CPSC Staff Statement on Manufacturing Cost Analysis Report: "Manufacturing Cost Analysis Cordless vs. Corded Window Covering Products"[1]
January 2017

The report titled, "Manufacturing Cost Analysis: Cordless vs. Corded Window Covering Products," presents the findings of research conducted by Dr. Jitesh Panchal, a subcontractor for Industrial Economics (IEc) under Contract CPSC-D-15-004, Task Order 4. In 2015, CPSC staff issued this task order to provide estimates of the incremental manufacturing costs associated with cordless window coverings over corded ones. The attached report details the results of this work.

The attached report provides an estimate of incremental manufacturing costs associated with various cordless window coverings. The methodology is based on a combination of (i) the product archaeology approach for identifying the manufacturing content of products, and (ii) the Boothroyd-Dewhurst approach for calculating manufacturing and assembly costs. The focus of the study is on entry-level stock products that are available for purchase off-the-shelf in home improvement stores. The study also attempted to distinguish between U.S. and overseas production (i.e., high cost and low cost production environments), and to account for variation in production volume.

[1] This statement was prepared by CPSC staff, and attached report was produced by IEc for CPSC staff. The statement and report have not been reviewed or approved by, and do not necessarily represent the views of the Commission.

Manufacturing Cost Analysis

Cordless vs. Corded Window Covering Products

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Executive Summary

The goal of this study is to estimate the incremental manufacturing cost of implementing cordless designs within window covering products. The methodology is based on a combination of (i) the product archaeology approach for identifying the manufacturing content of products, and (ii) the Boothroyd-Dewhurst approach for calculating manufacturing and assembly costs. Six classes of window covering products are analyzed: (a) horizontal blinds, (b) cellular shades, (c) roman shades, (d) vertical blinds, (e) roller shades, and (f) curtains and drapes. Sample products from each class are disassembled, and the incremental manufacturing costs are estimated. The primary focus is on entry-level stock products that are available for purchase off-the-shelf in home improvement stores. The results indicate that the cost of implementing cordless technology differs significantly between the manual cordless and the motorized concepts. For manual cordless products, the incremental costs can be as low as a few dollars per product. On the other hand, for motorized products, these incremental costs can be in the range of hundreds of dollars. To compare the incremental manufacturing costs for lower-end products with corresponding costs for higher-end custom products, a similar approach is applied to Hunter Douglas products. The results demonstrate that the incremental costs of implementing cordless technology for the higher-end products is higher than for the corresponding lower-end products. Key sources of uncertainty in our analysis are described in greater detail throughout this report.

Methodology

In this section, an overview of the methodology used to estimate the incremental manufacturing costs of cordless designs within window covering products is provided. The first section provides a conceptual overview of the steps. Then, key factors typically affecting cost estimates, such as the type of product, the design concept, the product's size and weight, its quality, and the manufacturing and assembly location are discussed. Next, the application of the methodology to window covering products is described. Finally, key modeling assumptions are presented.

Product Archaeology Approach

The overall methodology is based on the product archaeology approach developed by Ulrich and Pearson (1998) for identifying the manufacturing content, supplemented by the Boothroyd-Dewhurst (2010) approach for calculating manufacturing and assembly costs. The methodology is used to calculate the differences in manufacturing cost for functionally similar products through direct observation and comparison of the physical products. The comparison reveals the differences in the design attributes, such as the number and complexity of parts, number of fasteners, and materials used. The differences in design attributes are then assessed in terms of manufacturing content, defined as the set of attributes that drive manufacturing cost. These include additional attributes such as assembly and processing time. The manufacturing content is finally used to estimate the incremental manufacturing costs for an assumed manufacturing setting.

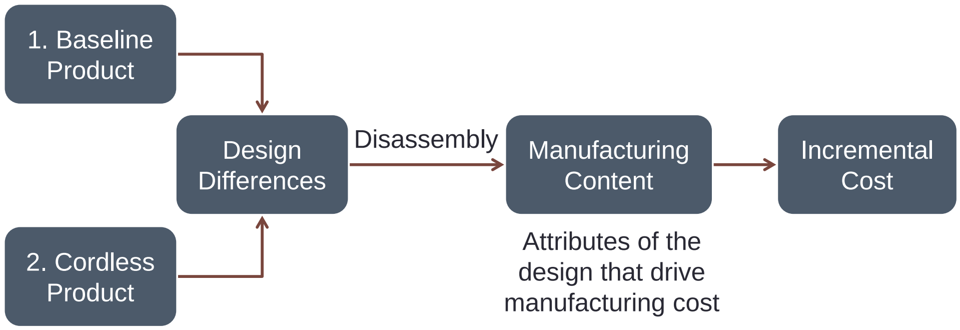


Figure 1 - Overall approach based on product archaeology

Factors Affecting Incremental Manufacturing Costs

There are a number of factors that affect the incremental costs of implementing cordless technologies within window covering products. The major factors include (i) product category, (ii) the design concept used, (iii) the size and weight of the specific product, (iv) the quality of the desired product, (v) the supply chain of the manufacturer, and (iv) the place where the products are manufactured and assembled. These factors are further discussed in the following.

Product category

Different types of window covering products have different incremental manufacturing costs for the cordless option. One of the reasons is the difference in functional requirements. For example, compared to cellular shades, blinds have an additional functional requirement of tilt, which necessitates additional parts, and therefore additional cost. Additionally, certain product types are more suitable for certain cordless concepts. For example, due to their design, it is easier to implement motorization in roller shades than other product types.

Design concept used

For a given product type, there are multiple cordless design concepts. Background research conducted for the study revealed that window-covering manufacturers have a variety of patents on cordless designs, and new designs are continuously entering the market. Some examples of patents and patent application publications include 7975748, 8522852, 2012/0267060, 2013/0032300, 2014/0216666, 2011/0265958, 2014/0311686 and 2015/0191970. These designs vary widely in their complexity and functionality. For example, some design concepts use sophisticated transmission systems to ensure that the user needs to apply the same amount of force at any position of the bottom rail (see example in Figure 2) whereas some other concepts are based on simpler spring motor assembly with friction which require the user to apply different amounts of forces to operate the product (see example in Figure 3). Therefore, depending on the requirements of the final product, different concepts may be suitable, thereby affecting the cost.

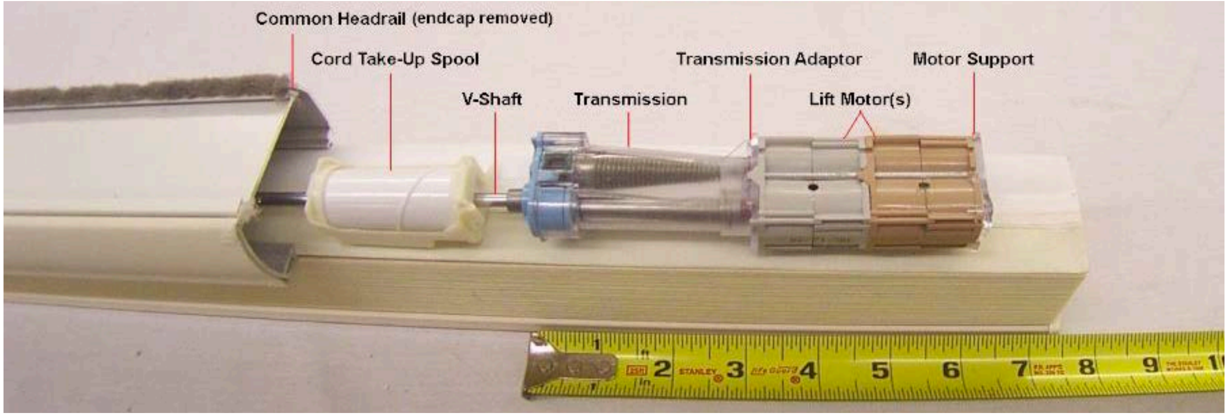


Figure 2 – Cordless lift system from Hunter Douglas (source: http://www.automatedshadestore.com/shop/product-info.php?HD_Duette_LiteRise_Lift_System_Replacement_Kit-pid578.html)

Figure 3 - Cordless module based on Patents 7975748 and 8522852

Size and weight of the specific product

For a specific product type, the product size and the resulting weight also affect the incremental manufacturing cost of cordless products. The weight is dependent on both size and the type of material used for the window covering. For example, faux wood blinds have higher weight than identically sized vinyl blinds. Increasing the size and the weight may result in design modifications. In some cases, these modifications may be as simple as adding additional cordless modules to the product or changing the sizes of components, whereas in other cases, the required design changes may make the design concept unusable. For example, the use of constant force springs with friction is appropriate for products where the change in weight over the travel of the bottom rail is small. However, in large faux wood blinds where the change in weight is high, the design may not be feasible.

Additionally, any customization of the product (e.g., changes in width & length, choice of fabric, etc.) requires that the cordless technology be designed to work for the entire range of customization, thereby increasing the cost.

Quality of the desired products

There is a cost associated with higher quality products. For cordless technologies, the same concept can be manufactured at different qualities by using different materials (e.g., steel gears instead of plastic gears), different tolerances and surface finish, and using sophisticated transmission systems for smoother operation. Higher quality increases the life and reliability of the product, thereby reducing warranty costs for the manufacturers.

The supply chain and where the parts are being manufactured and assembled

The cost is dependent on whether the parts are directly manufactured by the same firm or purchased from suppliers. Similarly, the cost is also dependent on whether the parts are manufactured within the United States or overseas.

