Light-Duty Vehicle Technology Cost Analysis, Advanced 8-Speed Transmissions

United States
Environmental Protection
Agency

Light-Duty Vehicle Technology Cost Analysis, Advanced 8-Speed Transmissions

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
FEV, Inc.
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NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

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Executive Summary

The United States Environmental Protection Agency (EPA) contracted with FEV, Inc. to determine the incremental direct manufacturing costs for a set of advanced, light-duty vehicle technologies. The technologies selected are on the leading edge for reducing emissions of greenhouse gases in the future, primarily in the form of tailpipe carbon dioxide (CO_2).

This report, the fourth in a series of reports, addresses the direct incremental manufacturing cost of two (2) new powertrain configurations, relative to two (2) existing baseline configurations, with comparable driver performance metrics. The complete costing methodology used in the analysis of these configurations, as well as the pilot case study, is described in “Light-Duty Technology Cost Analysis Pilot Study (EPA-420-R-09-020).”

The two (2) new powertrain technology configurations analyzed are:

- A next generation ZF 8-speed automatic transmission, compared to a ZF 6-speed, Lepelletier concept-based, automatic transmission
- A 6-speed wet dual clutch transmission (DCT), compared to an 8-speed wet dual clutch transmission (DCT)

The results for the two (2) case studies are shown below in Table ES-1.

Table ES- 1 New Technology Configurations Incremental Unit Cost Impact

Case Study Reference Number	Technology Definition	Vehicle Class	Base Technology	New Technology	Incremental Unit Cost
1005	8-Speed AT replacing a 6-Speed AT	Large Truck Passenger or Commercial Vehicle with Strong Towing Capabilities	CS# B1005 6-Speed AT	CS# N1005 8-Speed AT	+ $61.84
1202	8-Speed DCT Replacing a 6-Speed DCT	Mid to Large Size Car, Passenger 4-6	CS# B1202 6-Speed Wet DCT	CS# N1202 8-Speed Wet DCT	+ $198.14

1 Introduction

1.1 Objectives

The objective of this work assignment was to determine the incremental direct manufacturing costs for two (2) new advanced light-duty vehicle transmission technology configurations using the costing methodology, databases, and supporting worksheets developed in the previously concluded pilot study (Light-Duty Technology Cost Analysis Pilot Study [EPA-420-R-09-020]).

1.2 Study Methodology

The first report published, "Light-Duty Technology Cost Analysis Pilot Study (EPA-420-R-09-020)," covers in great detail the overall costing methodology used to calculate an incremental cost delta between various technology configurations. In summary, the costing methodology is heavily based on teardowns of both new and baseline technology configurations having similar driver performance metrics. Only components identified as being different, within the selected new and baseline technology configurations, as a result of the new technology adaptation are evaluated for cost. Component costs are calculated using a ground-up costing methodology analogous to that employed in the automotive industry. All incremental costs for the new technology are calculated and presented using transparent cost models consisting of eight (8) core cost elements: material, labor, manufacturing overhead/burden, end item scrap, SG&A (selling general and administrative), profit, ED&T (engineering, design, and testing), and packaging. Information on how additional associated manufacturing fixed and variable cost elements (e.g., shipping, tooling, OEM indirect costs) are accounted for within the cost analysis are also discussed in the initial report (EPA-420-R-09-020).

Listed below, with the aid of Figure 1-1, is a high level summary of the ten (10) major steps taken during the cost analysis process. For additional information concerning the terminology used within the ten (10) steps, please reference the glossary of terms found at the end of this report.

Step 1: Using the ***Powertrain-Vehicle Class Summary Matrix (P-VCSM)***, a technology is selected for cost analysis.

Step 2: Existing vehicle models are identified for teardown to provide the basis for detailed incremental cost calculations.

Step 3: Pre-teardown ***Comparison Bills of Materials (CBOM)*** are developed, covering hardware that exists in the new and base technology configurations. These high level CBOM's are informed by the team's understanding of the new and base technologies and serve to identify the major systems and components targeted for teardown.

<u>Step 4</u>: Phase 1 (high level) teardown is conducted for all subsystems identified in Step 3 and the assemblies that comprise them. Using ***Design Profit® software***, all high level processes (e.g., assembly process of the high pressure fuel pump onto the cylinder head assembly) are mapped during the disassembly.

<u>Step 5</u>: A ***cross functional team (CFT)*** reviews all the data generated from the high level teardown and identifies which components and assumptions should be carried forward into the cost analysis. The CBOMs are updated to reflect the CFT input.

<u>Step 6</u>: Phase 2 (component/assembly level) teardowns are initiated, based on the updated CBOM's. Components and assemblies are disassembled, and processes and operations are mapped in full detail. The process mapping generates key process information for the quote worksheets. Several ***databases*** containing critical costing information provide support to the mapping process.

<u>Step 7</u>: ***Manufacturing Assumption and Quote Summary (MAQS) worksheets*** are generated for all parts undergoing the cost analysis. The MAQS details all cost elements making up the final unit costs: material, labor, burden, end item scrap, SG&A, profit, ED&T, and packaging.

<u>Step 8</u>: Parts with high or unexpected cost results are subjected to a ***marketplace cross-check,*** such as comparison with supplier price quotes or wider consultation with company and industry resources (i.e., subject matter experts) beyond the CFT.

<u>Step 9</u>: All costs calculated in the MAQS worksheets are automatically inputted into the ***Subsystem Cost Model Analysis Templates (CMAT)***. The Subsystem CMAT is used to display and roll up all the differential costs associated with a subsystem. All parts in a subsystem that are identified for costing in the CBOM are entered into the Subsystem CMAT. Also both the base and new technology configurations are included in the same CMAT to facilitate differential cost analysis.

