n_j \), and \( T_j(1) \) is the number of hours for the first unit of variant \( j \). \( \theta_j \) is the work fraction unique for the variant \( j \). We based the values for \( \theta_j \) on commonality values for the airframe as provided by the Program Office. The percent unique values are 13.3 percent for CTOL, 48.1 percent for CV, and 34.4 percent for STOVL.

Generalizing equations 2a and 2b into a combined formulation, we arrive at

\[
T_j(n_{j,i}) = T_j(1)\left(\frac{\ln(\text{slope})}{\ln(2)} \theta_j n_{j,all} + (1-\theta_j) n_{all,all} + \theta_j (1-\gamma) n_{j,i} + (1-\theta_j) (1-\gamma) n_{all,i}\right),
\]

where \( j \) is the index of variant and \( i \) is the index of location, \( n_{all,all} \) is the cumulative number of units produced of all variants at all locations, \( n_{j,all} \) is the cumulative number of units produced of variant \( j \) at all locations, \( n_{all,i} \) is the cumulative number of units produced of all variants at location \( i \), \( n_{j,i} \) is the cumulative number of units produced of variant \( j \) at location \( i \), \( T_j(n_{j,i}) \) is the number of hours for unit \( n_{j,i} \), and \( T_j(1) \) is the number of hours for the first unit of variant \( j \), assumed to be location independent.

**Indirect Costs**

Indirect costs consist of overhead, G&A expenses, and other components of indirect cost listed later in this report. Overhead costs, the larger of the two, are costs related to fabrication and assembly activities, but cannot be allocated on a direct basis to a particular product.
for reasons of either practicality or accounting convention. Overhead includes the costs of fringe benefits, indirect labor, depreciation, building maintenance and insurance, computer services, supplies, travel, and so forth.\textsuperscript{10} G&A expenses relate more to the company as an entity and may not relate to activity levels at only one plant. The G&A expenses include such general business costs as executive salaries, human resources costs, and the costs of such staff services as legal, accounting, public relations, and financial functions.\textsuperscript{11} G&A costs are generally incurred and accounted for at a corporate level, whereas overhead is a site-specific cost.

While these indirect costs are related to and scale with the total direct labor for a site, the relationship is not strictly linear. Indirect costs include both fixed and variable components. As the number of direct labor hours at a site increases, the overhead and G&A rates decrease because the fixed costs are spread over a greater number of hours. To reflect the relationship between direct hours and the indirect cost rates, we use the following formulation:

$$rate_i = \frac{A_i}{\text{Total Hours}} + B_i,$$

where \(rate_i\) is the indirect rate, and \(A_i\) and \(B_i\) are constants. To determine these constants, we surveyed each of the potential sites for their rate information and the sensitivity of those rates to changes in labor base. The constants \(A_i\) and \(B_i\) for each site were determined by fitting these data (the FY 2001 rate at several hypothesized labor hour levels) to equation 3.\textsuperscript{12}

By using the current indirect rate information from each of the sites, we assume that no significant changes to the site or its business structure will occur. This assumption is very tenuous; almost certainly, changes will occur in what each site produces over the next

\textsuperscript{10}DSMC, 2001.
\textsuperscript{12}We are not able to present the results of this analysis because the results are business-sensitive to each of the firms.
few decades. However, it is impossible to predict what these changes might be over the 20-plus years of JSF production, which does not even begin until FY 2006.\textsuperscript{13} The potential FACO sites did provide a workload forecast for the next five years.\textsuperscript{14} We have assumed a flat workload after the fifth year. This is the best estimate we can make at this time.

The FACO activities for JSF will also change the fixed component of overhead for the sites.\textsuperscript{15} For example, some new facilities will be necessary, which will lead to additional depreciation charges, franchise taxes, and property taxes. For the changes to the fixed components of indirect costs caused by FACO, we will calculate each item explicitly and add it to the overhead costs (from equation 3) to determine a new effective overhead rate. This separate accounting was done to isolate the effects of these costs. These explicitly modeled components of overhead (discussed later in this chapter) are

- facilities depreciation
- franchise taxes
- property taxes
- sales and use taxes
- tax credits
- additional power costs
- environmental costs.