Application to Window Covering Products

This study estimates the incremental costs of manufacturing for sample cordless products in each of the following window covering product categories:

(a) Horizontal blinds;
(b) Cellular shades;
(c) Roman shades;
(d) Vertical blinds;
(e) Roller shades; and
(f) Curtains & drapes.

Although a few examples of higher-end custom window coverings were evaluated, the study primarily focuses on the lower-end of the market stock products that can be purchased off-the-shelf at home improvement stores such as HomeDepot, Lowes and Menards. To gain an understanding of the diverse cordless design concepts used, *manual cordless* products were chosen for horizontal and vertical blinds, cellular shades, and roman shades, and *motorized* products were studied for roller shades and curtains and drapes.

The study did not focus on higher-end custom products because of the large amount of variety in options such as sizes, materials, and fabrics. These options would increase the incremental manufacturing cost of cordless products. Additionally, the custom products are manufactured in smaller quantities, which further increase the incremental cost.

Smaller sizes of the products were acquired for disassembly and product archaeology analysis. Changes in the designs to accommodate bigger sizes were observed, and the manufacturing costs were correspondingly adjusted to study the effect of size on the incremental manufacturing cost. Uniform quality standards were assumed across the products to enable comparison across different design concepts. It was assumed that the organization owns the manufacturing facilities, and all plastic parts are manufactured in-house. No price markups were considered.

Since manufacturing cost varies with the environment, the impact of different cost environments is analyzed. Two manufacturing cost environments are considered: (a) high cost (corresponding to manufacturing within the United States), and (b) low cost (to represent overseas manufacturing costs). The parameters for high cost environment are based on data obtained from the U.S. Bureau of Labor Statistics[1], and the parameters for the low cost environment are based on Ulrich and Peterson (1998). Further details are provided in Appendix B.

Assumptions

The model used in this study only quantifies the incremental manufacturing costs. The costs associated with design innovation, customization, licensing of technology, etc. are not considered in this model. For a manufacturer, these will add further costs to implementing the cordless technologies.

The calculations carried out in this study are based on openly available data sources, and widely accepted manufacturing cost calculation methods. Average values of labor cost are used. The model is based on assumed assembly sequence, materials, and manufacturing process.

The focus of this study is on estimating the manufacturing costs of the design concepts used in cordless products. During the analysis, it was observed that different products were manufactured at different quality levels (e.g., surface finish, tolerances, etc.). However, for a meaningful comparison across different concepts and product categories, the quality was assumed to be the same for all the products. Therefore, the resulting costs correspond to entry-level products in the market.

Finally, the study does not attempt to model the actual cost structure of any specific manufacturers' production system, which can vary based on factors such as where manufacturing is carried out, actual wage rates, specific assembly sequence used, the structure of the supply

[1] See Appendix B for specific sources of parameter values.

chain, the ability to negotiate with suppliers, the actual quantities produced, the efficiency of operations, etc. Much of this information is specific to the manufacturers, and is proprietary.

Overview of the Cost Model

The previous chapter outlines the steps in the analysis (see Figure 1). This chapter describes, in greater detail, the methods and models employed in the "Manufacturing Content" and "Incremental Cost" steps. Specifically, the overall cost model, as presented by Ulrich and Pearson (1998), consists of the cost of assembly, purchased parts, molded plastic parts, sheet-metal parts, tooling, supervision, inventory, facilities, and energy on a per-product basis.

$$C = C_{\text{Assembly}} + C_{\text{PurchasedParts}} + C_{\text{MoldedParts}} + C_{\text{SheetMetalParts}} + C_{\text{Tooling}} + C_{\text{Supervision}} + C_{\text{Inventory}} + C_{\text{Facilities}} + C_{\text{Energy}}$$

This cost equation is used in this study to estimate the incremental cost of manufacturing and assembling a cordless unit. The individual cost components in the equation are calculated using the manufacturing content identified through product archaeology. In this section, the attributes of manufacturing content from Ulrich and Pearson, and well as Boothroyd and Dewhurst's supporting models for assembly cost and the cost of molded parts are described in greater detail.

The assembly cost (C_{Assembly}) and the cost of molded parts ($C_{\text{MoldedParts}}$) are calculated using the Boothroyd and Dewhurst method, described in Boothroyd et al. (2010). The parameters in the cost model are obtained from Ulrich and Pearson (1998) or publicly available data (e.g., wage rates, hardware prices). Additional details, including the equations for calculation of individual cost components are presented in Appendix A, and the values of the parameters are listed in Appendix B.

Manufacturing Content

The manufacturing content consists of the set of attributes of design that drive manufacturing cost. The details of the attributes considered within manufacturing content are as follows:

1. *Assembly content* (measured in hours): the time required to assemble the parts into the product. The Boothroyd-Dewhurst method for manual assembly is used for estimating the assembly time (see discussion in the following section).
2. *Purchased parts* (measured in US$): the cost of purchasing standardized components such as screws, washers, bearings, motors, etc.
3. *Sheet metal use* (measured in kg): the mass of sheet metal consumed for each part. The mass of sheet metal is converted to equivalent mass of mild steel through the ratio of metal cost to mild steel cost.

4 *Sheet metal processing time* (measured in hours): the total processing time for each sheet metal part.
5 *Sheet metal press requirements* (measured in kN-hours): the sum of maximum press force multiplied by the press cycle time for all sheet metal parts.
6 *Sheet metal tooling fabrication time* (measured in hours): comparison of size and complexity to dies.
7 *Plastic use* (measured in kg): the mass of plastic parts with allowance for mass of sprues and runners. The mass of resins is converted to the mass of polypropylene with equivalent cost. The equivalent mass of polypropylene is used to calculate the cost of plastic used in the product.
8 *Molding processing time* (measured in hours): the sum of time required for molding of plastic parts.
9 *Molding machine requirements* (measured in kN-hours): the sum of clamp force times mold cycle time for all plastic parts.
10 *Total plastic mass* (measured in kg): the mass of all plastic parts in the product. This parameter is used for energy cost calculation.
11 *Mold fabrication time* (measured in hours): the total amount of time required for mold fabrication for all plastic parts in the product.
12 *Tooling lead-time* (measured in weeks): the latency between the initiation and completion of tooling.
13 *Number of parts* (count): the total number of parts in the product.
14 *Number of molded parts*: the number of molded plastic parts.
15 *Number of unique parts*: the number of unique parts in the bill of materials.
16 *Number of fasteners*: the number of fasteners in the product.

Assembly Cost Estimation

The estimation of assembly cost ($C_{Assembly}$) is based on the Boothroyd and Dewhurst (2010) method. The method is based on a classification and coding system for manual handling and assembly processes. The assembly costs are influenced by the number and types of parts, and the ease of handling, insertion and fastening processes.

Manual handling times are dependent on the part size and symmetry in different directions. Smaller parts (e.g., those with thickness less than 2mm and size less than 6mm) are more difficult to handle than larger parts, and therefore take more handling time. Parts that nest or tangle with each other (e.g., springs) are associated with higher handling times than the parts that can be grasped and manipulated with one hand without grasping tools. Heavier parts that require handling assistance are associated with greater handling times. The detailed classification system including two-digit codes, their definitions and corresponding time standards for manual handling times (in seconds) is presented in Boothroyd et al. (2010), page 83.

Similar classification system has also been developed for manual insertion and fastening. Parts that are easy to align and present no resistance to insertion take less time for assembly, as compared to parts that require holding down, are difficult to align, and present resistance to insertion. Assembly operations that do not require screwing operation or plastic deformation take less time compared to screw tightening. The details of the classification system and associated average times (in seconds) are presented in Boothroyd et al. (2010), page 84.

The approach is implemented in an Excel worksheet for each product, and corresponding assembly time (in hours) is calculated for the sub-assemblies that differentiate the cordless products from the corded products. A sample worksheet for the assembly of a cordless module is presented in Figure 4. In the worksheet, angles alpha and beta refer to the symmetry of the parts. Symmetrical parts are easier to handle and assemble, and therefore require less time. The operation time is equal to the sum of manual handling time and the manual insertion time, multiplied by the number of times the operation is carried out consecutively.

S.No.	Part Name	Alpha	Beta	Alpha+Beta	# of times the operation is carried out consecutively	two-digit manual handling code	manual handling time per part	two-digit manual insertion code	manual insertion time per part	operation time (sec)
1	Cartridge part 1	360	180	540	1	"20"	1.8	"31"	5	6.8
2	Cartridge part 2	360	180	540	1	"20"	1.8	"06"	5.5	7.3
3	Gear_basic	360	13.846	373.85	2	"10"	1.5	"01"	2.5	8
4	Gear_spring	360	13.846	373.85	2	"10"	1.5	"01"	2.5	8
5	Constant Force Spring	360	0	360	2	"10"	1.5	"00"	1.5	6
6	Cord	360	360	720	2	"88"	6.35	"08"	6.5	25.7
7	Tilter base	360	180	540	2	"20"	1.8	"41"	7.5	18.6
8	Tilter pulley	180	180	360	2	"10"	1.5	"00"	1.5	6
9	Tilter head	360	180	540	2	"20"	1.8	"00"	1.5	6.6
10	Tilter cord guide	360	360	720	2	"31"	2.25	"03"	3.5	11.5
11	Positioning pins	360	0	360	2	"52"	4.75	"41"	7.5	24.5
									Time in seconds	129
									Time in hours	**0.036**

Figure 4 - Sample worksheet for assembly cost calculation

Cost of Molded Parts

The cost of molded parts ($C_{MoldedParts}$) is dependent on the cost of material ($C_{plastic}$) and the cost of molding. The cost of molding operation is further dependent on mold cost, and the machine operation costs (including labor). The mold cost for plastic parts is calculated based on the approach developed by Boothroyd and Dewhurst, detailed in Boothroyd et al. (2010), pages 349-359. A sample worksheet for the amount of time required for mold manufacturing and calculating the parameters required for manufacturing time calculations is presented in Figure 5.