<u>Step 10</u>: The final step in the process is creating the ***System CMAT*** which rolls up all the subsystem differential costs to establish a final system unit cost. The System CMAT, similar in function to the subsystem CMAT, is the document used to display and roll-up all the subsystem costs associated within a system as defined by the CBOM. Within the scope of this cost analysis, the System CMAT provides the bottom line incremental unit cost between the base and new technology configurations under evaluation

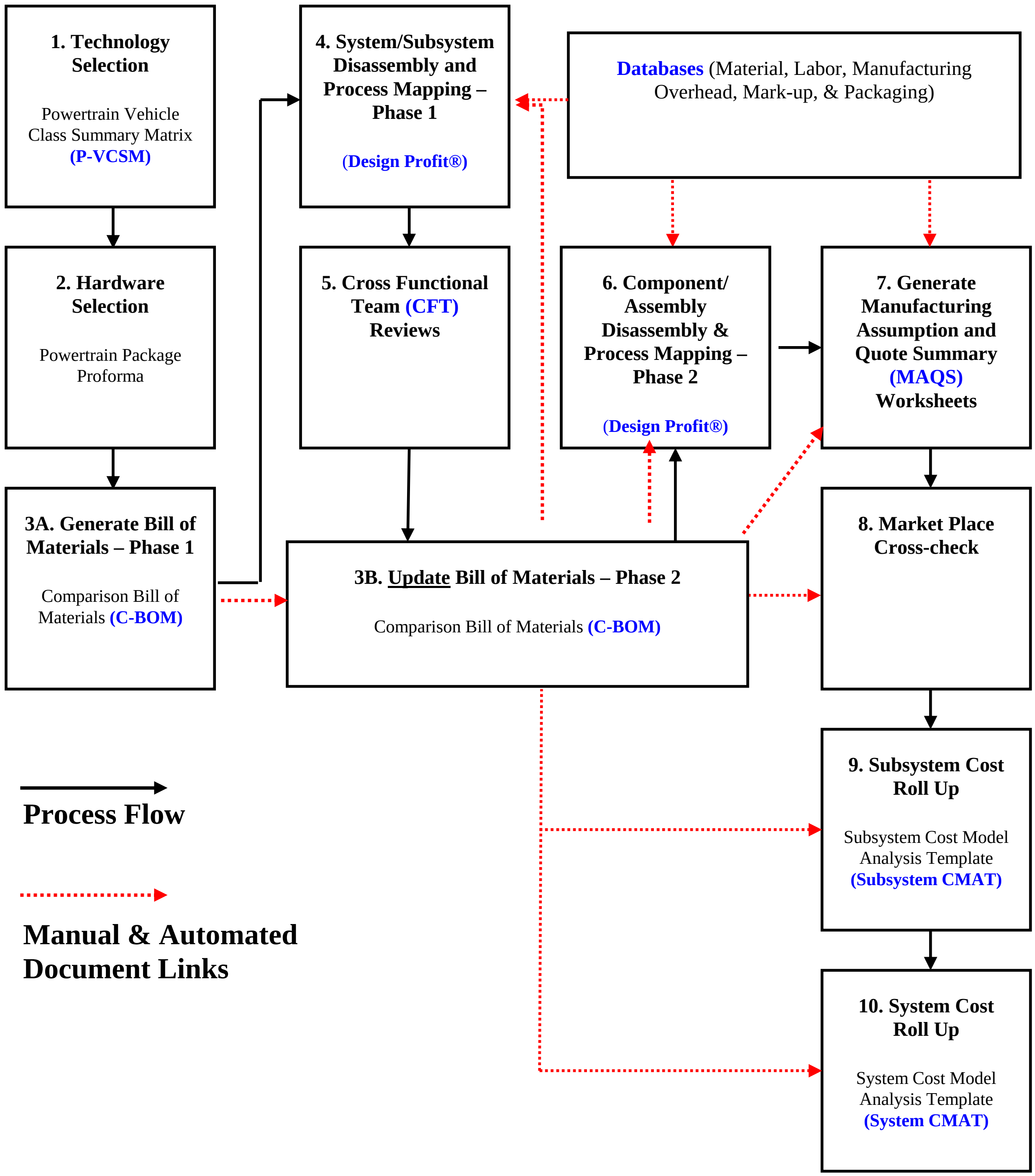

Figure 1-1: Cost Analysis Process Flow Steps and Document Interaction

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1.3 Manufacturing Assumptions

When conducting the cost analysis for the various technology configurations, a number of assumptions are made in order to establish a consistent framework for all costing. The assumptions can be broken into universal and specific case study assumptions.

The universal assumptions apply to all technology configurations under analysis. Listed in **Table 1-1** are the fundamental assumptions.

The specific case study assumptions are those unique to a given technology configuration. These include volume assumptions, weekly operation assumptions (days, shifts, hours, etc.), packaging assumptions, and Tier 1 in-house manufacturing versus Tier 2/3 purchase part assumptions. Details on the case study specific assumptions can be found in the individual MAQS worksheets.

Table 1-1: Summary of Universal Cost Analysis Assumptions Applied to All Case Studies

Item	Description	Universal Case Study Assumptions
1	Incremental **Direct** Manufacturing Costs	A. Incremental **Direct** manufacturing cost is the incremental difference in cost of components and assembly, to the OEM, between the new technology configuration and the baseline technology configuration. B. This value does not include **Indirect** OEM costs associated with adopting the new technology configuration (e.g. tooling, corporate overhead, corporate R&D, etc).
2	Incremental **Indirect** OEM Costs are not handled within the scope of this cost analysis	A. Indirect Costs are handled through the application of "Indirect Cost Multipliers" (ICMs) which are not included as part of this analysis. The ICM covers items such as ..... a. OEM corporate overhead (sales, marketing, warranty, etc) b. OEM engineering, design and testing costs (internal & external) c. OEM owned tooling B. Reference EPA report EPA-420-R-09-003, February 2009, "Automobile Industry Retail Price Equivalent and Indirect Cost Multiplier" for additional details on the develop and application of ICM factors.
3	Product/Technology Maturity Level	A. Mature technology assumption, as defined within this analysis, includes the following: a. Well developed product design b. High production volume c. Products in service for several years at high volumes c. Significant market place competition B. Mature Technology assumption establishes a consistent framework for costing. For example, a defined range of acceptable mark-up rates. a. End-item-scrap 0.3-0.7% b. SG&A/Corporate Overhead 6-7% c. Profit 4-8% d. ED&T (Engineering, Design and Testing) 0-6% C. The technology maturity assumption does not include allowances for product learning. Application of a learning curve to the calculated incremental direct manufacturing cost is handled outside the scope of this analysis.

