CHAPTER 5. MANUFACTURING COST ASSESSMENT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 5. MANUFACTURING COST ASSESSMENT

A manufacturing assessment was conducted to estimate the manufacturing costs associated with an increase in energy efficiency for clothes washers. This approach involved the disassembly of eight clothes washers, analysis of the materials and manufacturing processes, and the development of a spreadsheet model. The model was run using a Monte Carlo simulation to approximate industry manufacturing costs and to determine sensitivities to key inputs.

The model contains separate manufacturing assumptions for both high-volume manufacturers (producing 1.5 million units per year) and low-volume manufacturers (producing 0.3 million units per year). The analysis of low-volume manufacturers was done to capture the differentiated cost structure of this market group. Table 5.1 summarizes the type of clothes washer analyzed and whether or not it was analyzed for a high or low volume manufacturer.

Table 5.1 Summary of Clothes Washers Analyzed

Clothes Washers	**High Volume Manufacturer**	**Low Volume Manufacturer**
Analyze two vertical-axis (V-axis) washers (baseline)	X	X
Analyze four high-efficiency V-axis washer designs	X	
Analyze two horizontal axis (H-axis) washer designs	X	X

5.1 PROJECT OBJECTIVES

The project had five core objectives which were followed throughout the assessment:

- Develop a clear and consistent manufacturing cost assessment methodology.
- Build a detailed manufacturing cost assessment model that accurately predicts the cost differential of selected models.
- Develop a model that estimates the cost premium of low-volume versus high-volume manufacturers of V-axis and H-axis washers.
- Report the differential manufacturing costs in aggregated form or as a range to maintain confidentiality of the data.
- Obtain input from stakeholders on the manufacturing cost estimates and assumptions to confirm accuracy.

5.2 MANUFACTURING COST ESTIMATES AND ASSUMPTIONS

The categories used to summarize the manufacturing costs developed closely parallel the cost categories used by the Association of Home Appliance Manufacturers (AHAM). Full production cost is defined as the sum of direct material, direct labor and overhead (including investment depreciation).[a] Other cost elements (SG&A, R&D, and interest) are grouped under the non-production cost category. Together these costs make up the full factory cost of the product as shown in Figure 5.1.