Given that increasing the workload at a site typically lowers indirect rates, a benefit accrues to other government programs at JSF FACO sites. The increased workload will decrease the allocated indirect costs for these programs. We calculate the indirect cost savings for these programs as the difference between rates with and without the

\textsuperscript{13}The 14 SDD aircraft will be built before then.

\textsuperscript{14}We have also assumed that all FACO work for a given fiscal year lot is completed in one calendar year. FACO is expected to take only about 40 days, so overlap would be relatively insignificant. However, there is an offset of two years between the fiscal year (year of purchase) and the year that FACO activities complete for the lot.

\textsuperscript{15}The formulation of G&A expenses is assumed to be unaffected by FACO activities—that is, the fixed portions of G&A costs do not change when FACO work is added.
FACO activities, multiplied by an average direct wage rate and the number of forecast hours for the other work.

We also include as part of the indirect cost calculations the following:

- fringe benefit costs\textsuperscript{16} (e.g., vacation, health insurance, workers’ compensation insurance, FICA).
- facilities cost of money (COM).
- overtime premium.
- marketing fees.
- hiring and training costs.

These indirect costs are added based on current Lockheed Martin Aero and Northrop Grumman practices as agreed with the DCMA.

**Investments: Facilities, Equipment, and Tooling**

To undertake FACO activities for JSF production, a site will need a variety of facilities, equipment, and tooling investments, which were described in Chapter Three. There are two general types of investments:

- **Contractor-owned.** These investments are not specific to the JSF program—i.e., they could be used for other aircraft production programs. An example of such an investment is a paint facility. Contractor-owned facilities, equipment, and tooling are typically subject to property and sales taxes.\textsuperscript{17} Cost recovery for these items is through depreciation and cost of money components of overhead.

- **Government-owned.** These investments are specific to JSF FACO activities. An example of a government-owned investment is unique tooling used for JSF FACO work. Government-owned items are not subject to sales and property tax (although some

\textsuperscript{16}While fringe benefit costs could be considered “direct charges,” Lockheed Martin Aero applies a uniform rate to the direct labor dollars for purposes of billing.

\textsuperscript{17}As described in Chapter Six, real property (e.g., a building) is not subject to sales tax, regardless of ownership.
states [California, for example] levy a “possessor” tax on such items). The government generally reimburses the contractor in full for these investments.

The investment cost at each site is modeled as a function of the rate of production at the site. For example, the manufacturing floor space required will increase as the annual production rate increases.

We used three steps to determine investment costs:

- **Determine requirement.** Based on the maximum rate that a site will produce over the entire production run, we determine a required level of investment at a site. Rate dependence is modeled as a step function. For a value between two steps, the requirement is linearly interpolated. The step function can have arbitrary form and can include only one step. For example, a STOVL pad is a requirement for each facility where FACO activities for that variant will take place. One pad is sufficient to handle the highest total annual rate now planned for that variant.

- **Determine facilities/equipment/tooling already available.** Some sites might have existing infrastructure not currently being used and not set aside for other work or programs; therefore, a particular investment might be reduced or not needed at all. This step determines the usable facilities, equipment, and tooling existing at a site. This information was obtained through surveys submitted to the sites and through follow-up data collection with the sites.

- **Calculate cost of needed investment.** If the requirement exceeds that already available, the site will need to add an investment. We estimated the cost of such additions based on existing information on such factors such as dollars per square foot, dollars per unit, etc. Lockheed Martin provided most of this investment cost information.

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18 The investments have been treated as onetime investments, although, in practice, sites could build up facilities incrementally. However, because the production profile for the JSF builds to a full rate by 2012 and remains rather flat after that, this should not significantly affect the calculations. Also, we assume that assets are not transferred between sites.
Three other variables are tracked along with the investment costs: depreciation, residual asset value, and operations and maintenance costs. Depreciation is tracked because it is an allowable overhead expense for contractor-owned items. Therefore, adding contractor investments to a site will increase the overhead rate through increased depreciation.

Some states have property taxes on manufacturing equipment. Therefore, the residual asset value must be tracked for a new contractor-owned investment to estimate the property tax implications (property tax itself is an allowable cost charged to the government). The residual value for a contractor-owned investment is also tracked to calculate the appropriate facilities cost of money, which is part of overhead. Each year, the residual asset value for these FACO-specific facilities is multiplied by the COM rate to determine the COM charge. We assume the rate to be 5.5 percent.\(^{19}\)

Some investments might require significant annual maintenance or have significant operating expenses. An example of such an investment would be a thermal oxidizer for pollution control of VOCs. These units require a large amount of natural gas to operate and are expensive to maintain. We assume that the annual level of operations and maintenance cost is a function of the size of the facility or investment.