Item	Description	Universal Case Study Assumptions
4	Selected Manufacturing Processes and Operations	A. All operations and processes are based on existing standard/mainstream Industrial practices. B. No additional allowance is included in the incremental direct manufacturing cost for manufacturing learning. Application of a learning curve to the developed incremental direct manufacturing cost is handled outside the scope of this analysis.
5	Annual Capacity Planning Volume	450,000 Units
6	Supplier Manufacturing Location	North America (USA or Canada)
7	OEM Manufacturing Location	North America (USA or Canada)
8	Manufacturing Cost Structure Timeframe (e.g. Material Costs, Labor Rates, Manufacturing Overhead Rates)	2009/2010 Production Year Rates
9	Packaging Costs	A. Calculated on all Tier One (T1) supplier level components. B. For Tier 2/3 (T2/T3) supplier level components, packaging costs are included in T1 mark-up of incoming T2/T3 incoming goods.
10	Shipping and Handling	A. T1 supplier shipping costs covered through application of the Indirect Cost Multiplier (ICM) discussed above. B. T2/T3 to T1 supplier shipping costs are accounted for via T1 mark-up on incoming T2/T3 goods.
11	Intellectual Property (IP) Cost Considerations	Where applicable IP costs are included in the analysis. Based on the assumption that the technology has reached maturity, sufficient competition would exist suggesting alternative design paths to achieve similar function and performance metrics would be available minimizing any IP cost penalty.
12	Material Cost Reductions (MCRs) on analyzed hardware	Only incorporated on those components where it was evident that the component design and/or selected manufacturing process was chosen due to actual low production volumes (e.g. design choice made to accept high piece price to minimize tooling expense). Under this scenario, assumptions where made, and cost analyzed assuming high production volumes.
13	Operating and End-of Life Costs	No new, or modified, maintenance or end-of-life costs, were identified in the analysis.
14	Stranded Capital or ED&T expenses	No stranded capital or non-recovered ED&T expenses were considered within the scope of this analysis. It was assumed the integration of new technology would be planned and phased in minimizing non-recoverable expenses.

1.4 Subsystem Categorization

As with the first case study analysis, a design based classification system was used to group the various components and assemblies making up the technology configurations. In general, every vehicle system (e.g., engine system, transmission system, etc) is made up of several subsystems levels (e.g., the transmission system includes a case subsystem, geartrain subsystem, internal clutch subsystem, launch clutch subsystem, oil pump and filter subsystem, etc.), which, in turn, is made up of several sub-subsystem levels (e.g., the geartrain subsystem includes the following sub-subsystems: input shaft, output shaft, transfer shaft, planetary gear, etc). The sub-subsystem is the smallest classification level in which all components and assemblies are binned.

Table 1-2 provides an overview of the major subsystems and sub-subsystems included for each system evaluated within this analysis. In Section 2, Case Study Results, costs are presented for both transmission evaluations using these design subsystem categorizations.

Table 1-2: Transmission System, Subsystem and Sub-Subsystem Classification

Subsystem	Sub-Subsystem
Externally Mounted Component	Lift Eye, Vent Cap, Bracket, Bolting
Case(s)	Transaxle Case, Transaxle Housing, Covers, Bearing Race, Plug, Actuator
Gear Train	Input Shaft, Output Shaft, Transfer Shaft, Sun Gear, Planetary Gear, Ring Gear, Counter Gear, Differential Gear, Bearing (Roller, Needle)
Internal Clutch	Sprag Clutch, Clutch & Brake Hub, Disc and Plate, Piston, Snap Ring, Bearing (Roller, Needle), Synchronizer
Launch Clutch	Torque Converter, Clutch Assembly, Flexplate, Flywheel
Oil Pump and Filter	Oil pump, Cover, Oil Filter, Oil Cooler, Oil Squirter, Pipes/Tubes
Mechanical Control	Valve Body Assembly, Mechanical Controls (e.g., Shift Forks), Sealing Elements, Bearing Elements, Plugs & Cups
Electrical Control	Controller, Solenoid, Sensor, Switches, Wiring Harness
Park Mechanism	Rod/Shaft/Pin, Spring, Pawl, Bracket, Bolt

2 Case Study Results

The incremental direct manufacturing cost impact for the 6-speed to 8-speed automatic transmission (AT) comparison and the 6-speed to 8-speed wet dual clutch transmission (DCT) are shown above in

Within Section 2.0, for each case study, a brief description of the performance attributes of both the baseline and new technology configurations are provided. In addition a high level overview of key hardware content is included for each technology evaluated.

In the 6-speed DCT to 8-speed DCT analysis, no 8-speed DCT hardware was available at the time of the analysis. Using the 6-speed DCT as the foundation, the FEV team made some basic assumptions on how the 6-speed DCT could be modified to produce an 8-speed variant. The assumptions can be found in the respective section.

Following the system performance and hardware overviews for each case study, the increment direct manufacturing cost impact is summarized at a subsystem level in a system Cost Model Analysis Template (CMAT).

Because each case study consists of a large quantity of component and assembly Manufacturing and Assumption Quote Summary (MAQS) worksheets, hard copies were not included as part of this report. However, electronic copies of the MAQS worksheets, as well as all other supporting case study documents (e.g., Subsystem CMATs, System CMATs), can be accessed at **http://www.epa.gov/otaq/climate/publications.htm**

2.1 Case Study #1005 Results

Case Study #1005 analyzed the direct incremental manufacturing cost for updating from a ZF 6-speed, Lepelletier concept, automatic transmission to a next generation 8-speed automatic transmission.

2.1.1 6-Speed AT Hardware Overview – Baseline Technology Configuration

Figure 2-1: Illustration of ZF 6HP28 RWD Transmission

The 6-speed automatic transmission selected for the baseline analysis was the ZF 6HP28 RWD transmission (second generation of ZF 6HP26). This transmission is/has been used in various applications including the BMW Series 3 Coupe and the X5 SUV in the 2007-2012 timeframe. The ZF 6-Speed transmission incorporates a Lepelletier AT gearing configuration which utilizes a single planetary gear set along with a Ravigneaux gear set. The use of a Lepelletier configuration allowed ZF to add an additional gear without sacrificing size, weight and part content over the existing 5-speed AT. In fact the 6-speed AT weighs approximately 12% less, and has 29% fewer parts, than its predecessor. (Source: SAE Technical Paper 2003-01-0596). Listed below are a few design parameters for the 6-speed AT.

- Total of five (5) shift elements, two (2) open shift elements per gear
- Three (3) clutches and two (2) brakes
- Full planetary gear set and a Ravigneaux gear set
- The total weight of the transmission, including Automatic Transmission Fluid (ATF), is approximately 92.5kg. The maximum output torque rating is 650 Nm.