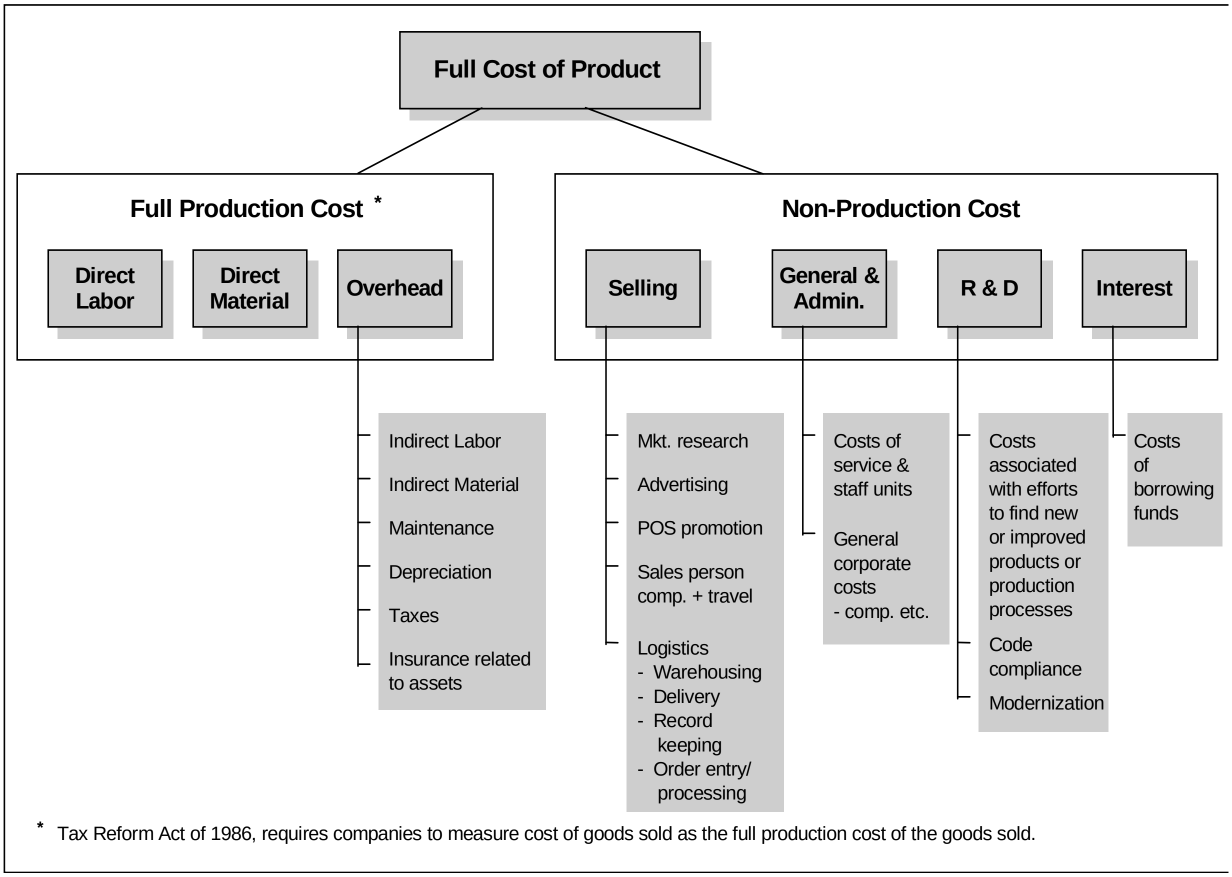

Figure 5.1 Full Product Cost

It is understood that the cost of specific models - or costs to individual manufacturers - will vary, depending on elements such as the product's precise characteristics, actual manufacturing processes, and the product mix in the factory (multiple clothes washer and dryer products). Also there are considerable differences in the levels of vertical integration as some manufacturers prefer purchasing partially complete sub-assemblies to manufacturing themselves. However, as this set of assumptions remain constant, the differential cost estimation methodology reduces the impact of plant-specific characteristics.

In developing the cost model for the manufacturing cost assessment, several assumptions were made. These assumptions are based on general industry practice, determined from manufacturer

[a] Overhead costs in the AHAM data collection do not include investment depreciation

interviews, 1992 U.S. census data, and internal Arthur D. Little sources. Table 5.2 summarizes the key manufacturing assumptions used in the analysis.

Table 5.2 Key Manufacturing Assumptions

Category		Assumption
Work Days per Year (days)		250
Average Shifts per day (shifts) *		2.0
Runtime per Shift (hours)		8
Lot Size (work days)		1
Assembly Worker Downtime		20%
Equipment Uptime (% workdays)	Monte Carlo mean	85%
	Range	75% to 95%
Burdened Wages (per hour)	Monte Carlo mean	$23
	Range	$17 to $28
Building Depreciation Life (years)		25
Conveyor Depreciation Life (years)		15
Tooling Depreciation Life	Small Stamp 0-60 ton, (years) †	5
	Medium Stamp 60-600 ton, (years) †	5
	Large Stamp 600-1500 ton, (years) †	10
	Small IJM 0-150 ton, (years) †	5
	Medium IJM 150-500 ton, (years) †	5
	Large IJM 500-1250 ton, (years) †	10
Average Depreciation Life (adjusts equipment, tooling dep. lives)	Monte Carlo mean	100%
	Range	75% to 125%
Maintenance Cost (% of Equipment Cost)	Monte Carlo mean	4%
	Range	2.5 to 5.5%
Utilities Cost (% of Materials Cost)	Monte Carlo mean	2.1%
	Range	1 to 3.5%
Capacity Utilization	Monte Carlo mean	85%
	Range	60 to 95%
Investment Requirements	Monte Carlo mean	100%
	Range	50 to 150%
Taxes (% of Factory Cost)		0.9%
Insurance (% of Factory Cost)		0.8%

* *Fabrication, 2.5 Shifts, Assembly 1.0 Shifts*

† *Tooling depreciation life is the maximum number of years that a stamping or molding die is expected to be used before a design iteration makes it obsolete. However, dies may wear out from use before their maximum design life. For metal stamping dies, we assumed two million hits, for injection molding (IJM) dies we assumed one million hits. For the purpose of depreciation, we select whichever leads to a shorter life. The design life of a die is factored by the average depreciation life variable which thus may increase or decrease its design (but not hit) life.*

Manufacturing plants are assumed to require investment for a "green field" site, including all new equipment, tooling, installation, and building. It is also assumed that manual final assembly is necessary to reflect the need for flexibility in production of multiple models.

Table 5.3 characterizes the two scenarios used in this analysis – high volume and low volume manufacturers. Low volume manufacturers suffered from several disadvantages, such as purchased parts costing 10% more than for their larger counterparts and higher overhead cost structures. Raw materials, on the other hand, were assumed to be price equivalent. The manufacturing volume for the low volume manufacturer was set at the lower limit of what industry sources consider to be a viable production capacity to compete in the overall mass market.

Table 5.3 Assumptions for High / Low-Volume Manufacturer

Manufacturer	**High Volume**	**Low Volume**
Plant Size (total square feet)	1000000	250000
Conveyor Length (feet)	57600	9400
Production capacity (maximum units / year)	1500000	300000
Indirect Labor Penalty (on top of already increased assembly time)	n.a.	10%
Low Volume Part Cost Penalty	n.a.	10%

5.3 COST STRUCTURE OF THE SPREADSHEET MODEL

The manufacturing cost assessment methodology used is a detailed, component-focused technique for rigorously calculating the manufacturing cost of a product (direct materials, direct labor and some overhead costs). Figure 5.2 shows the three major steps in generating the clothes washer manufacturing cost.