Table 9.1 summarizes the contractor-owned investments tracked along with the specific depreciation and cost methodology used, as well as the variants whose production requires these assets. Table 9.2 summarizes the government-owned investments. As these items are not depreciated and are general to all variants, depreciation method and variant requirement are not shown.

**Taxes and Incentives**

Each state has unique accounting rules for taxation that include different tax rates and different definitions of taxable income. For any

\(^{19}\)This is the current (2002) COM rate as published by the U.S. Department of the Treasury. See [http://www.publicdebt.treas.gov/opd/opdprmt2.htm](http://www.publicdebt.treas.gov/opd/opdprmt2.htm) (last accessed May 20, 2002).
### Table 9.1

**Investments Required for FACO (Contractor-Owned)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost Factor</th>
<th>Depreciation Type</th>
<th>Variants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing space</td>
<td>$/sq ft</td>
<td>Plant/hangars/storage</td>
<td>All</td>
</tr>
<tr>
<td>Flight ops run stations</td>
<td>$/unit</td>
<td>Plant/hangars/storage</td>
<td>All</td>
</tr>
<tr>
<td>Paint facility building</td>
<td>$/sq ft</td>
<td>Plant/hangars/storage</td>
<td>All</td>
</tr>
<tr>
<td>Robotic paint equipment</td>
<td>$/unit</td>
<td>Cranes/other equipment</td>
<td>All</td>
</tr>
<tr>
<td>Paint pollution control</td>
<td>$/unit</td>
<td>Cranes/other equipment</td>
<td>All</td>
</tr>
<tr>
<td>Storage hangars</td>
<td>$/sq ft</td>
<td>Plant/hangars/storage</td>
<td>All</td>
</tr>
<tr>
<td>Administration space</td>
<td>$/sq ft</td>
<td>Plant/hangars/storage</td>
<td>All</td>
</tr>
<tr>
<td>Low-observable verification building</td>
<td>$/sq ft</td>
<td>Plant/hangars/storage</td>
<td>All</td>
</tr>
<tr>
<td>Low-observable turntable</td>
<td>$/unit</td>
<td>Cranes/other equipment</td>
<td>All</td>
</tr>
<tr>
<td>Runway arresting gear</td>
<td>$/unit</td>
<td>Cranes/other equipment</td>
<td>All</td>
</tr>
<tr>
<td>Fuel barn</td>
<td>$/sq ft</td>
<td>Plant/hangars/storage</td>
<td>All</td>
</tr>
<tr>
<td>270V power transformer</td>
<td>$/unit</td>
<td>Cranes/other equipment</td>
<td>All</td>
</tr>
<tr>
<td>Hover pit</td>
<td>$/unit</td>
<td>Cranes/other equipment</td>
<td>STOVL</td>
</tr>
<tr>
<td>Hover pad</td>
<td>$/unit</td>
<td>Cranes/other equipment</td>
<td>STOVL</td>
</tr>
</tbody>
</table>

*aThe depreciation rates for these categories come from *IRS Pub 946, Chapter 3*, at http://www.irs.gov. The details are covered in the discussion on facilities.*

### Table 9.2

**Investments Required for FACO (Government-Owned)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic test system—Aircraft level</td>
<td>$/unit</td>
</tr>
<tr>
<td>Laser trackers</td>
<td>$/unit</td>
</tr>
<tr>
<td>Surface finish and appliqué testing</td>
<td>$/unit</td>
</tr>
<tr>
<td>General-purpose test equipment</td>
<td>$/unit</td>
</tr>
<tr>
<td>Avionics diagnostic equipment</td>
<td>$/unit</td>
</tr>
<tr>
<td>Mate alignment tool</td>
<td>$/unit</td>
</tr>
<tr>
<td>Dollies and stands</td>
<td>$/unit</td>
</tr>
<tr>
<td>Support equipment</td>
<td>$/unit</td>
</tr>
<tr>
<td>Maintenance test equipment—Direct</td>
<td>$/unit</td>
</tr>
</tbody>
</table>
two sites in different states, taxes can be quite different, even if the manufacturing operations are identical. To assess the effect of taxes on different FACO strategies, we include in the model four kinds of tax treatments: franchise taxes, property taxes, sales and use taxes, and state and local incentives (which take the form of tax credits and other kinds of benefits—i.e., negative taxation in these cases).20 These issues were discussed in more detail in Chapter Six.

