Porsche Engineering Services, Inc.

17 Economic Analysis

ULSAB-AVC evaluated manufacturing cost (part fabrication and assembly) of the vehicle concepts, where several different fabrication technologies had to be taken into account.

17.1 BACKGROUND

Part of the ULSAB-AVC Program was a cost assessment to estimate the manufacturing cost without logistic cost of both ULSAB-AVC vehicles concepts (C-Class and PNGV-Class).

To undertake this program, Porsche Engineering Services, Inc. (PES) organized an interactive process between product designers, process engineers and assembly line designers and cost analysts. The cost assessment team was comprised of the following organizations:

- Porsche Engineering Services (PES), Troy, MI, USA
- Camanoe Associates, a group of researchers of the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA
- Mercia, Southfield, MI, USA
- Economic Analysis Working Group, ULSAB-AVC Consortium

The ULSAB and ULSAC economic analysis (published in 1998 and 2000) assessed the cost of the body and door structures. The ULSAB-AVC Program required an evaluation of the manufacturing cost (part fabrication and assembly) of the vehicle concepts, where several different fabrication technologies had to be taken into account.

17.2. The Process of Cost Assessment

17.2.1. Approach

Due to the different degree of detail design for the vehicle components in this concept phase and the great variety of different fabrication methods, several cost assessment methods were used to establish the manufacturing cost of both ULSAB-AVC designs:

- The “Technical Cost Modeling” approach, which was used by MIT and PES in the ULSAB and ULSAC program was applied to all sheet metal parts and the corresponding assembly. Based on the part drawings provided by PES, Mercia developed the major process data for parts fabrication such as blank size, cycle time, utilized press line and tooling investment. Following validation by MIT, this data was integrated into the cost model for the calculation of parts cost, which were broken down in different cost elements.
- “Supplier Cost Assessments” were obtained by providing leading suppliers with component descriptions of functions and performances (e.g. mass target). Therefore, PES defined several subsystems and modules on the highest level of aggregation as useable.
- “Expert Judgements” by the cost assessment team were used along with internal and external information to assess the costs of components and subsystems.

Because several different definitions of manufacturing cost can be found in literature, it is necessary to define the cost elements included and excluded in these costs. The following cost elements were considered and included in the parts fabrication and assembly cost definition of the ULSAB-AVC program:

- Fabrication costs of all vehicle parts (including tooling costs)
- Press shop, body shop, paint shop and final trim line cost elements were considered as defined in the ULSAB and ULSAC economic analysis, which included material, direct labor, energy, equipment, tooling, building, maintenance, overhead labor (indirect labor directly connected to the manufacturing process)

Excluded from the manufacturing costs are logistic costs and overhead costs.

Logistic costs

- Logistic costs include tooling investments (pallets), equipment and building investments and labor cost elements (incl. shipping from all suppliers).

Overhead costs are defined in three cost groups A, B, C.

Overhead Cost Group A

- Overhead costs for plant which are not included in the manufacturing costs:
  - ⇒ Non-dedicated investment costs for plant not directly connected to the assembly process (e.g. fire brigade, canteen, administration offices including IT)
  - ⇒ Laborer not directly connected to the manufacturing process and all salary employees
  - ⇒ All planning and optimization activities of the manufacturing process
- Overhead costs for sales department
- Development and project costs
- Follow-up costs (production vehicle services)

Overhead Cost Group B

- Type-specific sales (e.g. introduction into the market)
- Warranty costs
- Profit of OEM

Overhead Cost Group C

- Costs of the trading organization
- Profit of trading organization

Nevertheless, it is likely, that the user of the cost model will have a different opinion for the allocation of some individual input parameters. Therefore, the cost model development provides the flexibility to allow the user to input their own data, if the magnitude of the results of this cost assessment caused by the allocation of the input parameters differ from the user's opinion.

17.2.2. General Assumptions

A virtual plant scenario with defined annual production volumes was the basis of assumptions for the whole assessment. The virtual plant scenario including material flow is shown in Figure 17.2.2-1:

- Two ULSAB-AVC assembly plants (A and B) are located in Mid West USA at two different locations (maximum distance 600 miles)
- Assembly plant A produces the PNGV-Class vehicle with 225,000 units/year
- Assembly plant B produces the C-Class vehicle with also 225,000 units/year
- Both plants have a body shop, a paint shop and a final trim line

- PNGV-Class vehicle is sold with the gasoline engine
- C-Class vehicle is sold with the diesel engine
- A press shop for fabrication of all body-in-white parts (plant C) is located in equal distance of plant A and plant B
- All purchased parts (including engines) are delivered by suppliers located in a 600 mile radii from plant A and plant B

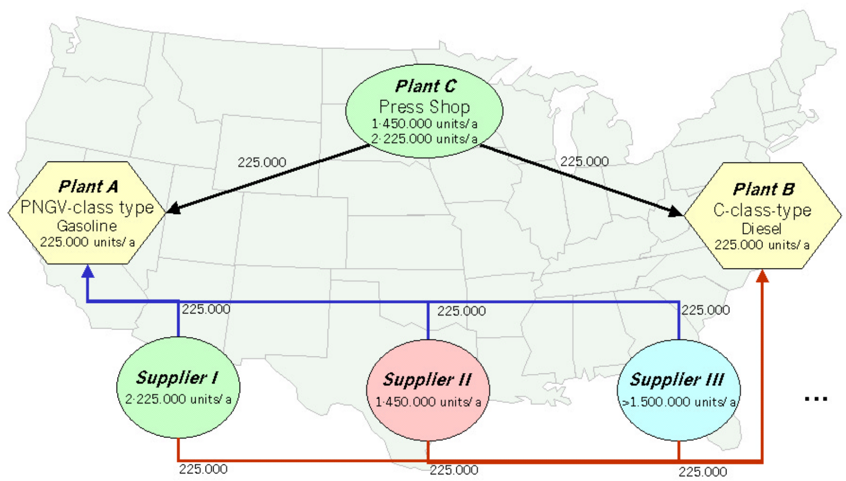

Figure 17.2.2-1 Virtual plant scenario and material flow

Two different vehicles, each with two different engines, were developed in the ULSAB-AVC program. Depending on the module/subsystem, a restricted platform strategy was partly modeled as shown in Table 17.2.2-1. The scenario assumes a C-Class type diesel and a PNGV-Class gasoline. Although, it is noted that the scenario is also valid for a C-Class gasoline and PNGV-Class diesel vehicle.