	Part Length (mm)	25	
	Part Width (mm)	16.5	
	Part Height (mm)	16.5	
	Number of surface patches	13	
	Weight (g)	2.7	
	Avg Wall Thickness (mm)	2	
		Value	**Points (hours)**
1	Base plate area (A_c), cm^2	291.375	70.64
2	Combined plate thickness (h_p)	16.65	0.00
3	Projected area (A_p), cm^2	4.125	10.54
4	Geometric complexity, X	1.3	8.14
5	Number of side-pulls	0	0.00
6	Number of internal lifters	0	0.00
7	Number of unscrewing devices	0	0.00
8	Surface Finish/Appearance	15%	2.80
9	Tolerance Level	Table 8.7	0.00
10	Texture	0	0.00
11	Parting Plane	Table 8.8	0.00
		Total Points for single cavity (hours)	**92.12**
		Number of Cavities	2
		Total points for multi-cavity mold (hours)	156.66
		Cooling time (sec)	10.05
		Clamping force (kN)	13.629
		Cycle Time (hours)	0.006
		Clamping force * Cycle Time (in kN hours)	0.085

Figure 5 - Sample worksheet for mold manufacturing time calculation

The mold cost is composed of two major components: (i) mold base costs, and (ii) cavity and core fabrication costs. The mold base cost depends on the surface area of the mold base plates and the thickness of cavity and core plates. The cavity and core manufacturing costs depend on various factors including the projected part area, the complexity of the part, the number of ejector pins required, number of cavities, required surface finish and tolerance level, texture requirements, and the number of side pulls and internal lifters. The cost of labor during the molding operation is dependent on the cycle time and the hourly cost of the machine is dependent on the clamping force. The detailed equations are provided in Appendix A.

Analysis of Selected Stock Products

This chapter presents the results of the analysis of products in six window covering categories, including: (1) horizontal blinds; (2) cellular shades; (3) roman shades; (4) vertical blinds; (5) roller shades; and (6) curtains and drapes. I analyze manual cordless technologies for the first four categories and motorized technologies for the last two. The analysis of the manual technologies focuses on entry-level products in terms of price (e.g., stock products).

1. Horizontal Blinds – Manual Cordless

Within the horizontal blinds category, the following product was analyzed: Cordless Vinyl Mini-blinds manufactured by Intercrown and marketed under the Designer's Image brand. The market price of the product (Menards SKU: 7901900) for the size of 27" width x 64" height is $15.99. This is one of the lowest cost cordless products available in the market. This product was selected for analysis of the incremental manufacturing costs associated with entry-level products. The product is available in different widths ranging from 27 inches to 72 inches. The market price (Menards SKU: 7901966) for the maximum width of 72 inches is $39.99.

Figure 6 – Picture of the horizontal blinds analyzed: Cordless Vinyl Mini-blinds

Figure 7 - Picture of the cordless module in the Cordless Vinyl Mini-blinds

The product with the 27" width was chosen for disassembly and product archaeology. A picture of the product is shown in Figure 6. A picture of the cordless module for this product is shown in Figure 7. The cordless module is the primary distinguishing feature between the cordless product and the corresponding corded product. Therefore, it is analyzed in detail.

The cordless module is disassembled and all the parts are identified. A picture of all the parts of the cordless module is shown in Figure 8. The module consists of fourteen plastic parts, two metal springs and two metal pins. The cost of manufacturing and assembling these parts is calculated using the method outlined in the previous section. The resulting costs for the two cost environments for different production quantities are shown in Figure 9.

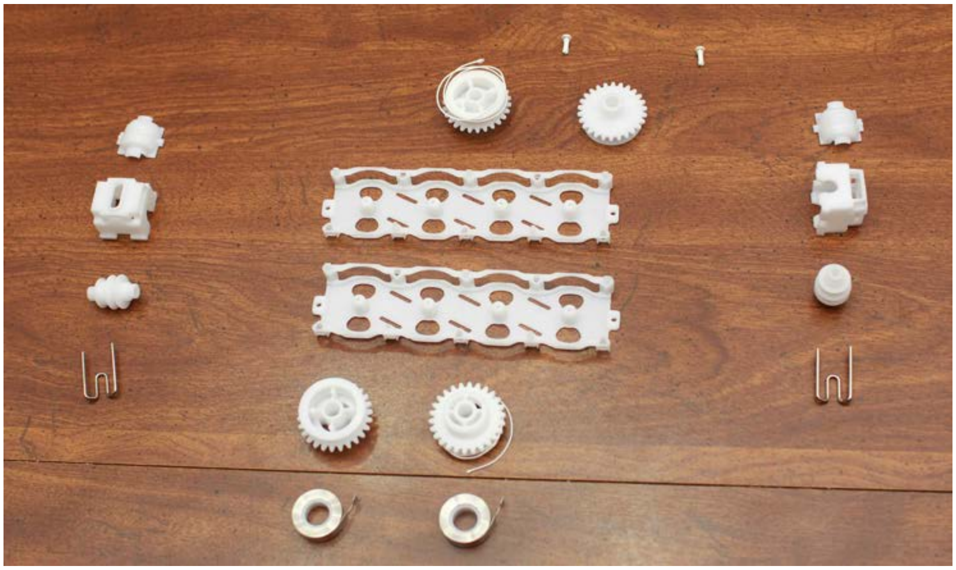


Figure 8 - Components of the cordless module in the selected horizontal blinds

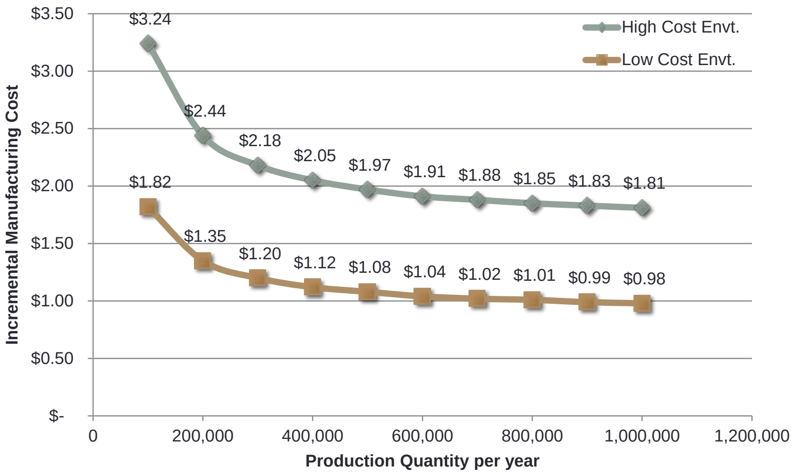


Figure 9 - Results from the cost model (horizontal blinds)

According to the model, the incremental cost of manufacturing (including assembly) the cordless module is expected to be between $1.81 and $3.24 per unit in the high-cost manufacturing environment, and between $0.98 and $1.82 per unit in the low-cost manufacturing environment.

This corresponds to approximately 11-20% of the market price for the high cost environment and 6-11% of the market price in the low price environment. The reduction in cost with the increase in production quantities is a result of the spread of fixed costs of machines and tooling (e.g., molds for plastic parts) over higher production quantities.

As the size of the product increases, the cordless module needs to be scaled (or increased in number), thereby increasing the incremental manufacturing cost associated with the cordless design. For the product analyzed in this study, it is observed that the maximum size available for purchase is 72” x 64”. Two cordless modules for the larger product result in doubling of the incremental cost. The corresponding incremental costs are $1.96 - $3.64 in the low cost environment and $3.62 - $6.48 in the high cost environment. With a retail price of $39.99, the increased manufacturing cost as a percentage of retail price is 5 – 9% for the low cost environment and 9 – 16% in the high cost environment. Therefore, the effect in terms of the percentage of retail price is lower for larger sized products than for smaller sized products. Considering this effect, for the rest of the products, the smallest size was chosen for analysis.

2. Cellular Shades – Manual Cordless

In the cellular shades category, the following product was analyzed: *Window Images* by Spring Window Fashions” in 23” width X 72” height. The retail price of the product is $29.99.[2] The product is also available in widths up to 72 inches. The corresponding retail price for the 72” width X 72” height is $83.98.[3] Since the incremental manufacturing cost of cordless products as a percentage of the retail price is higher for smaller-sized products, the smallest size was considered for analysis.

The product uses a cordless module that is based on patents 7975748 and 8522852. The detailed diagram of the cordless module is shown in Figure 12. The details of assembly of the cordless module are shown in Figure 13.