2.1.2 8-Speed AT Hardware Overview – New Technology Configuration

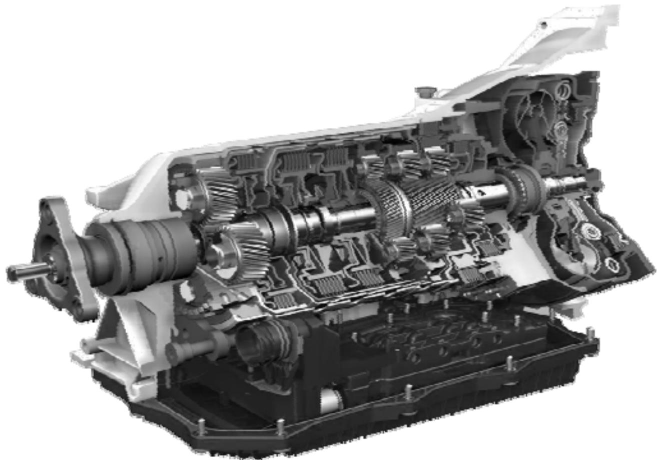
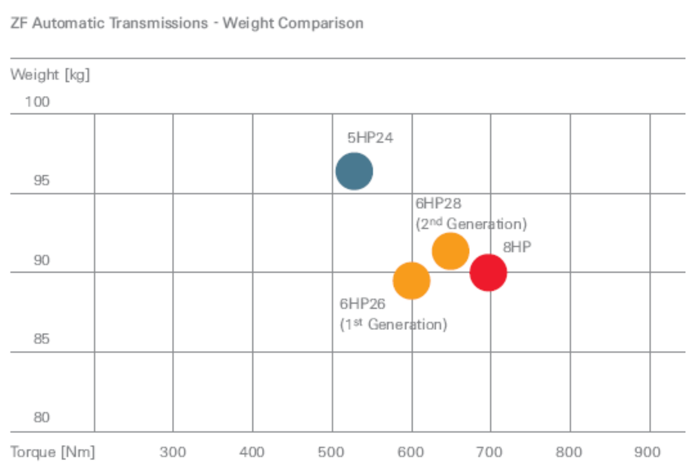


Figure 2-2: Illustration of ZF 8HP70 RWD Transmission

The ZF 8-speed automatic transmission (AT), the successor to the ZF 6-speed AT, was selected for the analysis representing the new advance technology configuration. The ZF 8-speed RWD transmission (8HP70) **(Figure 2-2)** was a complete redesign of the existing Lepelletier-based 6-speed transmission family, which originally launched in the 2001 timeframe. The implementation of a revolutionary gearing system, consisting of 4 planetary gear sets, controlled by an equivalent number of shift elements as compared to the ZF 6-speed AT, supports a net 6% overall fuel economy improvement relative to its predecessor. In addition to maintaining the same overall installation dimensions, the new 8-speed transmission has a higher torque to weight ratio as shown below in Figure 2-3.



(Source: ZF Published Document “The Freedom to Exceed Limits”, http://www.zf.com/media/media/en/document/corporate_2/products_3/innovation_1/8hp_1/8HP_de_2007s.pdf)

Figure 2-3: ZF Automatic Transmission Weight and Torque Comparison Data

Design parameters for the 8-speed AT, for comparison to the ZF 6-speed AT, are presented below.

- Five (5) shift elements, two (2) open shift elements per gear.
- Three (3) disk clutches and two (2) brakes
- Four (4) planetary gear sets.
- Lost torque is reduced by 33% compared to a 6-speed.
- Gear set efficiency exceeds 98%
- The total weight of the transmission (as measured), including ATF, is 89kg. The maximum output torque rating is 700 N*m

2.1.3 Net Incremental Direct Manufacturing Cost Impact (AT Analysis)

As discussed in the initial report (EPA-420-R-09-020), the costing methodology employs an exclusion approach to costing. Following completion of the comparison bill of materials (CBOMs), the cross functional team began the process of analyzing the differences between hardware on the six (6) and eight (8) speed automatic transmissions. A component function and design analysis was performed, eliminating many parts and components from further costing analysis. A baseline cost from which an incremental cost for the 8-speed was established. The majority of incremental cost increase of the 8-speed over the 6-speed was associated with the additional gearing.

It was obvious from the transmission teardown assessment that in addition to ZF's goal for improving overall performance with their new 8-speed automatic transmission relative to the 6-speed predecessor, ZF also focused on optimizing cost and weight. In regard to the 6-speed automatic transmission, many of innovative ideas implemented into the 8-speed automatic could have been incorporated into a new 6-speed if it were to be redesigned. The most obvious new technology advance (NTA) would be adopting a similar drum and carrier system, which would conceivably have the same benefits (compact packaging, streamlined and less costly to assemble) recognized by the 8-speed automatic. As part of this analysis, no additional work was conducted to determine what the financial impact would be on the 6-speed automatic by employing some of these new technology advances and material cost reduction concepts. The net incremental direct manufacturing cost shown below is solely based on the physical hardware evaluated.

Table 2-1 shows the net incremental direct manufacturing cost between the 8- and 6-speed automatic transmissions. In evaluating the physical hardware, the 6-speed automatic was analyzed to be less expensive to manufacture by approximately $62. Note that when the 8-speed transmission was redesigned, several other functional and performance updates not driven by the added gear ratios were incorporated (e.g., modified hydraulic control strategy, spool valve material, friction discs, as well as a newly-developed torque converter). These modifications were not estimated in the analysis since they are independent of the gear ratio addition and modifications.

As shown in **Table 2-1** many of the transmission subsystems where deemed cost neutral. Much of the cost analysis work was focused on the cost difference in the gear train and internal clutch subsystems. An internal clutch subsystem cost save of $12.56 was calculated for the 8-speed AT. However the 8-speed AT gear train subsystem increased in cost by $74.40 resulting in a net incremental direct manufacturing cost of $+61.84.