Table 17.2.2-1 Platform strategy

Annual Production Volume	Description	Examples
225.000	Parts, which are utilized either in PNGV-Class or in C-Class-type vehicles	Body Structure Rear
450.000	Parts, which are utilized in PNGV-Class and in C-Class type vehicles	Body Structure Front
> 1.500.000	"Of the shelf" components, which are utilized in one or several models of one or several OEMs	Battery

The costs were adjusted to a virtual Start Of Production (SOP) in 2004. Costs were calculated statically with annual savings in part costs not considered.

17.2.2.1 General Input Parameters

The general input parameters, which are independent of any part specific parameter were established and are shown in Table 17.2.2.1-1.

Table 17.2.2.1-1 General input parameters

General Input Parameters	
Annual Production Volume	225,000
Working Days per Year	240
Production Location	Mid-West USA
Wage including benefits	44 $/h
Interest Rate	10%
Equipment Life	20 years
Production Life	5 years
Building Life	25 years
No. of Shifts per day	2
Exchange rate	US-$ 1 = 1 €

17.2.3. Fabrication Input of Body-in-White

The body-in-white (BIW) costs were assessed with the technical cost modeling approach used by *MIT* and *PES* as in the ULSAB and ULSAC programs.

Process data for stamping, tailored welded blanks and sheet hydroforming were determined by *Mercia*, who supplied the manufacturing support for the ULSAB-AVC Program. *Mercia* was responsible for manufacturing process of BIW structure and Closure panels. Each part was reviewed to determine the following:

- Optimal blank size – *Mercia* utilized a PC based computer program to develop the optimum blank size for each part. This system was also used to review and determine nesting of blanks for a cost-effective use of materials.

- Stamping process – Each part was reviewed and examined to determine the manufacturing process capable of producing a repeatable quality part, using the most cost effective process, i.e. line dies, transfer or progressive dies. Each part was then reviewed to determine how it would be run (e.g. single out, double out attached or double out unattached).
- Initial inputs – After the process had been determined, the initial inputs for each part were established to develop a unit cost for input into the Cost Model. Major input parameters to be established, included tooling investment, blank size, cycle time and the specification of the relevant presses. Several different press types were defined by virtually generating press lines by multiplying the press type with the number of operations, which were necessary for one specific part.
- Cost estimation - Once the process had been established, each operation was reviewed and the number of hours required for tool design, manufacturing machining and tryout established. In addition, part size and complexity were examined to establish tooling costs for each operation and the checking fixture costs for each part.

The press lines were assumed to be non-dedicated assuming that the press line is only paid for the time utilized and that in the remaining time other parts can be fabricated. Investment costs for different press types were generated by *MIT* research. The key process data for the different press types used in the assessment is shown in Table 17.2.3-1.

Table 17.2.3-1 Press type process data

Stamping Press Types	Actual Press Tonnage	Base Cost ($/press)	Auxiliary & Installation Costs
Progressive Die Presses			
Type E	350	$5,000,000	$600,000
Tandem Presses			
Type A	1000	$1,050,000	$500,000
Type B	800	$940,000	$400,000
Type C	600	$815,000	$350,000
Type D	350	$620,000	$250,000
Transfer Presses			
TP 3600	3600	$15,000,000	$8,437,500
TP 4500	4500	$12,000,000	$6,750,000

Process data for all tubular hydroformed parts were provided by Krupp Drauz.

The process data for the door structures were generated utilizing the ULSAC data with adjustments for the difference in size between the ULSAC and the ULSAB-AVC doors. The use of the ULSAC data was feasible because the ULSAC design concept was adopted for the ULSAB-AVC vehicle concept.

All BIW process data for fabrication was assessed by *MIT* for plausibility and used in the cost model after the data was validated. The input data material prices were provided by the ULSAB-AVC Consortium.

17.2.4. Purchased Parts

PES defined a level-structure with the vehicle broken down into subsystems, modules and parts on several different levels of aggregation, depending on their design detail level. For these subsystems, technical descriptions with functions, performances, including design sketches, were generated and used for the cost assessment. An overview of the subsystems and the suppliers (all European based), which provided cost assessments is listed in Table 17.2.4-1.

Table 17.2.4-1 Cost assessment supporting suppliers

Subsystem	Supplier of cost assessment
Powertrain	
Engine electrical system (including auxilary components)	Robert Bosch
Exhaust system (without catalytic convertor)	Arvin Meritor
Manual transmission automatically shifted	GETRAG
Drive shafts	GKN Loebro
Chassis	
Lear spring (glass fiber)	Delphi
Ceramic brake discs (option)	SGL Carbon Group
Electrical parking brake	Continental Teves
Tires	Dunlop
Electrical systems	
Instrument cluster (TFT-display)	Mannesmann VDO
Alarm system	Delphi
Alarm horn	FER Fahrzeugelektrik
Lighting	Hella
Electrical wiring	Leoni
Radio system	Becker
Wiper system	Robert Bosch
Washing system	Mannesmann VDO
Battery (Lithium-Ionen as an option)	GAIA

No “virtual” negotiations concerning costs were held between the *cost assessment team* and the supplier who provided the cost estimate. Experience shows that by using a simultaneous engineering (SE) process with the suppliers, the costs of the first estimates can normally be reduced in a real OEM vehicle development program with the growing amount of detail in the component design and the supplier’s efforts of cost cutting. To account for this effect in the ULSAB-AVC program, it was decided to introduce a 10% cost reduction multiplier on all supplier cost estimates for purchased parts.

The supplier's cost assessment part fabrication costs did not include the expenses for transportation expenses between the supplier and the vehicle assembly plant. These costs have to be considered and included in the logistics costs.

17.2.5. Body-in-White Assembly Input

Based on assembly sequences and joining specifications provided by *PES* for body structure, liftgate, deck lid and hatch, *MIT* used their assembly cost model for estimating the body-in-white assembly costs.

The assembly model used in the ULSAB-AVC program expanded on the approach taken in the ULSAC program. Compared with the original ULSAB cost model (phase II), the assembly portion of the ULSAC model was constructed to overcome the serious limitation of having an assembly analysis which was only valid at a single production volume (225,000 bodies per year). The idea behind the ULSAC model was that the user should not have to specify all of the details of the line at every production volume. Instead the user would specify the assembly "effort" required, measured in terms of time to perform the various assembly operations. At any production volume level, a tact time for the process is determined and the assembly "effort" is compared with this tact time to determine the number of stations required for each assembly operation. Once the appropriate number of stations is determined, average levels of manpower, equipment and tooling investments, etc could be applied to determine the overall costs.