[2] Menards SKU: 7913324
[3] Menards SKU: 7913928

Figure 10 – A picture of the cordless cellular shade product analyzed

Figure 11 - Cordless module used in the cellular shades product analyzed

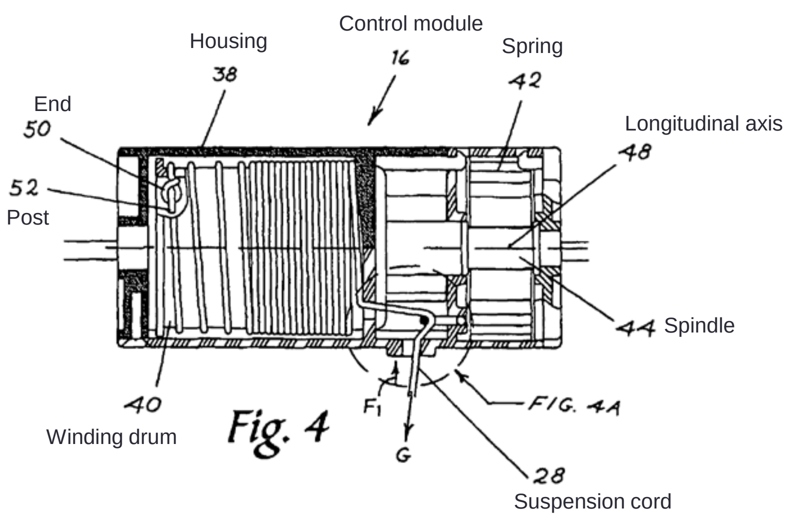


Figure 12 – Details of the cordless module (Source: Figure 4 from US patent 7975748. Annotations added)

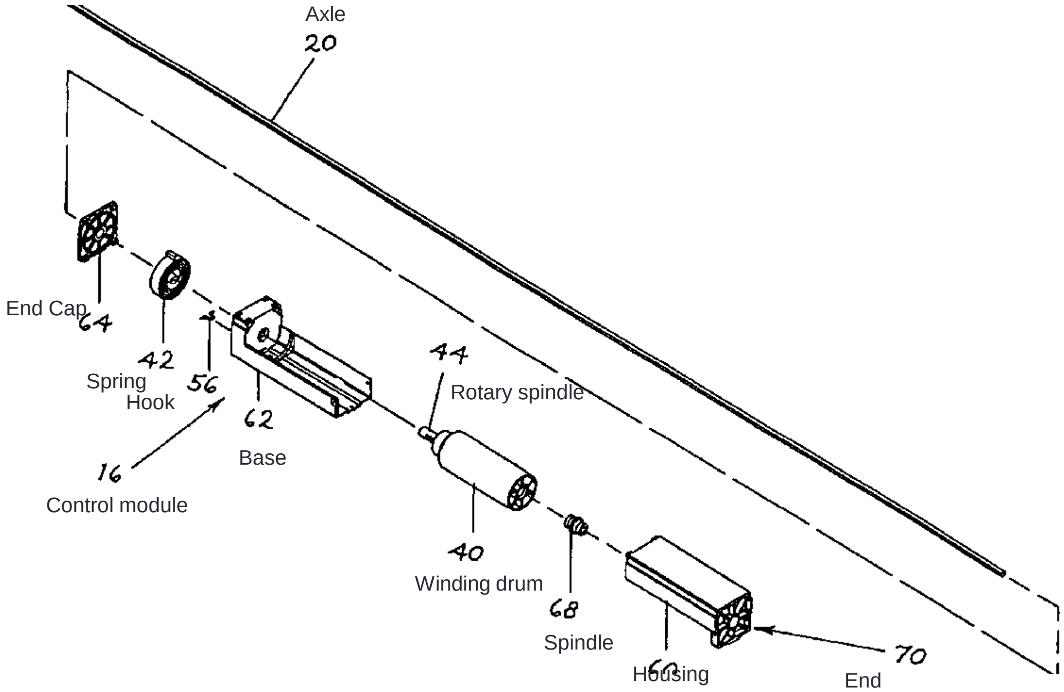


Figure 13 – Detailed assembly diagram of the cordless module (Source: US patent – 7975748 annotations added)

A picture of the parts of the cordless module obtained after disassembly is shown in Figure 14. The module consists of 11 plastic parts, one flat spring, and a metal axle. It is observed that the plastic parts for this specific product have a higher quality and better surface finish. However, to investigate the cost of producing this concept, the quality parameters are assumed to be the same as in the module for the horizontal blinds.

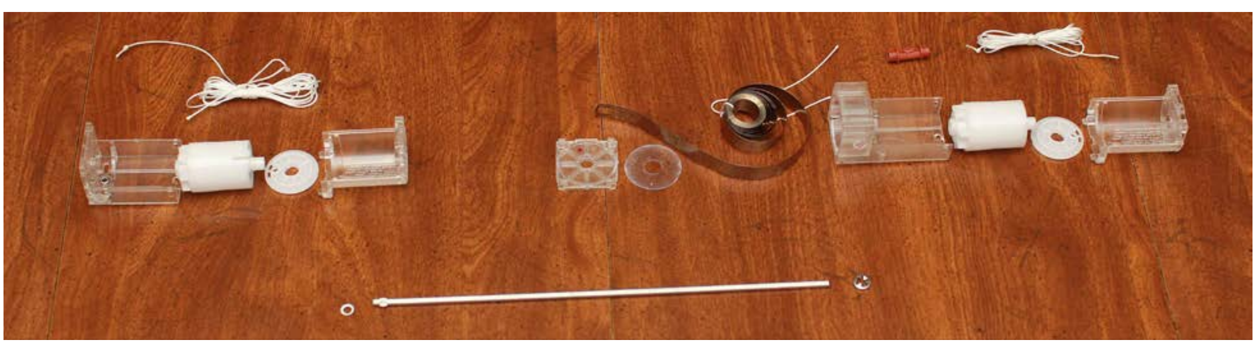


Figure 14 – Parts from the disassembled cordless module for the product analyzed

The results show that the cost of manufacturing this concept in a high-cost manufacturing environment ranges from $1.57 to $2.79, depending on the production quantities. The cost of manufacturing in the low-cost environment is in the range of $0.85 to $1.57. This corresponds to approximately 5-9% of the retail price in the high-cost environment, and 3-5% in the low-cost environment. For higher quality standards, these percentages are expected to be higher.

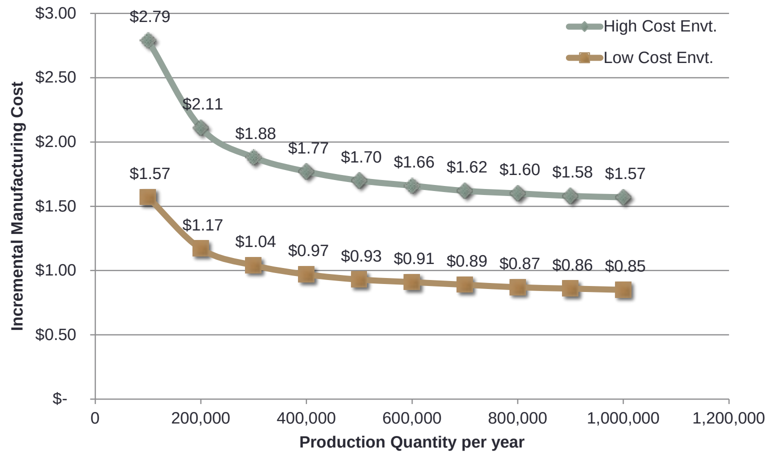


Figure 15 – Results from the cost model (Cellular Shades)

The effect of product size was also investigated for this concept. For the product size of 72” width X 72” height (which is the largest size offered for this product by this manufacturer), the manufacturer uses an additional cordless module. This is expected to increase the manufacturing cost of the cordless modules by no more than a factor of two. Therefore, the range of incremental costs would increase to $3.14 to $5.58 in the high cost environment. Using $83.98 as the retail price of the product, this range corresponds to 4-7% in the high-cost environment. Similarly, the incremental cost in the low cost environment is also doubled.

3. Roman Shades – Manual Cordless

The product analyzed in the Roman shades category is the *Cordless lift woven wood roman shades* by Intercrown. The retail price of the product for 27” width X 64” height is $39.99.[4] A picture of the product is shown in Figure 16. Pictures of the cordless module are shown in Figure 17.

[4] Menards SKU: 7900806

Figure 16 – A picture of the Roman shades product analyzed

The parts of the cordless module, obtained after disassembly are shown in Figure 18. The product uses a cordless module that is similar to the one used in the horizontal blinds discussed above. Again, the majority of the parts are injection molded plastic parts. Due to the weight of the product, the number of springs used is greater than those used in the horizontal blinds. Additional parts are included for cord guides.