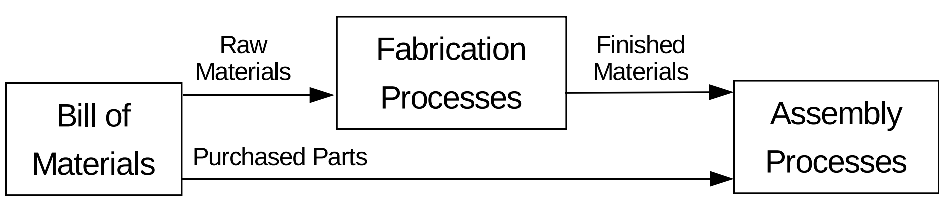

Figure 5.2 Manufacturing Cost Assessment Stages

First, a baseline was established to compare against the high efficiency models. Two clothes washers were chosen due to their high popularity in the 1997/8 market and the fact that they came from two different manufacturers. Following is a list of the *key characteristics* describing the *baseline clothes washers*:

- 27” overall width
- 3 wash/rinse temperature settings
- Unheated rinse
- 3 Settings for Load Size
- 2 wash/spin speeds
- 8 or more wash cycles
- Super capacity wash basket

The first step in the manufacturing cost assessment was the creation of a complete and structured bill of materials (BOM) from the disassembly of the two baseline and six high efficiency models. The washers were dismantled and each part was characterized according to weight, dimensions, material and quantity. The BOM incorporates all materials, components, and fasteners with estimates of raw material costs and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication were based on industry experience, information in trade publications and discussions with manufacturers. Interviews and plant visits were conducted at major manufacturing facilities to ensure accuracy on methodology and pricing. For more information on the BOM, see Appendix D.

Following the development of a detailed BOM, the major manufacturing processes were identified and developed for the spreadsheet model. These processes are listed in Table 5.4.

Table 5.4 Major Manufacturing Processes

Fabrication	**Finishing**	**Assembly / Joining**
Fixturing	Washing	Adhesive Bonding
Stamping / Pressing (Large, Medium, Small)	Powder Coating	Spot Welding
Brake Forming	Enameling	Seam Welding
Cut & Shearing	Deburring	Integral Fastner (i.e. clinching)
Machining		Other Fasteners
Injection Molding (Large, Medium, Small)		Press Fitting
Casting		Inspection & Testing

Information on equipment and tooling costs, typical processing cycle times, and materials used for fabrication were obtained from Arthur D. Little manufacturing databases. Equipment suppliers were contacted for further details concerning equipment capabilities and processing parameters (cycle times, scrap rates, etc.). The fabrication process cycle times were entered in the BOM and linked to the specific parts being fabricated. Each part / process had a time and labor cost assigned.

For this analysis $23.00 per hour was used as the average fully burdened labor rate based on typical yearly wages and benefits for union employees. This parameter was investigated using sensitivity analysis because labor rates can vary considerably, depending on geographic location, availability of skilled labor, and level of union representation.

In the final step of the cost assessment, assembly times and associated direct labor costs were estimated. Assembly cycle times were primarily derived from the disassembly of the selected clothes washers. The assembly sequence was built into the structured BOM, culminating with final assembly, testing and packaging.

Once the cost estimates for each machine were finalized, a detailed summary was prepared for relevant components, subassemblies and processes. The BOM and manufacturing process summaries provide detailed direct material, direct labor, indirect material, and investment costs. Indirect labor costs were estimated by subtracting the direct labor hours, determined from the bottom-up analysis, from the current average total labor hours per unit (1.8 hours). The current average labor content was derived from a top down analysis of several household laundry equipment manufacturing plants and conforms with data from the 1992 Census of Manufacturers.

The 1992 Census indicates an average labor content in the household laundry equipment segment to be 2.1 labor-hrs per unit. However, experts estimate 1.8 hours is more accurate for 1999, as a savings of 0.3 hrs per unit, or approximately 14% for the industry over the past 7 years, could be expected. The indirect labor-hour per unit was multiplied by the average labor rate ($23) in order to estimate the indirect labor cost. The average direct labor hour per unit was 1.32 hours; therefore the indirect labor content was calculated to be on average 0.48 labor hours per unit. The indirect labor is included in the overhead estimate, along with indirect materials, utilities, depreciation, maintenance, taxes, and insurance. The direct labor cost total is approximately $25 per unit, while the indirect labor costs are estimated to be $13.50 per unit at the fully burdened $23 per hour labor rate.

5.4 RESULTS FROM THE ANALYSIS

5.4.1 Results for High-Volume Manufacturers

In total, eight washing machines were disassembled and analyzed – two V-axis baseline models, four high-efficiency V-axis washers and two H-axis models. Compared with the baseline, Figure 5.3 shows the total incremental cost range that the H-axis and the high efficiency V-axis exhibited from the Monte Carlo analysis.