However, the ULSAC model had the limitation that the user must have a full understanding of the assembly time required for each operation and the corresponding baseline investments. This worked fine for a detailed design program where there was sufficient detail about the assembly line such as the ULSAC Program. However, in the ULSAB-AVC Concept Phase, this level of detail was not yet developed. An additional tool was needed to estimate the assembly times and the levels of investment from the assembly process requirements. In the "AVC assembly model", the user only needs to input the assembly method (for example, spot welding) and the amount of joining required (for example, the number of spot welds) and the model automatically determines an estimate for the required assembly times and equipment investments. These values are then used in much the same way as in the ULSAC model to determine the assembly costs.

As was the case for the ULSAC program, the model can respond to changes in production volume. For example, at lower production volumes, the takt time is higher and thus the number of stations required to accomplish the required assembly is reduced. As a result, all of the investments and manpower requirements are also reduced basically providing a modified assembly line description which can then be used to determine the per vehicle assembly costs. Of course, this approach is just an estimation of how costs change with changing production volumes. In practice the issue is far more complicated, and involves complex considerations of line balancing to minimize the investment and labor requirements for any set of operations while still remaining within the limits imposed by precedence (the need to assembly some parts before others can be added). Nonetheless, this mechanism provides a reasonable and consistent method allowing the assembly line to scale with production volume.

To ensure that this model was consistent its predecessors, both from ULSAB and ULSAC, a series of overrides concerning the levels of investment and time requirements was implemented. The user must be sure to input the proper baseline investment costs (in equipment and tooling) per station for each assembly operation, as well as the appropriate assembly time requirement (an appropriate time requirement is one which results in the correct specified number of stations).

17.2.6. Paint Shop

The painting of an automobile body is an extremely capital-intensive process, generally accounting for over half the total capital cost associated with an assembly plant. Such facilities are expensive because of the vast amount of floor space required for the paint bake ovens, the specialized equipment, and the substantial amount of pollution control equipment required.

A key feature of this process is that a great deal of effort is taken to make sure that all vehicles, irrespective of material substrate, are treated in order to be able to process all vehicles in the same fashion. This means that, while there may be a host of differences among vehicles, the only things that really matters in the costing of painting is (1) the throughput at the paint shop, leading to a fixed capital charge for each vehicle transiting the line, (2) the surface area of the product to be painted and (3) the type and color of the films to be applied to the surface, leading to a materials costing calculation.

Cleaning/Pretreat - Before any painting takes place, the body-in-white must be cleaned, not only to remove stamping lubricants, but also accumulated dust and dirt. This process is quite extensive, and uses a substantial amount of water and energy. In addition, this phase includes a surface pretreatment via a series of dips to ensure the formation of a zinc phosphate conversion coating to promote paint adhesion.

Electro-coat - The electrocoat, or e-coat, is applied to the BIW by applying an electrostatic potential to the vehicle while it is submerged and dredged through the e-coat tank. The objective is to assure that the entire vehicle, including hard-to-reach interior passages, is coated in this process step. The post-dip oven is generally the hottest step of the painting process, and usually establishes the service limits for most polymeric materials on the BIW.

Sealer Application - Sealer is applied to the underbody and the engine compartment of the car to guarantee that the passenger compartment will be watertight and also for noise reduction and dust intrusion. The film thicknesses for the sealer coat will vary widely by vehicle line and maker.

Primer Coat Application - In order to achieve the film and image quality that is considered acceptable in today's market, a primer coat is applied to the BIW. While a single primer used to be the norm, today's automobile primers are usually "color keyed," meaning that the primer color is matched to the basecoat color to achieve the desired surface color. Sealer thickness varies widely according to the degree of environmental exposure of different parts of the vehicle and certain parts of the car (the rocker panels, for example) are coated with anti-chip primers in addition to the primer surfacer. Following application of the primer, the vehicle is baked to set the primer for subsequent film applications.

Basecoat Application, and Clearcoat Application - The application of basecoat and clearcoat achieve the vehicle color and the glossiness of the painted surface, respectively. A variety of effects can be achieved by varying film thicknesses at this stage, and a third layer is frequently used when an opalescent effect is desired. The cost of the basecoat can be very high, and is a function of the color and the amount of flake included in the paint. For solvent-based paints, these tend to be high solids paints, with high viscosity and the associated difficulties to achieve the desired mirror-like surface. Water-base paints have been introduced, in part for environmental reasons and in part because of their lower viscosity. However, the transfer efficiencies of the water-based paints were quite low and process improvements are continuing. In all cases, the quality of the surface is a strong function of the control that can be achieved in the painting process over film thickness (achieved through the use of electrostatic bells and paint quality) and the cleanliness of the production environment. Subsequent to these process steps, the painted BIW is run through a long cure cycle to assure that the films set properly.

Rework - While OEMs would like to eliminate this step, the fact remains that rework is an expensive fact of life for painting. Spot reworking can be done, but vehicles are generally never run through the paint cycle more than two times, both because of cost and because the poor surfaces that result.

The cost model for this process calls for specification of cycle times, material composition, capital costs and labor intensities for each stage in the process. These costs are then accumulated and applied as a function of production rate to each BIW painted.

17.2.7. Final Trim Line Assembly Input

PES and *Mercia* introduced a final trim sequence as the basis for the *MIT* final trim line model which was part of the cost model. The process was reviewed by *Classic Design* of Troy to establish the best utilization of manpower and robots to provide an optimized assembly process. For complete illustration of the Final Trim Line Assembly, see Appendix - Section 1.

The trim line model starts with the assumption of the existence of a specified assembly process. Each station is assigned a number. Stations whose number is evenly divisible by 100 are declared to be “main” stations, while stations whose number is not evenly divisible by 100 are “feeder” stations. The “feeder stations” are assumed to be part of smaller sub lines which feed the main trim line, and are used to pre-assemble components to a subassembly - for example, elements of a door trim line.

Main stations are assumed to have a fixed cost of transfer equipment, equipment & tooling costs, building area and energy consumption rate, averaged over the entire line. The user can specify the number of men working at each station, as well as the number of robots employed at each station.

The user must specify the minimum time required to complete the operations at a station. The model will add enough stations to achieve the necessary product throughput. However, the model does not assume that, at reduced line rates, stations can be consolidated, although such a consolidation would occur in practice. However, such a consolidation would be limited by the layout of the facility, and would almost certainly be accompanied by a reorganization and restructuring of the operations within each station, limited by assembly precedence.

The parts assembled at each station are listed next to the base station inputs, and this list is constructed by a spreadsheet macro that refers to the parts list spreadsheet. The user can assign parts to the appropriate station by supplying the appropriate station number in the input column.