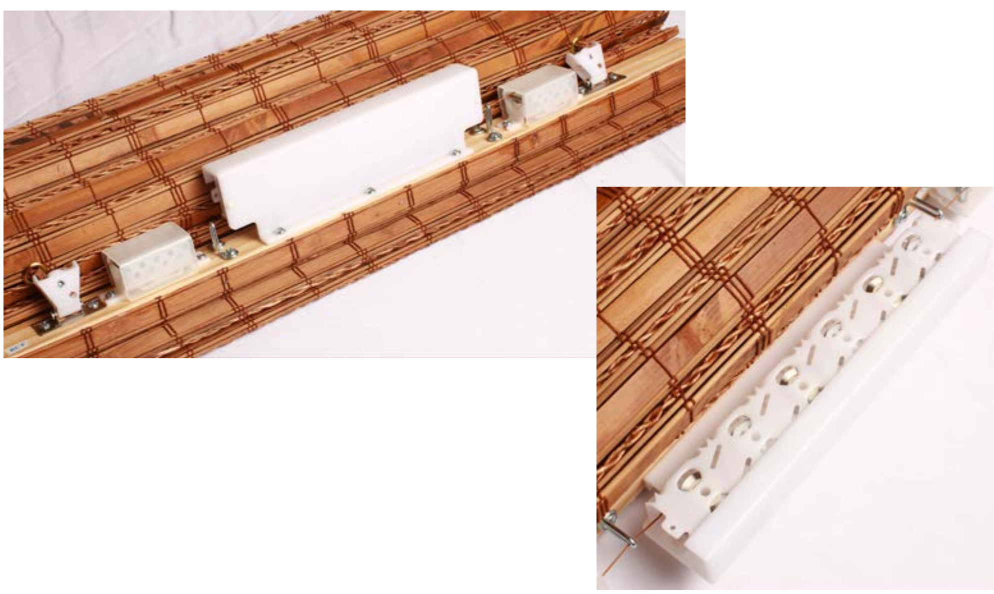


Figure 17 – Picture of the cordless module used in the roman shades analyzed

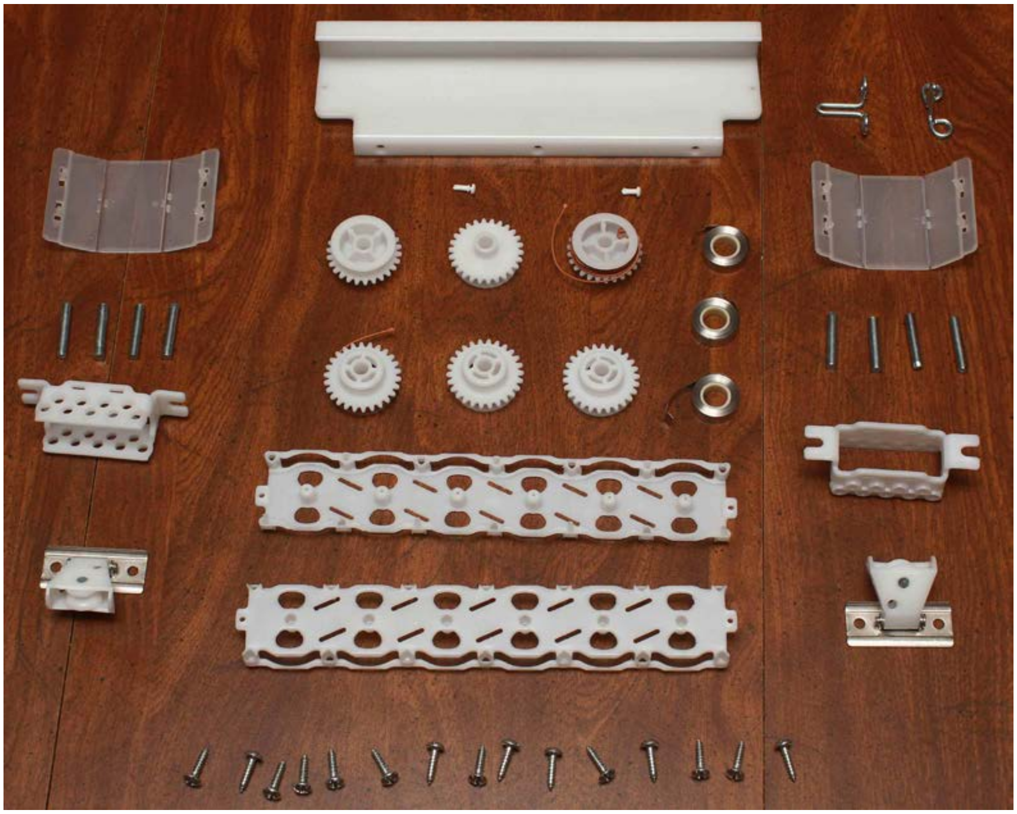


Figure 18 – Parts used in the cordless module

The results from the cost model for the Roman shades are shown in Figure 19. The incremental manufacturing cost for high-cost environment is in the range of $3.39 - $6.03 depending on the production quantity. The corresponding range for the low-cost environment is $1.55 - $3.06. This increased manufacturing cost as a percentage of retail price is 8 – 15% for a high cost environment, and 4 – 8% for a low cost environment. This increase in cost, as compared to the horizontal blinds can be attributed to the increase in the number of parts (e.g., additional springs, and cord guides) to accommodate the higher weight of the product, and the unique design needs for Roman shades product category.

For the larger sized Roman shades (72” x 64”), two such cordless modules are used. Therefore, the incremental manufacturing cost is twice that of the smaller sized shades (27” x 64”). This incremental cost corresponds to $3.10 - $6.12 for a low cost environment and $6.78 - $12.06 for a high cost environment. The retail price for 72” x 64” shade is $94.99. Therefore, the increased manufacturing cost as a percentage of retail price is 3 – 6% for a low cost environment, and 7 – 13% for a high cost environment.

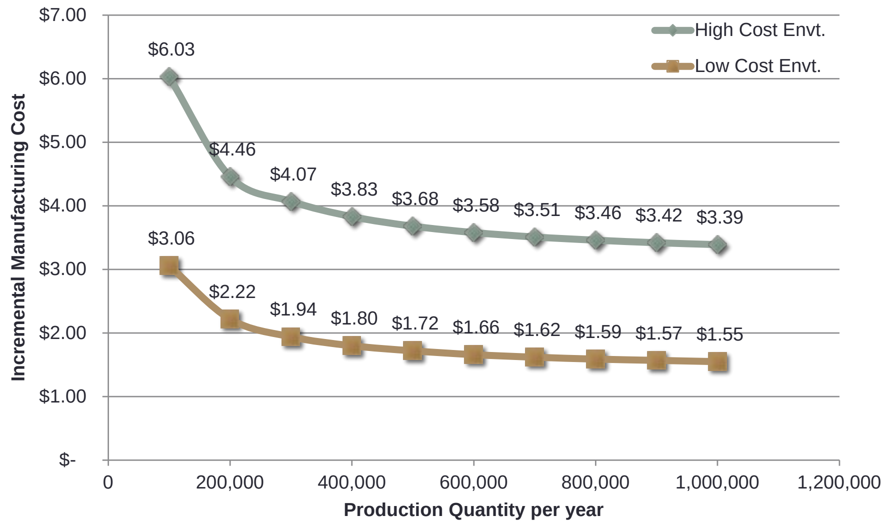


Figure 19 – Results from the cost model (Roman shades)

4. Vertical Blinds – Manual Cordless

In the vertical blinds category, customers can purchase the headrail and louvers separately. The louvers are identical for the cordless and corded products. Therefore, only the headrail was analyzed. The product analyzed in the vertical blinds category is 53" width vertical blind headrail[5] sold under the brand Bali by Springs Window Fashions. The retail price of the head rail is $15.97.

A picture of the purchased headrail is shown in Figure 20. The product was disassembled to identify the parts that are different between the cordless and the corded products. It was found that most of the components between the two products are similar. There is only one unique module (with five plastic parts and one metal pin) in the cordless product that converts the rotation of the wand into the rotation of the wand into the rotation of the shaft. These parts are shown in Figure 21.

[5] HomeDepot SKU: 564368; Model No: 65-0232-00

Figure 20 - A picture of the product analyzed in the vertical blinds category

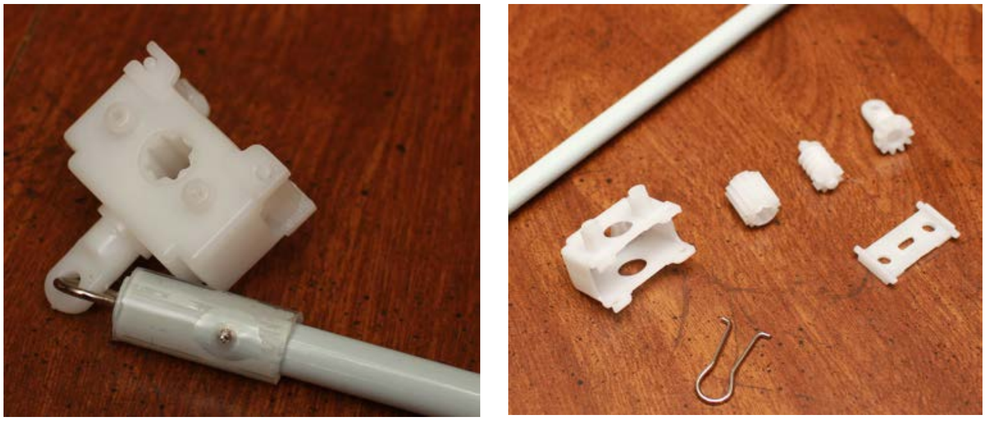


Figure 21 – Unique parts in the cordless vertical blinds (assembled and disassembled)

These unique parts in the cordless product replace a set of parts in the corded products, as shown in Figure 22. These parts have similar size, complexity and materials. Therefore, the cost of manufacturing of the unique parts in both corded and cordless products is identical. This is likely to be one of the reasons that most of the vertical blinds available off-the-shelf at home improvement stores are cordless with wand-control.

Figure 22 – Pictures of parts used in corded vertical blinds

While the wand control is a cost effective cordless control mechanism, it may not be suitable for all vertical blinds. For example, large vertical blinds (e.g., over 8 feet in height) may be difficult to operate using a wand. Similarly, custom blinds using heavier materials require greater operating forces, thereby posing difficulty in wand-operation.