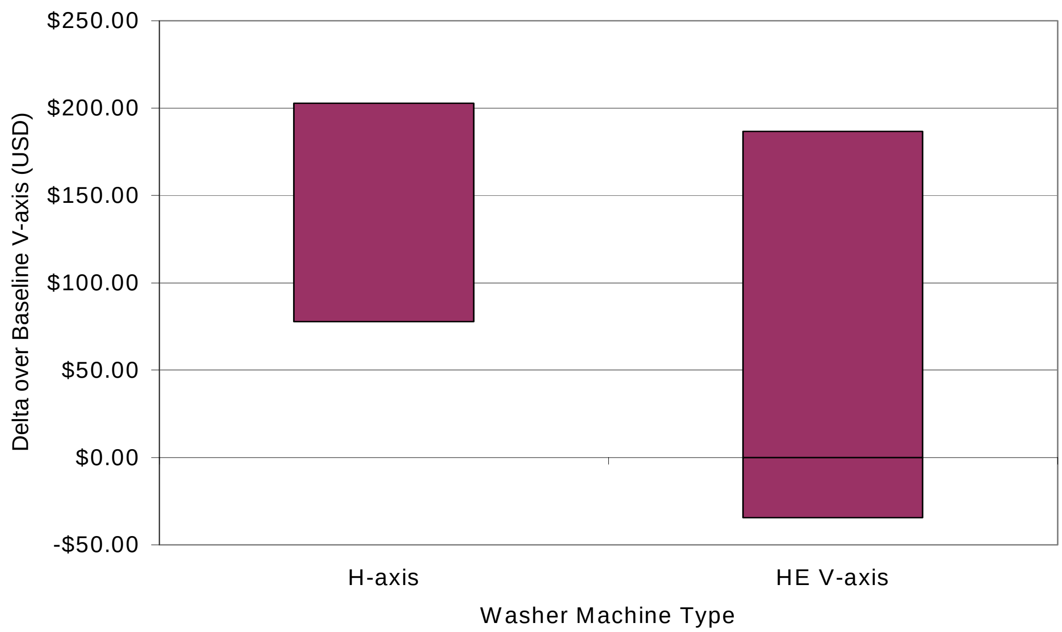

Figure 5.3 Range of Cost Premiums for H-axis, high efficiency V-axis over V-axis Baseline

The breakdown of costs by category also varies by washer type. Of the total costs, the proportion attributable to material increases for the high efficiency model, while the other components decreased. In Figure 5.4 the breakdown is reported using average values by washer type.

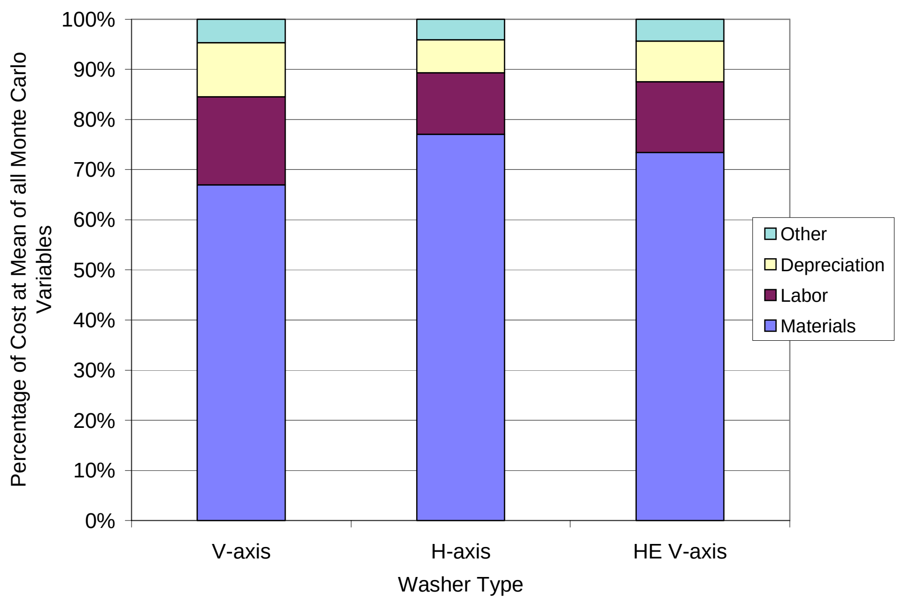

Figure 5.4 Cost Composition by Washer Type

Figure 5.5 illustrates the cost breakdown of sub-assembly by washer type.