The model then accumulates the capital and variable costs according to the inputs specified and the time constraints upon the operation to calculate a total operating cost for the trim line.

17.3. Cost Model Description

The ULSAB-AVC cost model provides a platform for understanding the costs of all aspects of manufacturing an entire vehicle. The model tracks the costs of all parts in the vehicle, the production of subassemblies and the final assembly process. Emphasis is placed on understanding the costs of metal fabrication and assembly processes which are modeled in considerable detail. The remaining parts costs are estimated via supplier quotes, industry information and other cost estimates. OEM activities' such as painting and final assembly/trim line are modeled using industry data concerning these processes.

The model has been constructed in Excel™ in order to allow for ease of use. The workbook provides the basis for estimating the cost of a single vehicle, and does not provide a comparison with other vehicles, although this can be accomplished by making multiple copies of the model. The model workbook consists of 14 worksheets that can be classified into three (3) types; inputs, calculations and outputs. Each of these can be further divided into four (4) topics; body structure, closures, “non body” (all parts that are neither body structure nor closures structure) and paint & trim lines. There are also worksheets with general inputs that are applicable to the entire model, and a summary of results.

Individual Worksheets:

General Inputs: The general inputs sheet describes assumptions common to all aspects of the model. These include exogenous variables (general accounting assumptions), parts fabrication process assumptions, materials prices and automotive assembly plant assumptions.

Body and Closures Inputs: These worksheets provide the input data for the body structure, closures and other parts fabrication and assembly. All model inputs should be made in these worksheets (and the general inputs worksheet). These sheets are divided into several sections, one for each of the production processes being considered. These are (1) stamping, (2) stamping using tailored blanks, (3) sheet hydroforming, (4) tube hydroforming and (5) assembly. In addition, there is an area dedicated to purchased parts. This allows the user to directly input the cost of a part rather than model its cost.

"Non-body" Inputs: The "non-body" worksheet only considers stamped and purchased parts, however the purchased parts are listed, since they constitute a large portion of these costs. In this case, the parts list is based on a multi-level (up to 4 levels are permitted) part hierarchy. The user can then input costs for either detailed part breakdowns, or entire subsystems depending on the detail that is desired. The user is also asked to provide the final trim line station at which the part will be attached to the vehicle. This is done to ensure that the trim line calculation addresses all parts.

Paint & Trim Inputs: The paint line is modeled according to the major painting activities. The model user is asked to input the painting steps to be considered (in the case of ULSAB-AVC, the model considered cleaning, electrocoat, primer, sealer, basecoat and clearcoat application and final rework). For each painting activity the user must also input some basic data about the investments, materials and labor required.

The trim line model estimates the costs of the final vehicle assembly by assessing the time required for each trim line activity and then determining the required number of stations. The user is required to inputs the various trim activities and the times required to accomplish each activity. The model automatically matches the parts inputted in the "non-body" inputs to assure that all parts are assigned to a trim line station in order to ensure completeness.

Body, Closures, "Non-body" and Paint & Trim Calculations: These sheets provide the basic model mechanisms for calculating costs. The detailed data provided on the input sheets are used to determine equipment utilization levels, material, labor and energy requirements, etc. While these sheets do not provide final cost estimates, they provide useful intermediate values including the cost breakdowns for each individual sub-process step.

Body and Closures Results: These sheets provide the final cost estimates for all parts and assembly processes associated with the body structure and closures. Cost estimates are provided for each part and are broken down by their cost drivers (materials, labor, equipment, etc.). Assembly cost estimates are provided for each subassembly and each assembly activity (such as spot welding, laser welding, etc.).

"Non-body" Results:
Cost estimates based on detailed modeling are provided for the stamped parts. For the remaining purchased parts, the model consolidates the various levels of the part hierarchy and reports on the aggregate costs of the highest level subsystems.

Paint & Trim Results: The paint & trim line results sheet provides the line rate assumptions for these processes and then the cost breakdown for each activity. For the trim line this includes all of the various trim stations defined in the inputs area.

Summary: The summary worksheet provides a final high level overview of all of the vehicle costs. Costs are provided for the assembled subsystems modeled; (1) body structure, (2) closures, (3) "non-body" parts and the automaker final assembly processes (1) paint and (2) final trim line. This sheet also provides the users with a way to convert manufactured costs into a final vehicle selling price. The user has the opportunity to add costs (in terms of incremental percentages) for items such as logistics, several types of overhead and the costs of the sales and trading organization (see overhead discussion for more details).

17.4. ULSAB-AVC Manufacturing Cost Results

17.4.1. Overall Manufacturing Cost Results

The results of the overall manufacturing cost assessment for ULSAB-AVC are shown in Figure 17.4-1 and detailed in Table 17.4.1-1.

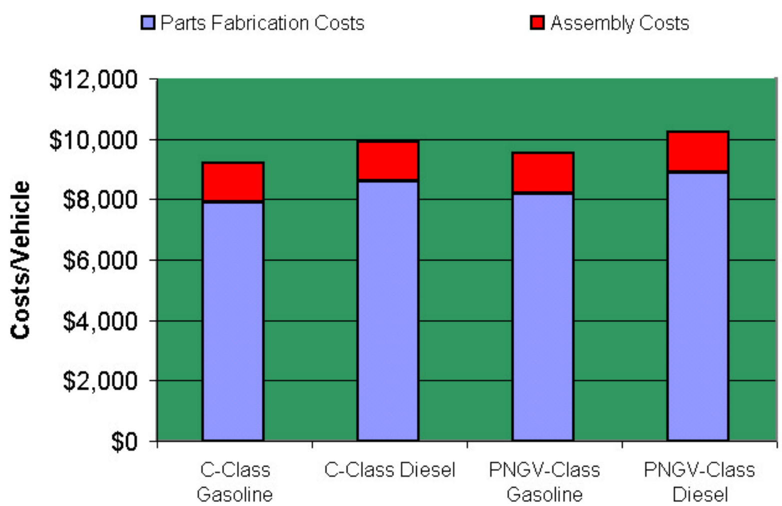

Figure 17.4.1-1 ULSAB-AVC manufacturing (without logistics)

Table 17.4.1-1 ULSAB-AVC manufacturing cost details (without logisitcs)

	C-Class		PNGV-Class	
	Gasoline	**Diesel**	**Gasoline**	**Diesel**
Parts Fabrication Cost	$7,906.0	$8,606.0	$8,162.7	$8,862.7
Assembly Cost	$1,284.3	$1,284.3	$1,375.7	$1,375.7
Manufacturing Costs*	**$9,190**	**$9,890**	**$9,538**	**$10,238**

** without logistic costs*

Parts fabrication costs include all dedicated tooling costs per vehicle. Results show small differences between C-Class and PNGV-Class designs, which is caused by the "virtual" platform strategy where the same components are used for both vehicles.