Table 2-1: System Cost Model Analysis Template Illustrating the Incremental Subsystem Costs Roll Up for an 8-Speed AT compared to a 6-Speed AT

SYSTEM & SUBSYSTEM DESCRIPTION / NEW TECHNOLOGY PACKAGE COST INFORMATION – 8 Speed ZF Automatic Transmission

Item	Subsystem	Sub-Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		02 TRANSMISSION SYSTEM											
1		01 EXTERNAL COMPONENTS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2		02 CASE(S):	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3		03 GEAR TRAIN:	$ 49.58	$ 40.81	$ 92.84	$ 183.24	$ 0.92	$ 12.08	$ 11.11	$ 4.59	$ 28.70	$ -	$ 211.94
4		04 INTERNAL CLUTCHES:	$ 75.79	$ 27.13	$ 78.47	$ 181.39	$ 1.34	$ 12.69	$ 11.51	$ 4.58	$ 30.12	$ -	$ 211.50
5		05 LAUNCH CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6		06 OIL PUMP & FILTER:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7		07 MECHANICAL CONTROLS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
8		08 ELECTRICAL CONTROLS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
9		09 PARK MECHANISM:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10		10 MISCELLANEOUS ITEMS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
		SUBSYSTEM ROLL-UP	$ 125.37	$ 67.94	$ 171.32	$ 364.63	$ 2.26	$ 24.77	$ 22.62	$ 9.17	$ 58.82	$ -	$ 423.44

SYSTEM & SUBSYSTEM DESCRIPTION / BASE TECHNOLOGY PACKAGE COST INFORMATION – 6 Speed ZF Automatic Transmission

Item	Subsystem	Sub-Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		02 TRANSMISSION SYSTEM											
1		01 EXTERNAL COMPONENTS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2		02 CASE(S):	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3		03 GEAR TRAIN:	$ 35.12	$ 21.57	$ 62.26	$ 118.95	$ 0.60	$ 7.81	$ 7.19	$ 2.98	$ 18.58	$ -	$ 137.53
4		04 INTERNAL CLUTCHES:	$ 81.76	$ 31.27	$ 80.85	$ 193.87	$ 0.97	$ 12.68	$ 11.69	$ 4.85	$ 30.19	$ -	$ 224.07
5		05 LAUNCH CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6		06 OIL PUMP & FILTER:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7		07 MECHANICAL CONTROLS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
8		08 ELECTRICAL CONTROLS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
9		09 PARK MECHANISM:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10		10 MISCELLANEOUS ITEMS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
		SUBSYSTEM ROLL-UP	$ 116.88	$ 52.84	$ 143.11	$ 312.83	$ 1.57	$ 20.49	$ 18.88	$ 7.83	$ 48.77	$ -	$ 361.60

SYSTEM & SUBSYSTEM DESCRIPTION / INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE

Item	Subsystem	Sub-Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		02 TRANSMISSION SYSTEM											
1		01 EXTERNAL COMPONENTS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2		02 CASE(S):	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3		03 GEAR TRAIN:	$ 14.46	$ 19.24	$ 30.58	$ 64.28	$ 0.33	$ 4.27	$ 3.92	$ 1.61	$ 10.12	$ -	$ 74.40
4		04 INTERNAL CLUTCHES:	$ (5.97)	$ (4.13)	$ (2.38)	$ (12.49)	$ 0.36	$ 0.01	$ (0.18)	$ (0.27)	$ (0.08)	$ -	$ (12.56)
5		05 LAUNCH CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6		06 OIL PUMP & FILTER:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7		07 MECHANICAL CONTROLS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
8		08 ELECTRICAL CONTROLS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
9		09 PARK MECHANISM:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10		10 MISCELLANEOUS ITEMS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
		SUBSYSTEM ROLL-UP	$ 8.49	$ 15.11	$ 28.20	$ 51.80	$ 0.69	$ 4.27	$ 3.74	$ 1.34	$ 10.04	$ -	$ 61.84

2.2 Case Study #1202 Results

Case Study #1202 analyzed the direct incremental manufacturing cost for updating from a 6-speed, wet dual clutch transmission (DCT) to an 8-speed, wet DCT.

2.2.1 6-Speed DCT Hardware Overview – Baseline Technology Configuration

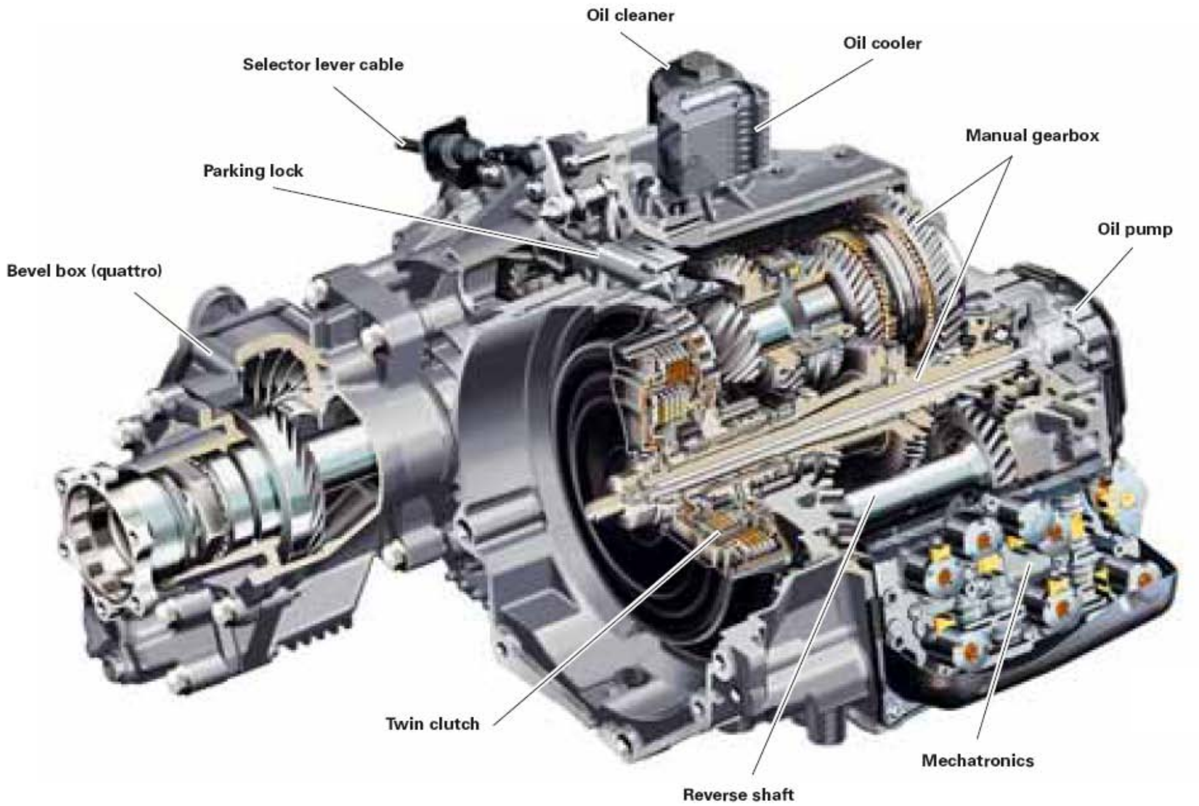
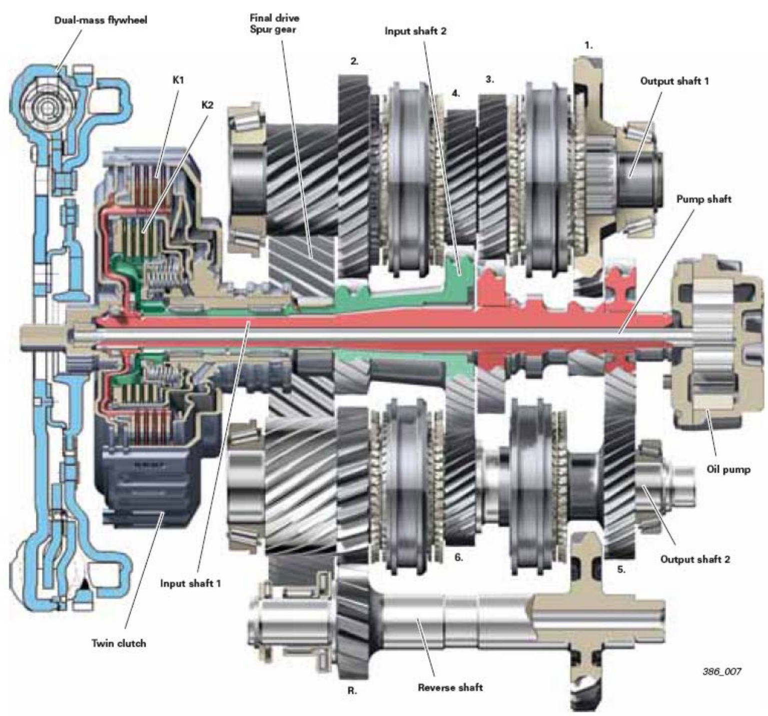