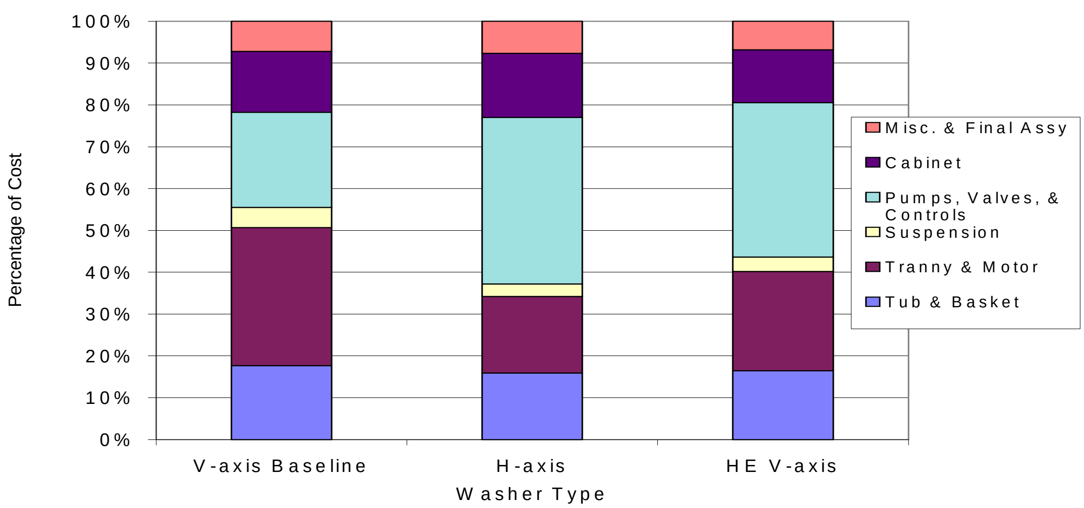

Figure 5.5 Full Production Cost Breakdown by Sub-Assembly Level

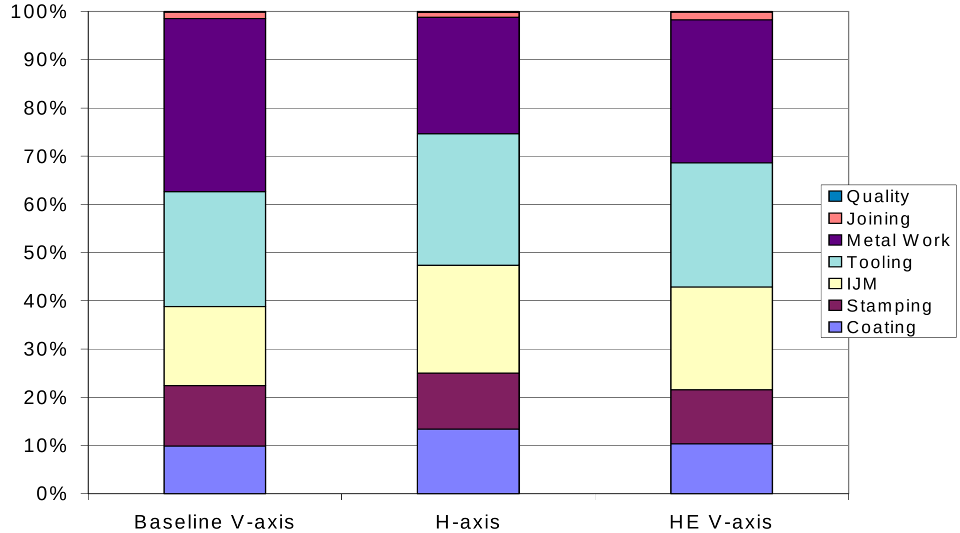

Figure 5.6 Investment Cost Breakdown by Major Manufacturing Process

Figure 5.6 provides a breakdown of investment costs by major manufacturing process.

Depreciation costs from fixed investments in equipment and tooling, a major overhead cost element, were estimated based on the requirements derived from the component cycle times and production volumes. Production volumes, in conjunction with equipment process times, determine the number of pieces of equipment necessary and the plant investment costs. Table 5.5 compares investments required to build manufacturing facilities and the depreciation lives of those investments.

Table 5.5 Greenfield Investment for and Depreciation Life of Plant, Equipment

High Volume Manufacturer Investment Requirements (USD MM)				
	Equipment	Tooling	Bldg	Total
V-Axis	$114.40	$34.17	$100.00	$248.58
H-axis	$96.02	$38.85	$100.00	$234.87
HE V-axis	$97.22	$35.20	$100.00	$232.42
Average Depreciation Lives (Years)				
	Equipment	Tooling	Bldg	Total
V-Axis	10.1	2.7	25.0	15.1
H-axis	11.0	2.8	25.0	15.6
HE V-axis	10.7	3.5	25.0	15.9

To evaluate the key parameters simultaneously and to understand the cumulative effects of variability and uncertainty we conducted a Monte Carlo simulation. This process generates random inputs within a prescribed distribution that then completes numerous iterations (10,000) to quantify the range of possible outcomes and the probability of each occurrence. Figure 5.7 shows the output from this simulation for the baseline V-axis washers.