17.4.2. Cost Breakdown for Parts Fabrication

17.4.2.1. Overall Cost Breakdown for Parts Fabrication

Table 17.4.2.1-1 shows the breakdown of the parts fabrication costs for the major systems and the identification of the included subsystem.

Table 17.4.2.1-1 Overall parts fabrication costs

System	Subsystem	C-Class		PNGV-Class	
		Gasoline	Diesel	Gasoline	Diesel
Powertrain	Engine including engine electrics				
	Cooling system				
	Fuel system				
	Exhaust system				
	Manual transmission - automatically shifted				
	Drive shafts				
Total Powertrain		**$2,350**	**$3,100**	**$2,350**	**$3,100**
Chassis	Front suspension incl. subframe				
	Rear suspension				
	Pedal system				
	Wheels & tires				
	Braking system				
	Steering system				
	Accessories				
Total Chassis		**$1,845**	**$1,845**	**$1,845**	**$1,845**
Body	Body structure **				
	Closures structure **				
	Fenders + Applique **				
	Closures assembly parts				
	Front end/ rear end / underbody, aerodynamic devices				
	Glazing / sealing				
	Interior equipment				
	Seats (incl. side airbag and seat belts)				
	Climate system				
Total Body		**$2,711**	**$2,711**	**$2,968**	**$2,968**
Electrics	General electric				
	Lighting				
	Electrical wiring				
	Radio system				
	Wiper system				
	Washing system				
	Battery				
Total Electrics		**$1,350**	**$1,350**	**$1,350**	**$1,350**
Potential for cost reduction with SE-process*		($350)	($400)	($350)	($400)
Overall Parts Fabrication		**$7,906**	**$8,606**	**$8,163**	**$8,863**

* assumption 10% of total supplier cost assessments
** Body-in-white parts fabrication costs are calculated in the cost model and summarized in Table 17.4.6-1

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The overall parts fabrication cost made up of the systems costs minus an estimated potential for cost reduction for parts purchased from suppliers (not for the calculated parts included in the cost model, such as body structure and closures). This cost reduction is the amount of cost savings achieved in the simultaneous engineering process with suppliers during detailed parts development and over production life (excluding body structure and closures).

17.4.2.2. Fabrication Cost Breakdown for Steel Components

The cost breakdown for the parts fabrication of the steel components/systems are shown in Table 17.4.2.2-1. There were two types of assessment sources, a technical cost modeling and a supplier cost estimate, which was done by either a Consortium Member Company or a part/system supplier.

Table 17.4.2.2-1 Cost breakdown for steel components

Part/Component Name	Assessment Source		Part/Component Cost	
	Technical Cost Modeling	Supplier Cost Estimate	C-Class	PNGV-Class
Body structure (assembled)	x		$916	$972
Closure structures				
Door front structures (assembled)	x		$137	$137
Door rear structures (assembled)	x		N/A	$128
Hood structure (assembled)	x		$51	$51
Decklid structure (assembled)	x		N/A	$52
Liftgate structure (assembled)	x		$54	N/A
Fenders	x		$16	$16
Appliques	x		$8	$12
Bumper front+ rear	x		$22	$22
Instrument panel beam	x		$15	$15
Front seat structure (RH+LH)	x		$40	$40
Lightweight steel wheels (4) *		x	$65	$65
Fuel tank with filler (assembled)**		x	$81	$81
Exhaust system (assembled; without Catalyst)**		x	$100(G)/$96(D)	$102(G)/$98(D)
Rear suspension (assembled without brake system)**		x	$175	$175
Front suspension without subframe and leaf spring, brakes and steering system**			$200	$200
Front Suspension subframe and bushings**		x	$100	$100

*Costs assessed by Consortium Member Company
**Costs assessed by Systems supplier

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17.4.3. Cost Breakdown for Vehicle Assembly

Table 17.4.3-1 shows the cost breakdown for assembly including body shop, paint and trim line.

Table 17.4.3 -1 Vehicle assembly costs

Description	C-Class	PNGV-Class
Investment Costs	$218	$254
Direct and Indirect Labor	$108	$136
Others	$30	$36
Body Shop Assembly	**$356**	**$426**
Material	$135	$135
Investment Costs	$245	$245
Direct and Indirect Labor	$116	$116
Others	$84	$84
Paint Shop	**$580**	**$580**
Investment Costs	$75	$75
Direct and Indirect Labor	$265	$287
Others	$8	$8
Final Trim Line	**$348**	**$370**
Overall Assembly	**$1,284**	**$1,376**

17.4.4. Cost Breakdown for Body Structure

Table 17.4.4-1 Breakdown of body structure costs by manufacturing process groups

	C-Class	PNGV-Class
Stamping	$258.5	$263.1
Tailored Welded Blanks	$208.2	$248.4
Sheet Hydroforming	$21.8	$22.1
Tube Hydroforming	$102.7	$102.7
Purchased Part Costs	$46.0	$45.0
Parts Fabrication Costs	**$637.2**	**$681.3**
Assembly Costs	**$278.5**	**$291.1**
Total Body Structure Costs	**$916**	**$972**