Analysis of Motorized Products

Motorized cordless operating systems are increasingly becoming popular in the window covering products. Motorization of products involves the choice of (i) motors, (ii) power options, and (iii) control options. Motors are available in a variety of torque outputs, depending on the needs of the application. The power options include battery-powered, plug in (24V DC), and in-wall wired (120V AC, 12V DC, or 24V DC). Control options include hand-held switches, wireless wall switch, wired wall switch, and sophisticated home automation systems with sensors.

There is a small set of manufacturers of motors used in the window covering products; the popular ones are Somfy, Lutron and QMotion. Most of the window covering product manufacturers use motors and motor control systems from these manufacturers. Hence, the cost of the motorized option to the window covering manufacturers would depend on the price at which motor manufacturers supply motors. Due to the proprietary nature of this information, it could not be obtained from the motor manufacturers. Instead, the analysis focuses on estimating the cost of motorization options based on price information available from the vendors' websites.

5. Roller Shades – Motorized Option

One of the relatively lower-price options for motorized roller shades is from *Serena shades* by Lutron. Through their online pricing tool[6], the price of non-motorized and motorized shades for different sizes was determined. These prices are listed in Table 1 and Table 2 respectively. These prices are used to calculate the differential prices for motorization.

Table 1 – Prices of Cordless Non-mototrized roller shades (Serena shades)

	Height = 24 inches	**Height = 72 inches**
Width = 27.25 inches	$290	$301
Width = 63 inches	$391	$403

[6] http://www.serenashades.com/design-your-shade/#

Table 2 – Prices of Cordless Motorized roller shades (Serena Shades)

	Height = 24 inches	Height = 72 inches
Width = 27.25 inches	$409	$420
Width = 63 inches	$510	$522

The total incremental price of motorized roller shade over cordless roller shade for different sizes is $156. This includes the cost of a motor pack ($119), a wireless controller ($25), and batteries ($12 for 8 D batteries – estimated from Amazon.com). Note that these are prices to the end-use customers. The wholesale costs to the blind manufacturers of purchasing the motors are expected to be lower.

6. Curtains and Drapes – Motorized Option

The estimated incremental cost of motorized drapery track systems to the customers is based on the retail price of the following systems available at http://www.floridaautomatedshade.com.

Two of the systems available in the market are Somfy Glydea 35 and Somfy Glydea 60. The details of these systems are as follows:

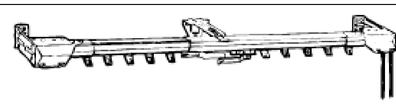
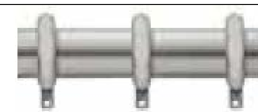
1. Somfy Glydea 35 DCT Motorized Drapery Track System 1001536: The price including the following options is $631.00;
   - Glydea 35 Track System: 4Ft (48 inch) (3) brackets required
   - Measurement Width in inches:45
   - Draw:Left Draw
   - Motor Side:Left
   - Fabric Type:Pinch Pleat
   - Glydea Mounting Brackets:One touch ceiling bracket
   - Wall Switch:Decorator Paddle Switch Maintained (Wht) 1800374

Source: http://www.floridaautomatedshade.com/Somfy-Glydea-35-DCT-Motorized-Drapery-Track-System-p/glydea-35-dct-1001536.htm

2. Somfy Glydea 60 RTS Motorized Drapery Track System 1001617: Price including the following options is $833.50:
    - Glydea 60e Track System:4Ft (48 inch) (3) brackets required
    - Draw:Split
    - Draw Motor Side:Left
    - Fabric Type:Pinch Pleat
    - Glydea Mounting Brackets:One touch ceiling bracket
    - Telis Remote Control:Telis Multi-channel Remote Control (Pure) 1810633

Source: http://www.automatedshadestore.com/shop/product-info.php?Somfy_Glydea_60e_RTS_Direct_Drive_Drapery_Motor-pid507.html

For a comparison with manual drapery tracks, the prices[7] for single curtain rods, single traverse two way-draw and decorative transverse rod sets for different sizes are listed below.

 (a) Single curtain rod	 (b) Single traverse, two-way draw	 (c) Decorative transverse rod set

(a) Single curtain rod (manual cordless)

- 28”-48”: $9.70
- 48”-86”: $14.70
- 66”-120”: $21.80

(b) Single traverse, two-way draw (corded)

- 30”-48”: $45.90
- 48”-86”: $70.45
- 66”-120”: $81.25

(c) Decorative transverse rod set (manual cordless)

- 30”-48”: $145.35

[7] Source: 2015 Kirsch Drapery Hardware Catalog, April 01, 2015.

- 48”-86”: $230.15
- 66”-120”: $314.90

These data demonstrate that the price to end-use customers of the motorized option for curtains and drapes can be an order of magnitude larger than for traditional, manual cordless or corded rods. The difference in price between manual cordless and motorized is significantly influenced by the quality and style of the traverse rod set.

Comparison with Selected Higher-end Custom Products

In order to compare the incremental manufacturing costs in lower-end (e.g., stock) products with corresponding costs in higher-end custom products, the same approach (shown in Figure 1) and the cost model were applied to Hunter Douglas products. Two categories of products are analyzed: cellular shades and horizontal wood blinds. The products analyzed have a common size of 36" x 48". The results are presented in the following sections.

Cellular Shades

In the cellular shade category, Hunter Douglas (HD) Duette honeycomb shade with LiteRise (cordless) lift system was analyzed. The corresponding corded product from the same manufacturer has a standard cordlock system. The LiteRise product uses modular cordless design concept detailed in US patent 8230896. The primary difference between the LiteRise system and the other lower-end cellular products analyzed in the previous section is that the LiteRise system is counterbalanced, such that a relatively small amount of force is required to open or close the shades. The force required to operate the shade remains the same at any position of the lower rail. The constant force is achieved through a combination of a LiteRise motor and a LiteRise transmission system. The parts of the cordless modules are shown in Figure 23.

Figure 23 - Parts of the cordless module (Honeycomb shades)

The results from the cost model are summarized in Figure 24. The incremental manufacturing costs for the high-cost setting are between $4.65 (for production quantity of 1 million) and $6.32 (for a production quality of 100,000). The incremental costs for the low cost environment are $3.85 and $4.86 for 1 million and 100,000 production quantities, respectively. These incremental costs are approximately three times the corresponding costs for the slightly smaller *Window Images* product (see Figure 15).

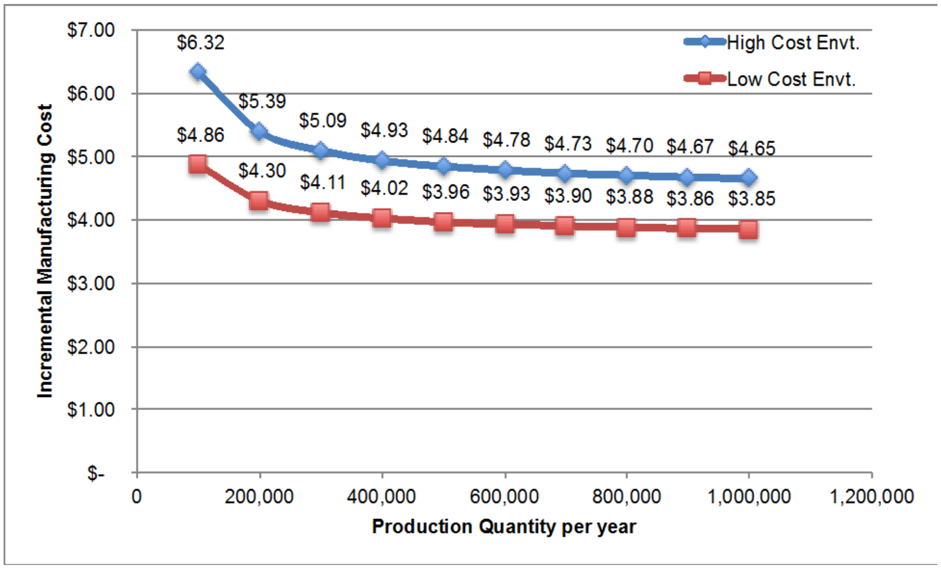


Figure 24 - Results from the cost model (Honeycomb shade)

A number of factors contribute to the cost increase. The HD cordless module has a higher complexity than the cordless module in the *Window Images* cellular shades (shown in Figure 10). Specifically, the HD cordless module has 27 parts, as compared to 14 parts in the *Window Images* product. The complexity of each individual part is also found to be greater in the HD product. The variety of materials used in the HD product is also higher. The components of the transmission system, e.g., gears and transmission shafts, are made of metal. All these factors contribute to the added cost in the custom products.

Horizontal Wood Blinds

The set of products analyzed in this category consists of 2" Wood blind with LiteRise (cordless) lift system and a corresponding product with a standard cordlock system. The design of the cordless module is based on the same patent (US8230896).

The unique components of the cordless module are shown in Figure 25. Wood blinds are significantly heavier than the cellular shades of the same size. Therefore, a higher-capacity transmission system is used in this product. The transmission system has a bigger spring motor and different transmission shafts, compared to that in the honeycomb shade. Most of the other parts are also modified to accommodate the change in weight. Additionally, there is a tilt module, and three tilt-roll assemblies. A total of 45 parts are used in the cordless module for the wood blinds, which is significantly higher than the number (27) used in the honeycomb product. The complexity of parts is also higher.