Franchise taxes are payments to a state for operating a revenue-generating entity in that state. These taxes are analogous to federal corporate income taxes. Determining the state-by-state taxable portion of income for a company that has a presence in multiple states is an intricate process. Most states use an apportionment formula to determine the fraction of the company’s total income that is taxable by that state. The formula is based on the fraction of assets, sales, and labor that the company has in the state. Each state being considered in this analysis applies different weights to these components.

To understand fully the franchise tax implications of alternative FACO strategies, we would need detailed financial data for all facilities of the companies involved. Such calculations and data gathering are not practical within the scope of this study and would involve considerable insight and involvement from the contractors’ corporate-level tax experts. Therefore, we have taken the following approach to estimating the change in the franchise tax a company would pay if it added FACO activity in any given state. We assume that the additional tax equals the state’s corporate income tax rate multiplied by the fee associated with FACO. The state corporate income tax rates were provided in Table 6.1.

This franchise tax simplification has drawbacks. One is that it does not reflect the effect of different states’ weighting formulas. Because each state has a different formula, one state might apportion more or less income to itself for identical operations compared with another state. Another, subtler, effect is that companies can use losses from

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20Because this analysis assesses the cost to DoD and not the net cost to the government, we do not include federal income taxes. It should also be noted that federal income taxes are not allowable costs.
other states and even other countries to reduce income in any given state. The apportionment formula is based on total corporate income.

Property tax calculations are more straightforward than franchise tax calculations. As discussed above (under “Investments”), the model tracks the residual asset value (original cost minus accumulated depreciation) of FACO property over time.\footnote{As a simplification, we have used a common set of depreciation schedules for all sites, based on Internal Revenue Service rules.} Property taxes are calculated as the product of residual asset value and the property tax rate (see Table 6.1). The reader should note that this calculation is based only on contractor-owned investments, not the tooling and equipment owned by the government. The exception is California, where the contractor is charged a possessor tax for government-owned items.

State sales and use taxes apply to some contractor-owned investments. As described in Chapter Six, some states exempt manufacturing equipment as well as real property from these taxes. We determine a sales tax for each investment, if appropriate, by multiplying the purchase price by the local rate.

Certain states offer tax credits as an incentive to increase local workforces. For every new employee, the company is given a onetime tax credit. For the FACO model, we determine the number of FACO workers based on total number of required work hours divided by the standard hours per year worked. Based on that head count, we calculate the employment credit assuming the number of new hires that will likely be needed by each site, which was provided during the site visits.

States sometimes offer investment tax credits to companies for new plants, facilities, and equipment. These credits are typically a percentage of the total investment cost. Using the investment costs described above, we calculate the investment credit by multiplying it by the credit percentage, where appropriate, and use it to reduce the net franchise tax at site.
Environmental and Permitting Costs

For FACO, the major environmental issues are VOC emissions resulting from painting and finishing activities and noise from flight tests. Environmental and permitting issues can add to overall FACO costs through such requirements as permit fees, preparation and maintenance time, and required equipment and facilities for pollution abatement. These costs are difficult to assess and forecast because few companies typically track them separately as a direct expense by program. Instead, environmental costs are usually part of overhead and are shared among all the work at one site.

Because we had no other method to estimate these costs, we used data provided by the contractor. Equipment needed for FACO-driven environmental reasons is included in the “investment” category. Permit fees are set by the state in Texas and Georgia and by the Air Quality Management District in California. For each location, Lockheed Martin provided an estimate of the permit preparation time and filing fees. For the Palmdale site, these preparation costs are higher because Lockheed Martin anticipates the need to file an EIS. Lockheed Martin also estimated the annual recurring permit costs and fees for each location. These costs have been included in the model.

Noise regulations do not have an associated cost in the model. As discussed in Chapter Seven, noise restrictions may limit or restrict flight-test activities.