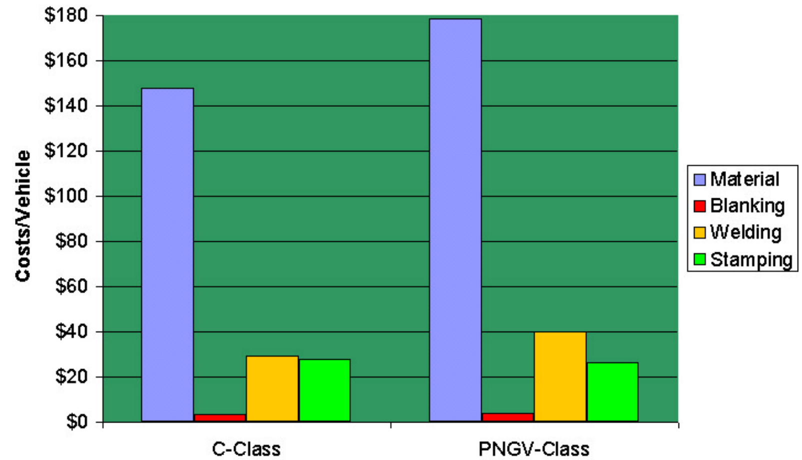

Figure 17.4.4-1 Body structure : tailor welded blank costs

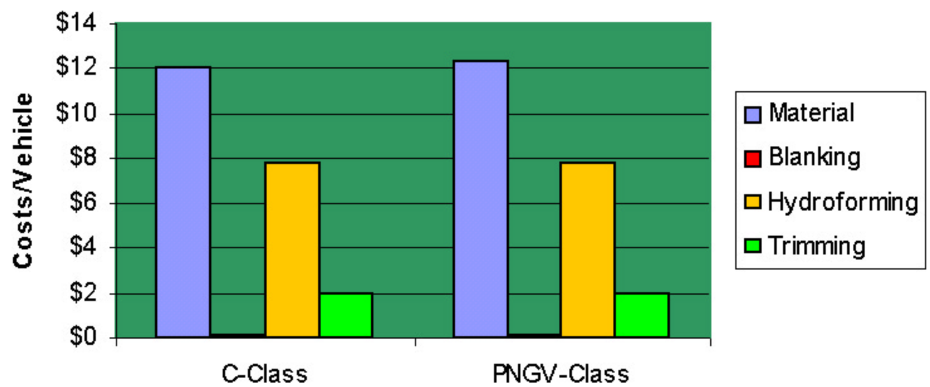

Figure 17.4.4-2 Body structure: sheet hydroforming costs

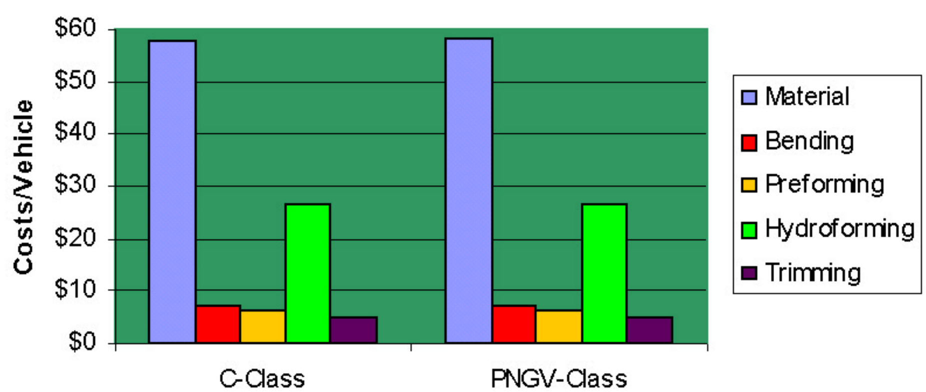

Figure 17.4.4-3 Body structure: tube hydroforming costs

Table 17.4.4-2 shows the body structure manufacturing costs broken down by fixed and variable costs including parts fabrication costs, purchased part costs and assembly costs.

Table 17.4.4-2 Body structure manufacturing costs

	Description	C-Class	PNGV-Class
Parts Fabrication	Material	$387.6	$423.4
	Labor	$35.1	$36.2
	Energy	$14.4	$15.0
	Total Variable Costs	**$437.1**	**$474.6**
	Equipment	$69.2	$72.8
	Tooling	$38.3	$39.2
	Building	$4.8	$5.2
	Overhead Labor	$32.0	$34.1
	Maintenance	$10.0	$10.5
	Total Fixed Costs	**$154.3**	**$161.8**
	Purchased Part Costs	**$46.0**	**$45.0**
	Part Fabrication Costs	**$637**	**$681**
Body Structure Assembly	Material	$0.9	$0.8
	Labor	$29.7	$28.9
	Energy	$5.2	$5.9
	Total Variable Costs	**$35.8**	**$35.6**
	Equipment	$139.3	$151.2
	Tooling	$40.8	$41.3
	Building	$5.8	$5.8
	Overhead Labor	$18.6	$20.0
	Maintenance	$38.2	$38.0
	Total Fixed Costs	**$242.7**	**$256.3**
	Assembly Costs	**$278**	**$291**
Body Structure Manufacturing Cost		**$916**	**$972**

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Economic Analysis

17.4.5. Closure Structures Manufacturing Cost

Table 17.4.5-1 Closure structures manufacturing costs detail

	Component Name	C-Class	PNGV-Class
Parts Fabrication	Door Front structure	$84	$84
	Door Rear structure	NA	$76
	Liftgate structure	$44	NA
	Decklid structure	NA	$37
	Hood structure	$36	$36
	Closure Structures Part Fabrication Costs	**$164**	**$233**
Closure Structure Assembly	Door Front assembly	$53	$53
	Door Rear assembly	NA	$52
	Liftgate assembly	$10	NA
	Deck Lid Assembly	NA	$15
	Hood Assembly	$15	$15
	Closure Structures Assembly Costs	**$78**	**$135**
	Closure Structures Manufacturing Costs	**$242**	**$368**

17.4.6. Body-in-white Manufacturing Costs

Table 17.4.6-1 Body-in-white manufacturing costs detail

	Component Name	C-Class	PNGV-Class
Parts Fabrication	Body Structure	$637	$681
	Closure Structures	$164	$233
	Fenders	$16	$16
	Appliques	$8	$12
	Body-in-white Parts Fabrication Costs	**$825**	**$942**
Assembly	Body structure	$278	$291
	Closure Structures	$78	$135
	Body-in-white Assembly Costs	**$356**	**$426**
	Body-in-white Manufacturing Costs	**$1,181**	**$1,368**

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17.4.7. Parts Fabrication Cost Breakdown Sheet Hydroforming Components

Table 17.4.7-1 Sheet hydroforming components

Component Name	C-Class	PNGV-Class
Roof panel	$22	$22
Fender (RH/LH)	$16	$16
Decklid outer panel	NA	$22
Liftgate outer panel	$19	NA
Hood outer panel	$21	$21
Panel front door outer (RH/LH)	$33	$31
Panel front door outer (RH/LH)	NA	$31

17.5. Uncertainty Analysis

17.5.1. Overview

The manufacturing costs of all ULSAB-AVC designs were assessed by using different methods of cost estimation. Therefore, MIT provided an error estimation of the approach to calculate an idea of accuracy of the results presented here.

Error estimation, in many respects, is a peculiar sort of guessing game for any cost analyst. In principle, a precise assessment of error depends upon a complete comprehension of the source of error and the structural relationship between the error source and the estimation process. Of course, such a complete appreciation of the source of error would immediately suggest to the analyst a mechanism to correct for that error, starting the cycle of error assessment all over again.