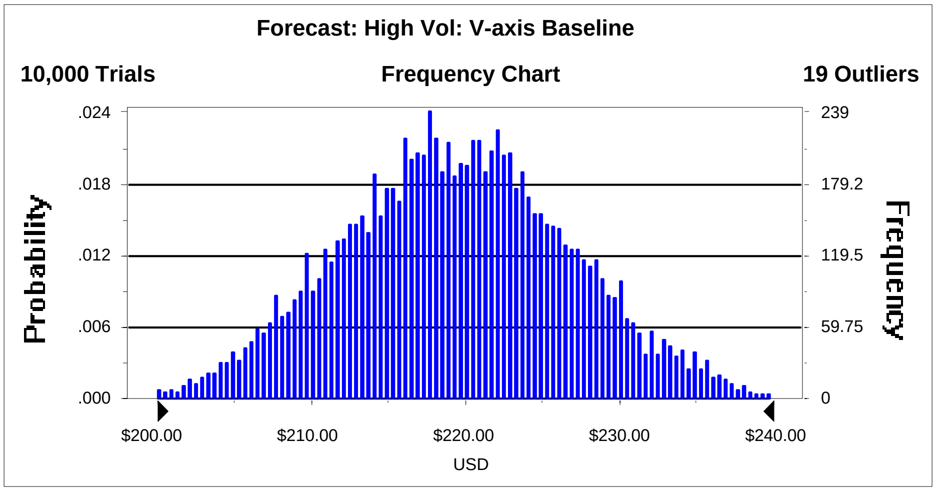

Figure 5.7 Monte Carlo Simulation of Aggregated Baseline Cost

Figure 5.8 illustrates the relative importance of all input factors on the final product cost of the V-axis baseline. Investment requirements and wages are the most important variables in determining the per unit washer cost. However, the importance of the investment factor is also due to its wide range (±50%).

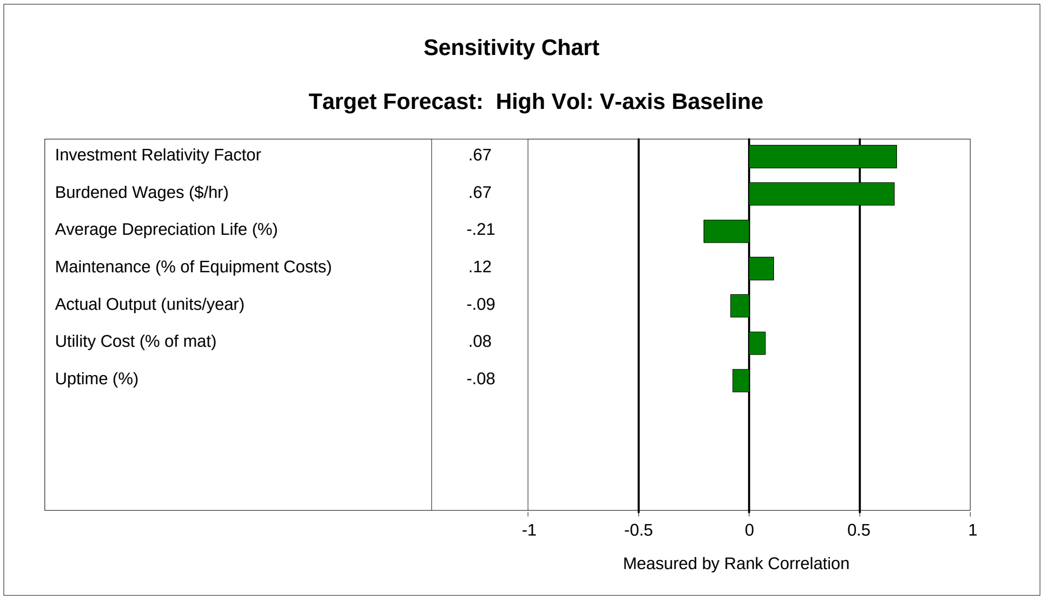

Figure 5.8 Monte Carlo Analysis: Relative Importance of Each Input Factor

In addition to the Monte Carlo simulation, which allows all parameters to vary simultaneously within the ranges given in Table 5.2, a sensitivity analysis was also conducted while holding other variables constant. The results of this analysis are presented in Table 5.6. Although Monte Carlo found wages to be the most important variable, this analysis identified Plant Investment factor as the critical variable. For the Plant Investment factor, we assume that 100% represents the baseline equipment cost. Actual higher or lower investment levels (on a percentage basis) can then be investigated.

Table 5.6 Summary of Sensitivity Analyses

MC Rank	Variable Studied	Input Parameter Variation	Variation Found in Manufacturing Cost		
			V-axis (baseline)	H-axis	HE V-axis*
1	Labor Rate (vary hourly labor rate)	$17-28	$17	$19	$16
2	Plant Investment (vary as % investment)	±50%	$24	$23	$20
3	Equipment and Tooling (vary depreciation)	7-12 yrs.	$5	$5	$4
4	Actual Plant Output (vary output)	60-100%	$5	$5	$4
5	Machine Availability (% work days)	70-95%	$4	$3	$3
6	Utility Costs - electricity, gas, steam (% of washer material costs)	1-3.5%	$3	$6	$5
7	Equipment Maintenance Costs (vary as % of installed equipment)	2.5-5.5%	$3	$2	$2

* *HE V-axis stands for the High Efficiency V-axis models studied*

In summary, the estimate of the mean production cost of the high volume baseline vertical axis washer is $219. The cost premium for horizontal-axis technology ranges from $78 to $203 over the vertical-axis baseline (based on two samples) while the cost premium for high efficiency vertical axis technology ranges from $-34 to $187 (based on four samples). It should be noted that some of the high-efficiency V-axis models analyzed represent large departures from current V-axis baselines and would require complete retooling of most manufacturing facilities. Furthermore, patent protections could restrict adoption of these designs by other manufacturers. Finally, as a group, the high efficiency V-axis clothes washers considered are less efficient than the H-axis designs analyzed.