Transportation

Typically, the majority (50–70 percent) of the value of any aircraft is produced by subcontractors and then incorporated into the aircraft by the primary assembler. In the case of the JSF, where Lockheed Martin is teaming with Northrop Grumman and BAE Systems, the portion that the prime contractor is contributing is even lower than average. The company estimates that it will have an 18-percent share of the total production value. Hence, much of the material, purchased equipment, and major subassemblies for the production of the JSF aircraft are manufactured at locations other than Fort Worth, and must be shipped to Fort Worth or whichever FACO site is used. Moving the FACO site or adding additional sites will change
the cost for shipping these items. The major components that must be available to each FACO site include

- forward fuselage
- center fuselage
- aft fuselage and tail
- wings
- edges
- doors
- weapons bay doors
- engines
- radar.

Changes of FACO location may change transportation costs. For example, Lockheed Martin plans to build many of the components for which it is responsible, such as the wings and forward fuselage, at its Fort Worth facility. If this location is the FACO site, these items will have no transportation costs. For other FACO sites, these items will need to be shipped to the assembly location.

Lockheed Martin plans for truck delivery of all components. For overseas sources, we assume that these items are transported by container ship to a common port—Houston. From that port, the items are trucked to the various FACO sites.

We developed a cost-estimating relationship (CER) to evaluate these trucking costs. We obtained notional quotes to ship partial truck-loads of subassemblies from their source (source locations were provided by Lockheed Martin) to the various potential locations. We also determined the driving distance between sites. The CER incorporated into the cost model is

$$\ln(\text{Cost}) = 0.556 + 0.568 \times \ln(\text{Volume}) + 0.392 \times \ln(\text{Distance}),$$

where,

- Cost is in FY 2002 dollars.
- Volume is in cubic feet.
- Driving distance is in miles.

$R^2$ was 0.91 with a root mean square error of 0.21.

Crate return costs, if needed, are expressed as a percentage of the initial shipping value.

**Power**

While electrical power is typically an indirect cost charged through overhead, we have estimated power costs of FACO activities. The estimate has two components. The first is a general facility demand based on square footage of manufacturing space. The power estimate for this purpose is 31.2 kWh per square foot per year, which is independent of the annual production rate (this power is mostly for lighting and heating and air conditioning and, therefore, the power usage is based on facility size). The second component of power cost depends on the annual rate, consisting of the power for high-draw equipment needed for FACO activities. This equipment includes run stations, the fuel facility, the paint facility, and low-observable testing equipment. Each piece of equipment has a power usage per year per station. Each station is assumed to operate at full capacity or not at all. The number of stations assumed to operate in a year depends on the number of JSF aircraft produced. For example, a total of eight paint stations might be at a site, but only six may be used due to workload. At the time this report was written, Lockheed Martin was unable to determine the power usage for each of these facilities. As an approximation, we used the same average power usage per square foot as given above for these items. To arrive at a power cost, the added power demand for the year is multiplied by the site’s power rate (dollars per kWh). We assume that the power rates remain stable (in constant dollars) over the production run because it is difficult to forecast future utility prices.
Management and Supplier Support

Having multiple FACO locations will result in additional management, oversight, travel, and communications effort by Lockheed Martin and its suppliers. To estimate these costs, we assume that a fixed number of dedicated prime contractor management representatives will be on site to run the FACO activities at any location outside Fort Worth. The estimate in the model is that 14.0 full-time equivalents (FTEs) would be required for Lockheed Martin representation the first year of production and 7.0 FTEs per year thereafter. The additional 7.0 FTEs for the first year are caused by the setup burden. To arrive at an estimate of the effect of the support costs of management representation on site, the total FTE value was multiplied by an estimated cost of $150,000 per manager (fully burdened).

Having supplier representatives on site to serve their customers is becoming an increasingly common manufacturing practice. We assume that the JSF program will have supplier representatives on site and estimate that 5.0 FTEs are required per year. (The cost of the supplier representatives typically would be included in the price of the component; however, as we do not include the cost of the major subassemblies in our analysis, we treat these costs as a direct cost to the government.)