In practice, however, the analyst must necessarily reach a point where the existence of errors is acknowledged and the focus of the effort turns to striving to establish the magnitude of the error, based upon a set of structural assumptions. At this point in the process, the analyst can turn to the field of statistics to help to structure the analysis, but ultimately the error result is dependent upon the assumptions embedded in the assessment. More detail of this uncertainty analysis can be found in Appendix 9.3.

The mechanism for estimating the error of a sum of several cost estimates is a reasonable compromise between precision and data availability. While the application of complex Monte Carlo modeling tools is sometimes suggested in these cases, these tools have important limitations. First, they require information that is not generally available, such as the explicit description of the statistics underlying each estimate of every "random" variable in the cost estimate. Second, and more importantly, the central limit theorem guarantees that, irrespective of the specifics of each random variable, the results will converge to a normally distributed value anyway.

The model does put an implicit burden onto the cost estimator to be able to judge the reliability and confidence that should be placed upon the individual estimates generated. However, in many respects, the analyst is likely to be the best person to make such an assessment. And, it is always possible for the users to modify the estimates supplied by the analyst to assess the implications of their own judgments at any time, while the spreadsheet assures that the structure underlying the final error estimates is preserved.

17.5.2. Results

The exemplary calculation was done by MIT for the PNGV-Class gasoline version showed that with a desired confidence level of 80% the manufacturing costs will be within the bandwidth of approximately ± 6% relative to the cost assessment as already discussed.

Table 17.5.2-1 Uncertainty analysis result

Uncertainty Calculation ULSAB-AVC PNGV-Class Gasoline		
Manufacturing Costs	$9,538	
Max. Costs at 80% Confidence	$10,164	6.6%
Min. Costs at 80% Confidence	$8,982	-5.8%

17.6. Sensitivity Analysis

Sensitivity analyses were performed to demonstrate the effects of changing key process variables and assumptions on the cost results for the ULSAB AVC vehicles. Analyses were performed at three different levels. These include (1) sensitivity of the overall vehicle cost, (2) the cost of the assembled body-in-white (BIW) (including closures, but excluding additional auxiliary parts such as the fenders and the appliqués), and (3) an analysis of the effect of different process cycle times for those parts fabricated using sheet hydroforming. Each analysis was carried out for both the C-Class and the PNGV-Class designs.

17.6.1. Body-in-White

The BIW sensitivity analysis focused on those process variables that might have a major effect on the costs of fabricating and assembling the steel structure of the vehicle. The analysis specifically addressed issues concerning the vehicle production volume, product life, labor wage and steel prices. Each of these parameters were varied individually over reasonable ranges to understand the resulting effect on the cost of the BIW. The Figures 17.6.1-1 and 17.6.1-2 show the range costs for the BIW for each sensitivity variable as well as the range of costs if all inputs are varied simultaneously. The results indicate the importance of variables which affect the size of the lifetime production run (production volume and product life) and thus the ability to spread out the large investments in tooling associated with vehicle manufacture. Steel price is also important since material costs make up a large portion of the overall cost of the body. Labor wages are relatively unimportant since advanced vehicle manufacturing, in particular the construction of the BIW, is highly automated and therefore, labor is a small component of the total cost. However, under more extreme conditions, such as those encountered in developing economies with extremely low wages, this effect will be amplified.