Figure 2-4: Illustration of the Volkswagen DQ250 Wet Dual Clutch Transmission

The baseline technology configuration selected for the analysis was the Volkswagen (VW) 6-speed, wet, dual clutch transmission (DCT); model number DQ250. Other industry naming conventions for this technology configuration include twin-clutch gearbox or dual shift gearbox (DSG). The basic components of the DCT include a twin clutch pack assembly driving two (2) coaxial input shafts. Power from the engine is transmitted to the input shafts through a dual-mass flywheel which is connected in series to the twin-clutch pack. Each input shaft, dependent on the selected gear, is designed to mesh with one (1) of two (2) output shafts. Upon reverse gear selection, there is an intermediate shaft which engages with both input shaft one (1) and output shaft two (2). There are four (4) shift forks, two (2) on each output shaft, hydraulically activated into one of two positions from their neutral home position. The controls for the DCT, which include the hydraulic controls, electronic controls, and various sensors and actuators, are integrated into a single module VW refers to as a Mechatronic unit. The total weight of the transmission module, including the dual-mass flywheel, is approximately 94 kg. The maximum output torque rating for the DQ250 transmission is 350Nm.

2.2.2 8-Speed DCT Hardware Overview – Baseline Technology Configuration

At the time of the study, there were no 8-speed DCTs available in the market to support the cost analysis. Therefore a modified approach was taken for this case study. Using the 6-speed wet DCT as the foundation, the FEV team developed some basic assumptions on how the 6-speed DCT could be modified to produce an 8-speed variant. Using the 6-speed parts and some concept sketches, the team created a bill of material for the 8-speed DCT. The 8-speed DCT is only a simple concept of what an 8-speed DCT may look like at a high level; providing sufficient information to develop an incremental direct manufacturing cost. **Figure 2-5** provides a cross-section view of the baseline 6-speed wet DCT.



(Source: Audi Service Training Manual, 6-speed twin-clutch gearbox 02E S tronic)

Figure 2-5: Cross-sectional illustration of the Volkswagen 6-Speed DCT

For the 8-speed DCT concept, the input, output and reverse drive shafts were extended between the 3rd and 4th gear such that a 7th and 8th synchronized gear set could be added in **(Reference Figure 2-6).** In addition to the added synchronized gear sets, associated components such as shift forks, hydraulic cylinders and pistons, fork detents, solenoids and hydraulic control valves were added to the BOM. These components are not shown in Figure 2-6 below. Further, additional considerations for modifying the front and rear cases, valve body, channel plate, input shafts, output shafts and pump shaft were included in the assumptions.

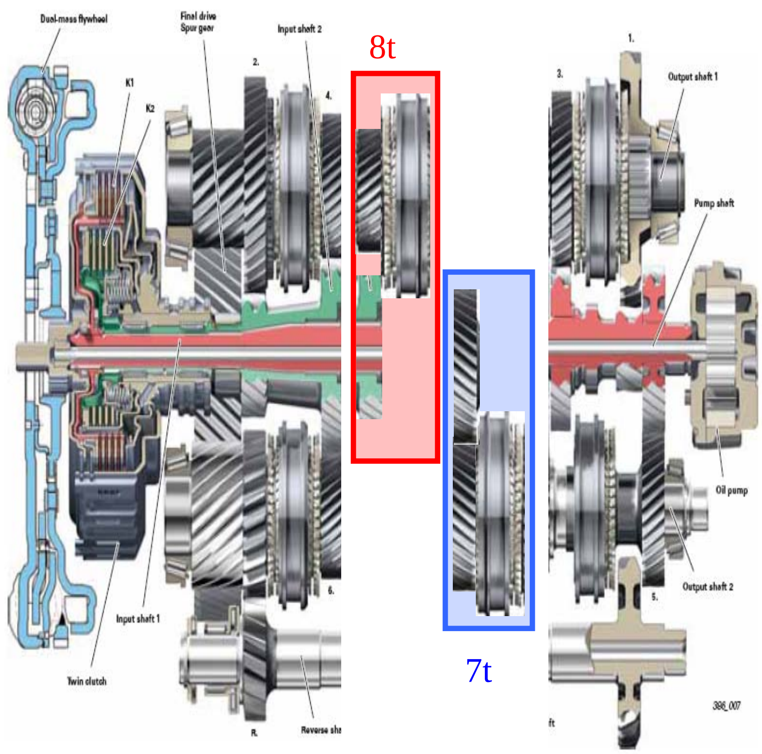


Figure 2-6: 8-Speed Wet DCT Concept Illustration

Additional assumptions made by the DCT evaluation team while developing the 8-speed DCT concept included the following:

- The addition of the 7^{th} an 8^{th} gear to the 6-speed DCT does provide fuel efficiency savings
- Engine torque and transmission capacity are matched
- The target vehicle(s) can accommodate the additional length of the transmission
- Additional length of output shafts do not cause shaft bending issues which lead to NVH problems
- Additional length of the reverse shaft does not cause shaft bending issues
- Center distances of the output shafts within the transmission cases will not be the same for six and eight speed DCT transmissions
- Output shaft diameters and splines configurations will change to accommodate the seventh and eighth gears
- Change gear internal diameters and splines will all change to accommodate the seventh and eighth gears
- Bearing supports for the output shafts ends will need to be adequately sized to support the torques and loads
- All input and output change gear outside diameters will change and the resulting ratios and number of teeth will fit into the launch through overdrive ratio requirements
- Final drive ratios for the output driven gear and the two drive gears will change to accommodate the eight forward and one reverse gear ratios
- The schematics show a separate synchronizer assembly for both the 7^{th} and 8^{th} change gears
- The schematics shown with this report are only intended to represent the additional and modified components required to go from a six-speed to an eight-speed DCT.
- These transmission schematics do not represent a fully functional design of an eight-speed DCT

2.2.3 Net Incremental Direct Manufacturing Cost Impact (DCT Analysis)

Table 2-2 shows the net incremental, direct manufacturing cost between the 6-speed wet DCT and 8-speed wet DCT. In the evaluation, the 8-speed wet DCT was analyzed to be more expensive to manufacture by approx $198. The major cost increment of the 8-speed DCT was the additional content in the mechanical controls subsystem at $106.15 Included in this add cost are the 7th and 8th gear synchronizers, hubs, shift fork assemblies, spool valves and solenoids. Modifications to the valve body to accommodate the additional function and hardware for the 7th and 8th gear set addition was also included in this subsystem.

The next largest contributor to the added cost was the gear train subsystem at $64.04. Included in this subsystem were the additional 7th and 8th input and output gears plus the additional modification to both input and output shafts and the reverse shaft. Modifications to the case accounted for the majority of remaining costs contributing $20.85 to the net incremental direct manufacturing cost.

Table 2-2: System Cost Model Analysis Template Illustrating the Incremental Subsystem Costs Roll Up for an 8-Speed DCT compared to a 6-Speed DCT

SYSTEM & SUBSYSTEM DESCRIPTION			NEW TECHNOLOGY PACKAGE COST INFORMATION 8-Speed Wet DCT										
			Manufacturing				Markup						
Item	Subsystem	Sub-Subsystem Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		02 TRANSMISSION SYSTEM											
1		01 EXTERNAL COMPONENTS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2		02 CASE(S):	$ 5.50	$ 1.19	$ 14.17	$ 20.85	$ -	$ -	$ -	$ -	$ -	$ -	$ 20.85
3		03 GEAR TRAIN:	$ 20.23	$ 5.58	$ 38.23	$ 64.04	$ -	$ -	$ -	$ -	$ -	$ -	$ 64.04
4		04 INTERNAL CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
5		05 LAUNCH CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6		06 OIL PUMP & FILTER:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7		07 MECHANICAL CONTROLS:	$ 47.26	$ 12.23	$ 36.26	$ 95.75	$ 0.33	$ 4.50	$ 4.04	$ 1.53	$ 10.40	$ -	$ 106.15
8		08 ELECTRICAL CONTROLS: (Combined w/ Mechnical Controls)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
9		09 PARK MECHANISM:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10		10 MISCELLANEOUS ITEMS:	$ 1.82	$ 2.78	$ 2.50	$ 7.10	$ -	$ -	$ -	$ -	$ -	$ -	$ 7.10
		SUBSYSTEM ROLL-UP	$ 74.82	$ 21.77	$ 91.16	$ 187.74	$ 0.33	$ 4.50	$ 4.04	$ 1.53	$ 10.40	$ -	$ 198.14

SYSTEM & SUBSYSTEM DESCRIPTION			BASE TECHNOLOGY PACKAGE COST INFORMATION 6 Speed Wet DCT										
			Manufacturing				Markup						
Item	Subsystem	Sub-Subsystem Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		02 TRANSMISSION SYSTEM											
1		01 EXTERNAL COMPONENTS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2		02 CASE(S):	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3		03 GEAR TRAIN:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
4		04 INTERNAL CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
5		05 LAUNCH CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6		06 OIL PUMP & FILTER:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7		07 MECHANICAL CONTROLS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
8		08 ELECTRICAL CONTROLS: (Combined w/ Mechnical Controls)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
9		09 PARK MECHANISM:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10		10 MISCELLANEOUS ITEMS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
		SUBSYSTEM ROLL-UP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

SYSTEM & SUBSYSTEM DESCRIPTION			INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
			Manufacturing				Markup						
Item	Subsystem	Sub-Subsystem Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		02 TRANSMISSION SYSTEM											
1		01 EXTERNAL COMPONENTS:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2		02 CASE(S):	$ 5.50	$ 1.19	$ 14.17	$ 20.85	$ -	$ -	$ -	$ -	$ -	$ -	$ 20.85
3		03 GEAR TRAIN:	$ 20.23	$ 5.58	$ 38.23	$ 64.04	$ -	$ -	$ -	$ -	$ -	$ -	$ 64.04
4		04 INTERNAL CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
5		05 LAUNCH CLUTCHES:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6		06 OIL PUMP & FILTER:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7		07 MECHANICAL CONTROLS:	$ 47.26	$ 12.23	$ 36.26	$ 95.75	$ 0.33	$ 4.50	$ 4.04	$ 1.53	$ 10.40	$ -	$ 106.15
8		08 ELECTRICAL CONTROLS: (Combined w/ Mechnical Controls)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
9		09 PARK MECHANISM:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10		10 MISCELLANEOUS ITEMS:	$ 1.82	$ 2.78	$ 2.50	$ 7.10	$ -	$ -	$ -	$ -	$ -	$ -	$ 7.10
		SUBSYSTEM ROLL-UP	$ 74.82	$ 21.77	$ 91.16	$ 187.74	$ 0.33	$ 4.50	$ 4.04	$ 1.53	$ 10.40	$ -	$ 198.14

3 Glossary of Terms

Assembly: generally refers to a group of interdependent components joined together to perform a defined function (e.g., turbocharger assembly, high pressure fuel pump assembly, high pressure fuel injector assembly).