5.4.2 Results for Low-Volume Manufacturers

The results from the analysis of low volume manufacturers (0.3 million units per year) are presented in Figure 5.9. The figures present costs for low volume manufacturers relative to the mean value for the high volume manufacturer. Figure 5.9 compares Monte Carlo simulation ranges from the low volume manufacturer to the high volume baseline V-axis cost.

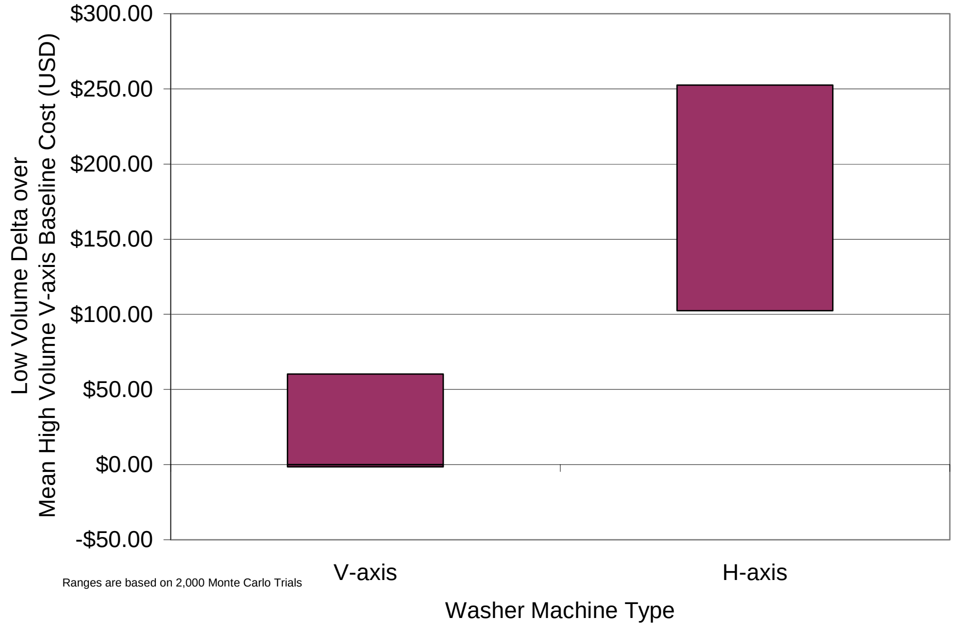

Figure 5.9 Range of Cost Premiums for Low Volume Manufacturers

Figure 5.10 presents the cost differential, by cost category, of low volume manufacturers compared to high volume manufacturers for both baseline V-axis and H-axis washers. Comparing low-volume to high volume manufacturing costs at the means of all input variables, it is to be expected that low-volume manufacturers' depreciation, and material costs are higher. Low volume manufacturers' labor costs increase mainly due to lower allocation efficiency and the additional 10% indirect labor cost penalty. Other costs (insurance, taxes, utilities, maintenance) also have a positive, but lesser impact.

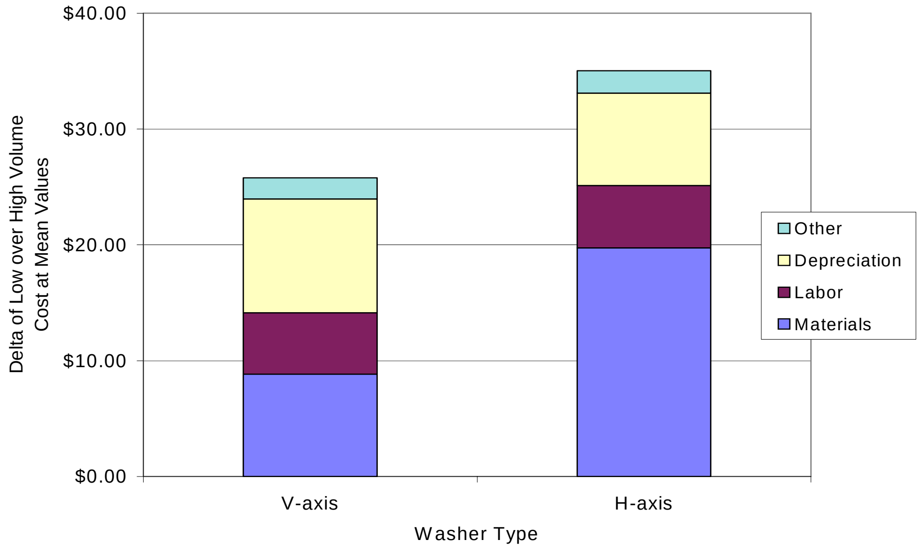

Figure 5.10 Averaged Cost Differentials by Category and Washer Type

Depreciation costs from fixed investments in equipment and tooling, a major overhead cost element,were estimated based on the requirements derived from the component cycle times and production volumes. Production volumes, in conjunction with equipment process times, determine the number of pieces of equipment and the plant investment. To size of the plant and the number of pieces of equipment, we assumed an up-time of 90%. Table 5.7 compares the investments required to build high and low volume V-axis and the H-axis plants and the depreciation lifetime of those investments.