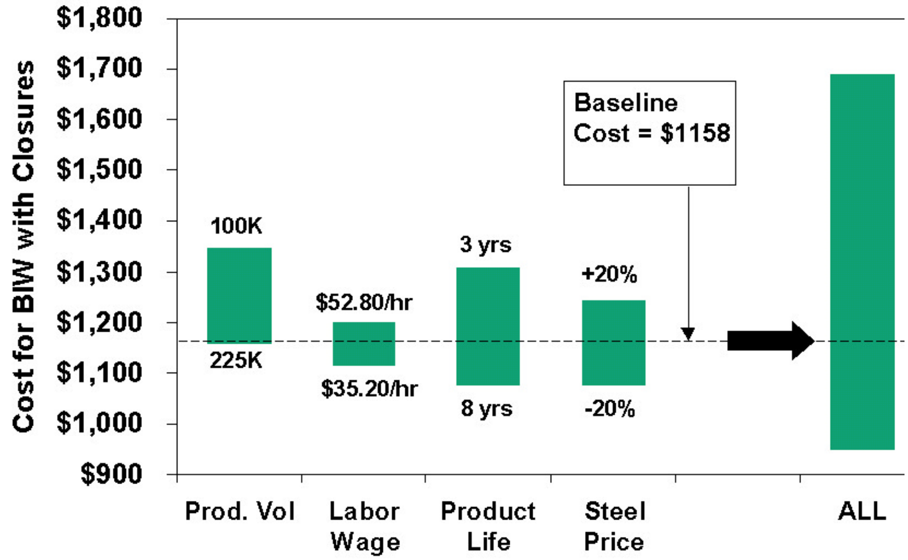

Figure 17.6.1-1 C-Class BIW fabrication cost sensitivity analysis result

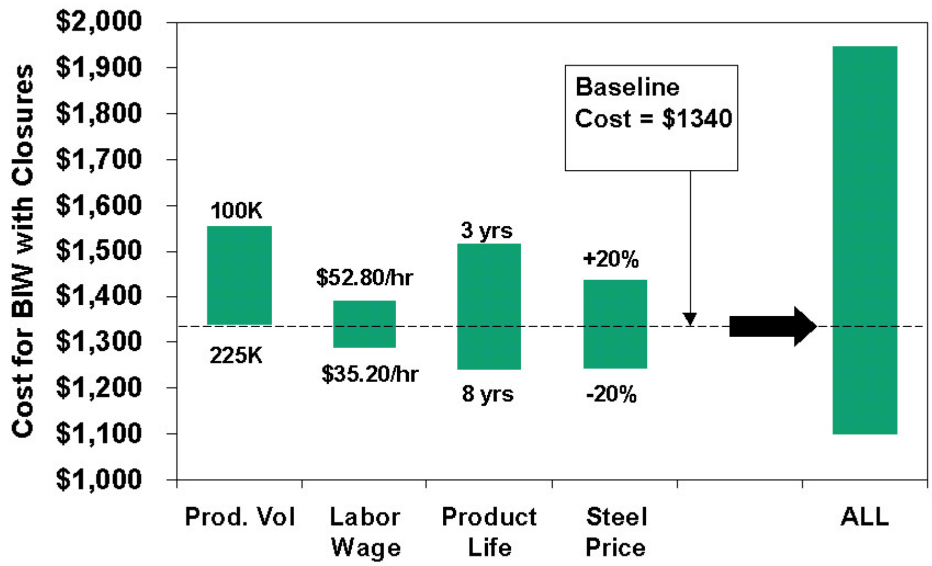

Figure 17.6.1-2 PNGV-Class BIW fabrication result sensitivity analysis result

17.6.2. Overall Vehicle (Non-Purchased Parts)

In the case of the overall vehicle, it was no longer relevant to look at such factors as the steel prices. Instead, the analysis was aimed at more macro-economic issues such as the product life, the interest rate and the labor wage. Again, product life is an important factor since it allows for the amortization of the costs of the tools over a longer period. Labor wage was more important in this case because the final assembly/trim line relies heavily on labor, thus amplifying its importance. The sensitivity analysis for body-in-white parts fabrication, body shop, paint shop, and final trim line for the C-Class and PNGV-Class are shown in Figures 17.6.2-1 and 17.6.2-2. The cost of purchased parts are assumed to be constant and are *not* considered in this sensitivity analysis.

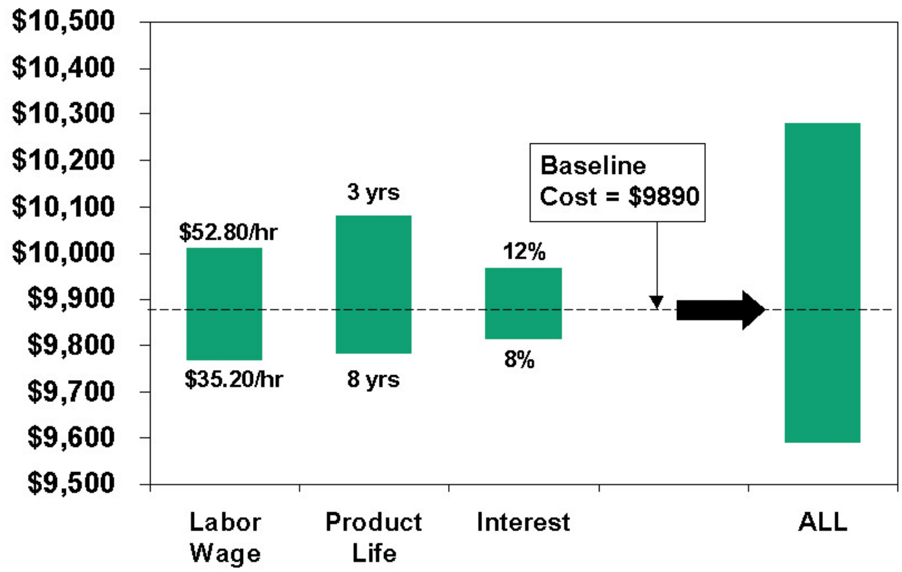

Figure 17.6.2-1 C-Class overall vehicle manufacturing cost sensitivity analysis

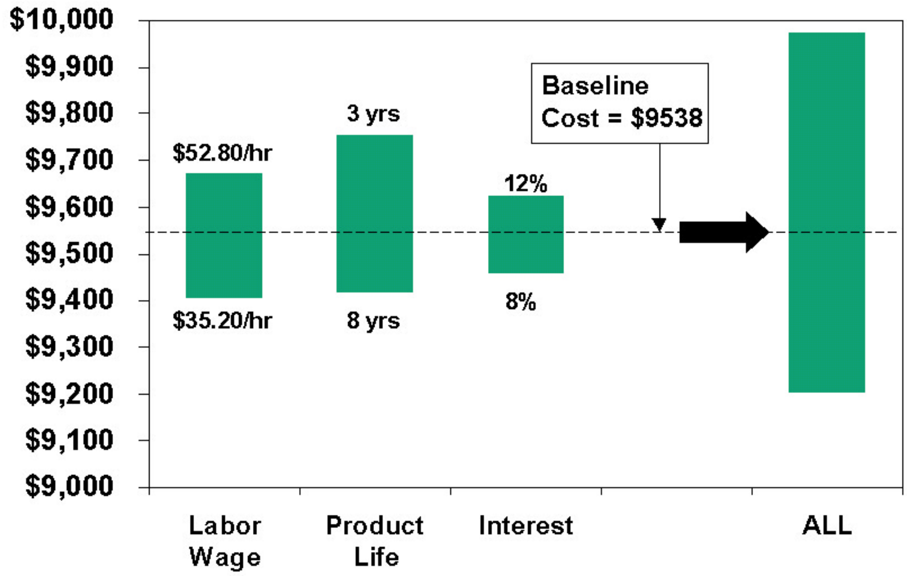

Figure 17.6.2-2 PNGV-Class overall vehicle manufacturing cost sensitivity analysis

17.6.3. Sheet Hydroforming

The use of sheet hydroforming for the production of outer panels is still not common practice among the world's OEMs. However, it has been demonstrated that the use of sheet hydroforming can in some cases allow for the use of thinner gauge steel sheets, thus resulting in materials savings. One limiting factor in using this production technique are the long process cycle times. Manufacturers claim to be able to produce many panels in only 30 seconds. However, for this study, a more realistic cycle time of 40 seconds was employed. In the case of difficult to form parts, cycle times of up to 90 seconds have been discussed by the industry. For this reason a sensitivity analysis for the cost of the sheet hydroformed panels to the process cycle time was performed as shown for both the C-Class and PNGV-Class in Figures 17.6.3-1 and 17.6.3-2. As one might expect, even a small reduction in the cycle time (from 40 to 30 seconds) will have a significant effect on the cost, resulting in roughly a 10%. Furthermore, if cycle times are far longer than expected, costs might rise by as much as 50%.

	30 sec.	40 sec. (Baseline Cycle Time)	90 sec.
Roof	$19.96	$21.83	$31.18
Closures	$65.52	$73.00	$110.40
Fenders	$13.82	$15.69	$25.04
TOTAL	$99.31	$110.53	$166.63

Figure 17.6.3-1 C-Class sheet hydroforming parts fabrication sensitivity analysis results

	30 sec.	40 sec. (Baseline Cycle Time)	90 sec.
Roof	$18.83	$20.40	$28.29
Closures	$85.25	$94.72	$142.04
Fenders	$12.50	$14.08	$21.96
TOTAL	$116.58	$129.20	$192.30

Figure 17.6.3-2 PNGV-Class sheet hydroforming parts fabrication sensitivity analysis results