Buy: is the terminology used to identify those components or assemblies as ones in which a manufacturer would purchase versus manufacture. All parts designated as a "buy" part, within the analysis, only have a net component cost presented. Typically these types of parts are considered commodity purchase parts having industry established pricing.

CBOM (Comparison Bill of Materials): is a system bill of materials, identifying all the subsystems, assemblies, and components associated with the technology configurations under evaluation. The CBOM records all the high level details of the technology configurations under study, identifies those items which have cost implications as a result of the new versus base technology differences, documents the study assumptions, and is the primary document for capturing input from the cross functional team.

Component: is the lowest level part within the cost analysis. An assembly is typically made up of several components acting together to perform a function (e.g., the turbine wheel in a turbocharger assembly). However, in some cases a component can act independently performing a function within a sub-subsystem or subsystem (e.g., exhaust manifold within the exhaust subsystem).

Cost Estimating Models: are cost estimating tools, external to the Design Profit® software, used to calculate operation and process parameters for primary manufacturing processes (e.g., injection molding, die casting, metal stamping, forging). Key information calculated from the costing estimating tools (e.g., cycle times, raw material usage, equipment size) is inputted into the Lean Design® process maps supporting the cost analysis. The Excel base cost estimating models are developed and validated by Munro & Associates.

Costing Databases: refer to the five (5) core databases which contain all the cost rates for the analysis. The material database lists all the materials used throughout the analysis along with the estimated price/pound for each. The labor database captures various automotive, direct labor, manufacturing jobs (supplier and OEM), along with the associated mean hourly labor rates. The manufacturing overhead rate database contains the cost/hour for the various pieces of manufacturing equipment assumed in the analysis. A mark-up database assigns a percentage of mark-up for each of the four (4) main mark-up categories (i.e., end-item scrap, SG&A, profit, and ED&T), based on the industry, supplier size, and complexity classification. The fifth database, the packaging database, contains packaging options and costs for each case.

Lean Design® (a module within the *Design Profit®* *software):* is used to create detailed process flow charts/process maps. Lean Design® uses a series of standardized symbols, each base symbol representing a group of similar manufacturing procedures (e.g., fastening, material modifications, inspection). For each group, a Lean Design® library/database exists containing standardized operations along with the associated manufacturing information and specifications for each operation. The information and specifications are used to generate a net operation cycle time. Each operation on a process flow chart is represented by a base symbol, operation description, and operation time, all linked to a Lean Design® library/database.

Make: is the terminology used to identify those components or assemblies as ones in which a manufacturer would produce internally versus purchase. All parts designated as a "make" part, within the analysis, are costed in full detail.

MAQS (Manufacturing Assumption and Quote Summary) Worksheet: is the standardized template used in the analysis to calculate the mass production manufacturing cost, including supplier mark-up, for each system, subsystem and assembly quoted in the analysis. Every component and assembly costed in the analysis will have a MAQS worksheet. The worksheet is based on a standard OEM (original equipment manufacturer) quote sheet modified for improved costing transparency and flexibility in sensitivity studies. The main feeder documents to the MAQS worksheets are process maps and the costing databases.

MCRs (Material Cost Reductions): is a process employed to identify and capture potential design and/or manufacturing optimization ideas with the hardware under evaluation. These savings could potentially reduce or increase the differential costs between the new and base technology configurations, depending on whether an MCR idea is for the new or the base technology.

Net Component/Assembly Cost Impact to OEM: is defined as the net manufacturing cost impact per unit, to the OEM, for a defined component, assembly, subsystem or system. For components produced by the supplier base, the net manufacturing cost impact to the OEM includes total manufacturing costs (material, labor, and manufacturing overhead), mark-up (end-item scrap costs, selling, general and administrative costs, profit, and engineering design and testing costs) and packaging costs. For OEM internally manufactured components, the net manufacturing cost impact to the OEM includes total manufacturing costs and packaging costs; mark-up costs are addressed through the application of an indirect cost multiplier.

NTAs (New Technology Advances): is a process employed to identify and capture alternative advance technology ideas which could be substituted for some of the existing hardware under evaluation. These advanced technologies, through improved function and performance, and/or cost reductions, could help increase the overall value of the technology configuration.

Powertrain Package Proforma: is a summary worksheet comparing the key physical and performance attributes of the technology under study with those of the corresponding base configuration.

Process Maps: are detailed process flow charts used to capture the operations and processes, and associated key manufacturing variables, involved in manufacturing products at any level (e.g., vehicle, system, subsystem, assembly, component).

P-VCSM (Powertrain–Vehicle Class Summary Matrix): records the technologies being evaluated, the applicable vehicle classes for each technology, and key parameters for vehicles or vehicle systems that have been selected to represent the new technology and baseline configurations in each vehicle class to be costed.

Quote: refers to the analytical process of establishing a cost for a component or assembly.

Sub-subsystem: refers to a group of interdependent assemblies and/or components, required to create a functioning sub-subsystem. For example, the air induction subsystem contains several sub-subsystems including the following: turbocharging, heat exchangers, and pipes, hoses and ducting.

Subsystem: refers to a group of interdependent sub-subsystems, assemblies and/or components, required to create a functioning subsystem. For example, the engine system contains several subsystems including the following: crank drive subsystem, cylinder block subsystem, cylinder head subsystem, fuel induction subsystem, and air induction subsystem.

Subsystem CMAT (Cost Model Analysis Templates): is the document used to display and roll up all the sub-subsystem, assembly and component incremental costs associated with a subsystem (e.g., fuel induction, air induction, exhaust), as defined by the Comparison Bill of Material (CBOM).

Surrogate part: refers to a part similar in fit, form and function as the part required for the cost analysis. Surrogate parts are sometimes used in the cost analysis when actual parts are unavailable. The cost of a surrogate part is considered equivalent to the cost of the actual part.

System: refers to a group of interdependent subsystems, sub-subsystems, assemblies and/or components, working together to create a vehicle primary function (e.g., engine system, transmission system, brake system, fuel system, suspension system).

System CMAT (Cost Model Analysis Template): is the document used to display and roll up all the subsystem incremental costs associated with a system (e.g., engine, transmission, steering), as defined by the CBOMs.