Figure 25 - Parts in the cordless modules of wood blinds

The results of the incremental manufacturing costs are shown in Figure 26. The incremental costs in the high-cost environment are $10.82 and $8.64 for 100,000 and 1 million production quantities, respectively. The corresponding costs in the low-cost environment are $8.47 and $7.17 respectively. These costs are on average 4-6 times the incremental costs of the lower-end products.

As mentioned above, the higher incremental cost is due various factors including the increase in number, sizes and complexity of parts, and the use of metal instead of plastic for certain parts. These factors are accounted for in the model. In addition to these factors, other factors contribute to further increases in the incremental cost, but are not included in the model. First, the cordless modules must be customized for the wide range of options (such as materials, product size and weight). An increase in the product weight may be accommodated by scaling the cordless module, i.e., increasing the sizes of the motor and the transmission. However, an increase in the size of the product may require a greater number of cordless modules spaced uniformly throughout the head rail. The costs associated with such customization and redesign may significantly add to the incremental cost. The customization also reduces the production quantities of individual parts, thereby increasing the cost of individual parts. Inventory costs are also higher as more parts are required. For a complete understanding of the overall impact on custom products, further analysis of these aspects is necessary.

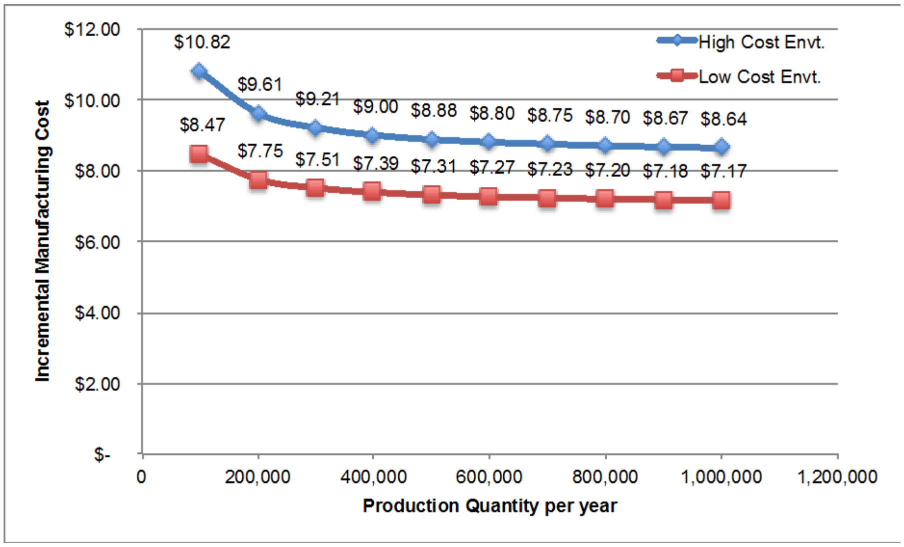


Figure 26 - Results from the cost model (Wood blinds)

Specific information on the retail prices of the samples provided by Hunter Douglas is not readily available. Thus, I am unable to calculate manufacturing costs as a percentage of retail prices for comparison with the lower-end, stock products. Based on phone conversation with one of the Hunter Douglas dealers, the retail prices of the cordless products analyzed above are estimated to be in the $300-$400 range.

Closing Comments

Summary of Results

In summary, the report provides an estimate of the incremental manufacturing costs of several cordless window covering technologies. The report focuses on a sample of entry-level window coverings, the more inexpensive products of the type that are available for purchase off-the-shelf from home improvement stores (e.g., stock products), but also compares the incremental costs of the entry level window coverings to those associated with some higher-end custom products. The study also attempted to distinguish between U.S. and overseas production (i.e., high cost and low cost production environments), and to account for increasing production volume.

The incremental costs for entry-level and higher-end custom products are summarized in Table 3 and Table 4 respectively. No increase in manufacturing cost is expected with the entry-level cordless (wand-control) option for vertical blinds. However, as described in the analysis of motorized products, the cost of manufacturing cordless products differs significantly between the manual cordless and the motorized concepts. For manual cordless products, the incremental costs can be as low as a few dollars per product. On the other hand, for motorized products, these incremental costs may be in the range of hundreds of dollars. Specifically, while cost data are unavailable, the additional retail price for motorization of roller shades for the products analyzed is $156. Motorization of drapes adds hundreds of dollars to the price per unit for the customers.

Table 3 – Summary of incremental manufacturing costs for sample entry-level products in different product categories

Window Covering Type	Incremental Cost to Manufacture A Single Unit		Increased Manufacturing Cost as a Percent of Retail Price	
	Low Cost Environment	High Cost Environment	Low Cost Environment	High Cost Environment
Horizontal Blinds				
27” x 64”	$0.98 - $1.82	$1.81 - $3.24	6 – 11%	11 – 20%
72” x 64”	$1.96 - $3.64	$3.62 - $6.48	5 – 9%	9 – 16%
Cellular Shades				
23”x72”	$0.85 - $1.57	$1.57 - $2.79	3 – 5%	5 – 9%
72”x72”	$1.70 - $3.14	$3.14 - $5.58	2 – 4%	4 – 7%
Roman shades				
27” x 64”	$1.55 - $3.06	$3.39 - $6.03	4 – 8%	8 – 15%
72” x 64”	$3.10 - $6.12	$6.78 - $12.06	3 – 6%	7 – 13%

Table 4 - Summary of incremental manufacturing costs for selected higher-end custom products

Window Covering Type	Incremental Cost to Manufacture A Single Unit	
	Low Cost Environment	High Cost Environment
Cellular Shades (36” x 48”)	$3.85 - $4.86	$4.65 - $6.32
Wood Blinds (36” x 48”)	$8.47 - $7.17	$8.64 - $10.82

If the changes in size and weight can be accommodated by scaling the cordless modules (or adding multiple modules), then the incremental cost of the cordless technology as a percentage of the retail price decreases with increases in size and weight. The incremental cost may increase with size if the design concept of the cordless module becomes infeasible from the standpoint of technical requirements. For example, the cordless modules used in the sample products in the entry-level horizontal blinds and cellular shades category are based on friction. As a result, users must apply different amounts of force depending on the position of the bottom rail. The difference in the force may be small for the entire range of widths if the blinds are made of lighter materials such as vinyl. However, if the binds are made of heavier material such as faux wood, the difference in force requirements may be significant, thereby making the concept infeasible for larger sizes. In such cases, there may be a need to consider sophisticated transmission systems, which would increase the incremental costs.

The analysis includes only the costs associated manufacturing content and the assembly of the product, and focuses on the smaller products available in the marketplace. It does not account for any costs associated with product development, testing, licensing of technology, and training of personnel, which would further increase the overall costs of implementing cordless technologies.

Consequently, the estimated incremental costs of producing the cordless products are most applicable to the more basic and inexpensive cordless products at the low end of the window coverings market. There are a number of factors that would result in higher incremental costs for other segments of the market. These include:

- The costs of product development and design innovation;
- The costs associated with the licensing of existing technology;
- Manufacturing restrictions due to existing patents;
- The costs associated with producing higher quality cordless systems;
- The costs of customizing solutions for cordless window systems of greater size or weight;
- Costs associated with the lower volume customized window coverings.

Recommendations

In order to further analyze the effects of size and weight on the applicability of different concepts, further analysis of technical aspects of the products is recommended. An analysis of the breadth of applicability of different cordless concepts is recommended. Further analysis of the product families and standard modules for cordless technologies is also recommended.

It is encouraging to see a variety of patents from the window covering manufacturers in the recent past, which clearly indicates manufacturers' commitment to safer products. There is diversity in the design concepts for cordless technologies. These patents may however present barriers for other manufacturers in using similar concepts, thereby reducing the adoption of cost-effective cordless technologies. Further investigation on the impact of patents on the adoption of cordless technologies is also recommended.

Appendix A: Details of the Manufacturing Cost Model

Overall manufacturing cost equation

$$C = C_{\text{Assembly}} + C_{\text{PurchasedParts}} + C_{\text{MoldedParts}} + C_{\text{SheetMetalParts}} + C_{\text{Tooling}} + C_{\text{Supervision}} + C_{\text{Inventory}} + C_{\text{Facilities}} + C_{\text{Energy}}$$

Assembly cost

$$C_{\text{Assembly}} = \frac{\text{assembly-content} \times \text{assembly-labor-cost}}{\text{assembly-productivity} \times \text{assembly-yield}}$$

where, assembly-content = standard hours of assembly content (hours)

assembly-labor-cost = cost per standard hour ($ per hr)

assembly-yield = fraction of products assembled correctly.