Table 5.7 Greenfield Investment for an Annual Production Volume of 1.5 and 0.3 Million Units

Investment Requirements and Depreciation Lives									
High Volume Investment Requirements ($MM)					Low Volume Investment Requirements ($MM)				
	Equipment	Tooling	Bldg	Total		Equipment	Tooling	Bldg	Total
V-Axis	$114.40	$34.17	$100.00	$248.58	V-Axis	$29.71	$22.80	$25.00	$77.51
H-axis	$96.02	$38.85	$100.00	$234.87	H-axis	$24.39	$22.10	$25.00	$71.49
High Volume Average Depreciation Lives (Years)					Low Volume Average Depreciation Lives (Years)				
	Equipment	Tooling	Bldg	Total		Equipment	Tooling	Bldg	Total
V-Axis	10.1	2.2	25.0	15.0	V-Axis	9.6	6.2	25.0	13.6
H-axis	11.0	2.3	25.0	15.5	H-axis	9.9	6.4	25.0	14.1

Hard tooling for stamping and injection molding operations is not included in indirect material costs for either small or large manufacturers. A per-hit or simple straight-line depreciation assumption is used to calculate the yearly amortized per unit cost, whichever leads to a shorter life. These assumptions can vary greatly, and have a significant effect on the total investment and the depreciation element of the overhead costs.

Low volume manufacturers face a proportionally higher investment hurdle than their high volume counterparts. A key driver is tooling costs which are more than 60% of the investments required for high volume manufacturers while the volume is just 20%. While large manufactures can wear out tooling in less than a year, small manufacturers may have to scrap tooling due to design changes after several years of use. On average, tooling expenses are 50% higher for small manufacturers and the average tool life is twice as long. Thus, large manufacturers have an inherent advantage in how quickly they can cycle through tooling changes since the penalty is lower.

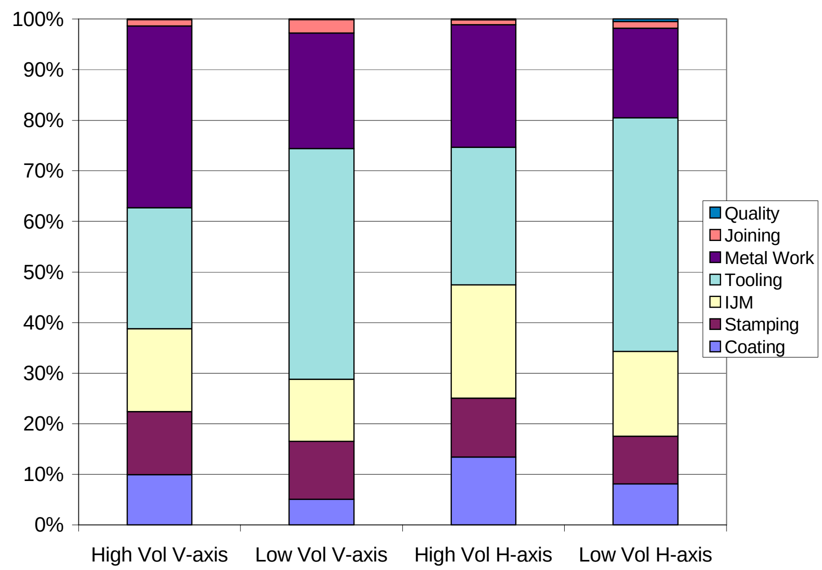

Figure 5.11 Investment Requirements by Category

In summary, the estimate of the full production cost of the baseline vertical axis washer was $219 for large manufacturers. The cost premium for low manufacturers over the mean high volume baseline V-axis ranges from -$1 to $60 over for the V-axis design and $103 to $253 for the H-axis designs, depending primarily on design and variations in key input parameters (Figure 5.9). At the mean of all input variables small manufacturers producing V-axis washers have a cost disadvantage of $26. For H-axis washers this disadvantage increases to $35. The greenfield assumption possibly overstates the V-axis penalty as depreciation costs as observed in 10K reports are lower than calculated in this analysis. This indicates that at least a portion of current V-axis facilities are able to use fully depreciated equipment. This equipment may not be reusable to produce H-axis washers however.

The cost disadvantages presented in Figure 5.10 is for production cost only and does not include any additional scale disadvantages that exist in non-production costs such as selling, general and administrative and R&D. Also the designs investigated may be patented, making them impossible for small manufacturers to replicate, and increasing the cost disadvantage even more.