Fee

The last element to discuss is fee. Fee represents the “profit” earned by the contractor on the cost of the work performed. Typically, the fee is negotiated between the government and the contractor beforehand. To determine a total price, we apply a fixed fee to the direct labor, support labor, and indirect costs. We assume that transportation costs and tooling and equipment costs are passed directly through to the government (i.e., no fee added) with administration expenses associated with those purchases already included in the indirect rates.
MODEL STRUCTURE

Interaction Among Cost Elements

Figure 9.1 illustrates the relationships among the nine cost elements as implemented in the model. Note that we have split investments into two boxes (government-owned and contractor-owned) for ease of presentation.

We now discuss the logic of some of these connections. The site’s FACO production plan for a facility will determine the needed investment in facilities, tooling, and equipment (both contractor-owned and government-owned) necessary for the various activities. The greater the rate of production at a site, the more investment will be necessary. These investment costs may be for JSF-specific items (government-owned) and, therefore, are charged directly to the program. Other investments (contractor-owned) get recovered through depreciation charges in overhead. Certain investments might be taxable as property and/or qualify for investment credits—thus the linkage to taxes and benefits. The major investments, such as facilities and equipment, will require power for operation. So, adding...
these types of investments increases power costs at the site. Because power costs are included in overhead, the overhead costs further rise with new investment.

Another example is environmental and associated permitting costs. The rate of production will, quite obviously, affect emissions and waste-generation levels and therefore a site’s facilities. Environmental and permitting issues also have an additional indirect impact through overhead. Indirect personnel are needed to file and maintain permits as well as to monitor compliance. Furthermore, annual fees associated with a permit must be paid. Finally, some environmental cost is directly coupled with production rate. It may be necessary to purchase environmental “credits” for certain activities (such as painting) as the production rate increases beyond a certain level.

Direct labor for FACO production offers another example. As with the other elements, the direct hours will scale with the production rate at the site. The direct hours for the work will affect the site’s overhead and G&A rates. Tax implications exist for the direct hours as well. The fee earned from the labor will count as taxable income for the firm. Another potential effect of the additional workload is to increase employment at the site. If the current workforce cannot accommodate the number of added hours, the firm will need to hire new workers. Also, some states provide tax credits for new hires under certain circumstances. Therefore, increasing workload at a site may result in some additional tax credits as well as additional training costs for the firm.

**FACO Production Strategy Assumptions**

We made several assumptions about how work would be allocated among multiple sites in this study. We assumed that FACO production would employ a “leader-follower” approach. That is, Lockheed Martin would begin FACO activities of the JSF aircraft at its Fort Worth site (the leader) by producing all of the SDD aircraft there. At some later time, other sites could begin FACO activities for the JSF. This approach is supported by the SDD contract awarded to Lockheed Martin on October 26, 2001, which included no language referring to restrictions on production locations. Lockheed Martin has publicly stated that it intends to do this work at its Fort Worth facility.
(We also have no way to estimate the costs to change the contract so that it includes a requirement to perform FACO at another location.)

The RAND-developed model was flexible enough to analyze the costs of running one to four FACO locations, with any site able to build any percentage of the total production for each JSF variant (0–100 percent). The range of possibilities includes the following:

- Equal percentages of each variant per year per site, so that all sites would perform FACO on equal numbers of variant aircraft over the entire forecast JSF production (subject to minor annual variations because we assume each site would produce a whole number of aircraft each year).

- Allowing one site to perform FACO for all of one or more variants during the entire forecast production, which would lead to different numbers of JSF aircraft being produced by site in some years because of the phasing of the buy quantities by variant.

- Allowing one primary site to build all the aircraft for any length of time in the program, and then having the subsidiary sites split off a portion of the FACO. We assume the decision to split the FACO activities will be made at one time and will hold for the remainder of the program life so there will be no later year-by-year variations in production allocation by site.

Figure 9.2 shows a sample time line for FACO activities. In this example, the primary site performs the FACO activities for all production until a decision is made to establish other FACO locations. After the breakpoint, the primary site continues with the entire CV and some of the CTOL FACO production. Site A does all of the FACO work for the STOVL variant after the break. Site B does the balance of the CTOL FACO work.

CONCLUSION

The cost model contains significant flexibility and incorporates a wide variety of cost elements that would potentially differ among production sites. In the next chapter, we will discuss the specific scenarios we analyzed for different JSF FACO alternatives and the results from the analyses of these scenarios.
Figure 9.2—Example Time Line for FACO Production