Cost of purchased parts

$$C_{\text{PurchasedParts}} = \frac{\text{total-purchased-parts}}{\text{sourcing-efficiency} \times \text{purchased-parts-yield}}$$

Cost of molded parts

$$C_{\text{MoldedParts}} = \frac{C_{\text{plastic}} + C_{\text{molding}}}{\text{molded-part-yield}}$$

where,

$$C_{\text{plastic}} = \text{plastics-use} \times \text{polypropylene-cost} \times (1 - \text{plastic-regrind-rate})$$

$$C_{\text{molding}} = \text{molding-processing-time} \times (\text{base-machine-rate} + \text{machine-capacity-rate} \times \text{molding-machine-requirements} + \frac{\text{operator-labor-rate}}{\text{molding-machines-per-operator}})$$

$$\text{base-machine-rate} = \frac{r(1+r)^n}{(1+r)^n - 1} \times \frac{\text{base-molding-machine-cost}}{\text{days-per-year} \times \text{hours-per-day} \times \text{equipment-utilization}}$$

$$\text{machine-capacity-rate} = \frac{r(1+r)^n}{(1+r)^n - 1} \times \frac{\text{molding-machine-capacity-cost}}{\text{days-per-year} \times \text{hours-per-day} \times \text{equipment-utilization}}$$

where r is the cost of capital, and n is the useful life of the machines.

$$\text{clamp-force} = \text{projected-area} \times \text{mold-cavities} \times \left(\frac{224}{\sqrt{\text{avg-wall-thickness}}} + 172 \right)$$

$$\text{cooling-time} = \frac{d^2 \rho C_p}{\pi^2 k} \times \ln\left(\frac{8(\text{melt-temp} - \text{mold-temp})}{\pi^2(\text{eject-temp} - \text{mold-temp})} \right)$$

where d is the nominal wall thickness in cm, ρ is the density in g/cc, C_p is the specific heat in J/g/K, k is the thermal conductivity.

$$\text{cycle-time} = 1.35 \times \text{cooling-time} + 0.0151 \times \text{Weight} \times \text{Cavities} + 8.87 \text{ seconds}$$

Mold cost estimation

The mold manufacturing cost (Boothroyd, Dewhurst and Knight, 3rd ed., p. 357) is dependent on:

1. Mold base plate area, A_c cm ^{2}, and combined plate thickness, h_p cm

$$M_b = 50 + 0.023 A_c h_p^{0.4} \quad \text{hours}$$

2. Projected area of part, A_p cm ^{2}

$$M_e = 2.5 \times A_p^{0.5}$$

$$M_{po} = 5 + 0.085 \times A_p^{1.2} \quad \text{hours}$$

Geometric complexity, X

$$M_x = 5.83(X_i + X_o)^{1.27} \quad \text{hours}$$

Other factors: number of side pulls, internal lifters, unscrewing devices, surface finish/appearance, tolerance level, texture, and parting plane.

Cost of sheet metal parts

$$C_{\text{sheet-metal-parts}} = \frac{C_{\text{metal}} + C_{\text{stamping}}}{\text{stamped-part-yield}}$$

where,

$$C_{\text{metal}} = \text{sheet-metal-use} \times \text{mild-steel-cost}$$

$$\begin{aligned} C_{\text{stamping}} &= \text{sheet-metal-processing-time} \times (\text{base-press-rate} \\ &+ \text{press-capacity-rate} \times \text{sheet-metal-press-requirements} \\ &+ \frac{\text{operator-labor-cost}}{\text{stamping-machines-per-operator}}) \end{aligned}$$

$$\text{base-press-rate} = \frac{r(1+r)^n}{(1+r)^n - 1} \times \frac{\text{base-stamping-machine-cost}}{\text{days-per-year} \times \text{hours-per-day} \times \text{equipment-utilization}}$$

$$\text{press-capacity-rate} = \frac{r(1+r)^n}{(1+r)^n - 1} \times \frac{\text{stamping-machine-capacity-cost}}{\text{days-per-year} \times \text{hours-per-day} \times \text{equipment-utilization}}$$

where r is the cost of capital, and n is the useful life of the machines.

Tooling and supervisor costs

$$C_{\text{tooling}} = \frac{(\text{mold-fabrication-time} + \text{sheet-metal-tooling-fabrication-time}) \times \text{tool-making-cost}}{\text{tool-life}}$$

$$C_{\text{Supervision}} = \frac{C_{\text{assembly}}}{\text{assembly-labor-cost} \times \text{span-of-control}} \times \text{supervisory-labor-cost}$$

Inventory costs

$$C_{\text{inventory}} = \frac{\text{inventory-level}}{\text{days-operation-per-year}} \times C_{\text{variable}} \times \text{inventory-holding-costs}$$

where,

$$C_{\text{variable}} = C_{\text{assembly}} + C_{\text{purchased-parts}} + C_{\text{molded-parts}} + C_{\text{sheet-metal-parts}} + C_{\text{supervision}} + C_{\text{energy}}$$

Cost of facilities

$$C_{\text{facilities}} = \text{base-facility-size} \times \frac{\text{base-yearly-hours}}{\text{base-operation-per-year} \times \text{hours-per-day}} \times \text{space-utilization-factor} \times \text{facility-cost} \times \frac{1}{\text{production-rate}}$$

where

$$\text{space-utilization-factor} = \frac{3}{\left(\text{ass'y-productivity} \times \text{ass'y-yield} + \text{eqpt-utilization} \times \text{mold-yield} + \frac{\text{base-inventory}}{\text{inventory-level}}\right)}$$

The base facility size is calculated as per Busch (1987), page 101.

Cost of energy

$$C_{\text{energy}} = \text{total-plastic-mass} \times \text{plastic-processing-energy} \times \text{energy-cost}$$

Appendix B: Cost Model Parameters

The model consists of the following parameters. Unless specified otherwise, the parameters are assumed to be the same as in Ulrich and Pearson (1998).

1 *Assembly and operator labor cost*: $13.81 USD per hour for the high-cost environment.
   - Source: http://www.bls.gov/oes/current/oes_nat.htm#51-0000 ; Description: 51-2099 "Assemblers and Fabricators, All Other"; Mean hourly wage rate
   - For the low cost environment, the cost is assumed to be $2.00 per hour, as per Ulrich and Pearson (1998). The 2009 BLS data for China is $1.74 per hour.

2 *Supervisory labor cost*: $28.39 per hour for high cost environment (mean hourly wage rate)
   - Source: http://www.bls.gov/oes/current/oes511011.htm
   - Description: "51-1011 First-Line Supervisors of Production and Operating Workers": Directly supervise and coordinate the activities of production and operating workers, such as inspectors, precision workers, machine setters and operators, assemblers, fabricators, and plant and system operators. Excludes team or work leaders.
   - For the low cost environment, the supervisory labor cost is assumed as $3.00.

3 *Tool making cost, shop and labor*: $60.00 per hour for high cost environment
   a. Mean hourly wage for tool and die makers is: $24.08. The remaining is an estimate for shop and other costs.
   b. Source: http://www.bls.gov/oes/current/oes514111.htm
   c. Description: "51-4111 Tool and Die Makers: Analyze specifications, lay out metal stock, set up and operate machine tools, and fit and assemble parts to make and repair dies, cutting tools, jigs, fixtures, gauges, and machinists' hand tools.
   d. For low cost environment, the cost is assumed $38.00 (as in Ulrich and Pearson)

4 *Days operation per year*: 240 days

5 *Hours per day*: 16 hours

6 *Facility cost*: $36.55 per sq-m per year.
   a. The facility cost is inflation adjusted from $25 in 1998 using http://www.bls.gov/data/inflation_calculator.htm

7 *Assembly productivity*: 1.2

8 *Assembly yield*: 1

9 *Sourcing efficiency*: 1.05

10 *Purchased parts yield*: 1

11 *Polypropylene cost*: $1.46 per kg
   a. Sources:http://plasticker.de/preise/pms_en.php?show=ok&make=ok&aog=A&kat=Mahlgut and http://www.protolabs.com/resources/molding-materials

b. Polycarbonate can go up to around $5.00 per kg

12 *Mild steel cost*: $ 0.4 per kg

a. Source: http://www.metalprices.com/p/SteelBenchmarkerFreeChart

13 *Molding machines per operator*: 3

14 *Molded part yield*: 0.995

15 *Stamping machines per operator*: 1

16 *Stamped part yield*: 0.995

17 *Equipment utilization*: 0.8

18 *Span of control*: 10

19 *Inventory level*: 30 days

20 *Molding machine base cost*: $31,261.95

a. The molding machine base cost is inflation adjusted from $21,383 in 1998 using http://www.bls.gov/data/inflation_calculator.htm

21 *Molding machine capacity cost*: $86.26 per kN capacity

a. The molding machine capacity cost is inflation adjusted from $59 in 1998 using http://www.bls.gov/data/inflation_calculator.htm

22 *Stamping machine base cost*: $44,444.80

a. The stamping machine base cost is inflation adjusted from $30,400 in 1998 using http://www.bls.gov/data/inflation_calculator.htm

23 *Stamping machine capacity cost*: $106.73

a. The stamping machine capacity cost is inflation adjusted from $73 in 1998 using http://www.bls.gov/data/inflation_calculator.htm

24 *Inventory holding cost*: 20% per year

25 *Cost of capital*: 10% per year

26 *Plastic regrind rate*: 20%

27 *Useful machine life*: 6 years

28 *Energy cost*: $0.1045 per kWh

a. *Source*: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_03

29 *Production rate*: Assumed to be between 100,000 and 1,000,000 units per year.

30 *Tool life*: 1,000,000 units

31 *Plastic Processing Energy*: 0.75 kWh per kg

32 *Base Facility Size*: Calculated based on plastic weight (Busch, 1987)

33 *Base inventory*: 60 days

34 *Base yearly hours*: 4000 hours per year

The values of the parameters that differentiate the high cost environment and the low cost environment are listed in Table 5.

Table 5 – Parameters used for high cost manufacturing environment and low cost manufacturing environment (hourly rates)

	High Cost Environment	**Low Cost Environment**
Assembly and Operator labor cost	$13.81	$2.00
Supervisory labor cost	$28.39	$3.00
Tool making cost, shop and labor	$60.00	$38.00
Facility cost	$36.55	$19.00

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Any opinions, findings, conclusions, and recommendations expressed in this report are those of the author only.

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