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Is the Automotive Industry Using Design-for-Assembly Anymore?

A Statistical Analysis of Repair Data

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Kieli
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Julkaisun nimike
Käyttääkö autoteollisuus vielä Design-for-Assembly -menetelmää?
Tilastollinen analyysi kunnossapitodatasta

Tiivistelmä

Työn tarkoitus: Lähitulevaisuudessa uudet autonvalmistajat Kiinasta ja Intiasta haastavat vanhempien teollisuusmaiden autonvalmistajat. Innovatiivisten suunnittelumenetelmien käyttö voisi kuitenkin muodostaa vahvan kilpailuedun haasteeseen vastaamisessa.

Metodologia: Tiettyjen korjausmääritelmien mukaan korjausaikadatasta voidaan ekstrapoloida Design-for-Assembly:n (DFA eli kokoonpano-orientoitunut suunnittelu) käyttö. Kirjallisuuskatsauksen ja autoteollisuuden asiantuntijahaastatteluiden avulla pystytään havaitsemaan positiivinen korrelaatio nopean kokoonpanon ja nopean purkamisen välillä.

Tämä työ tutkii korjausaikadataa 20 vuoden aikajaksolla ja vertaa yli 300 sedanmallin tietoja Aasiasta, Euroopasta ja USA:sta tilastollisesti tuotteittain ja yrityksittäin mm. ANOVA-analyysillä.

Tutkimuksen tulokset: Keskimääräisen auton kokoonpanoaika on kasvamassa: autoteollisuus käyttää yleiskäyttöisiä moduuleja, jotka eivät seuraa käytettävissä olevan DFA-suunnittelun menetelmiä. Tämä osoittaa toimitusketjun globaalia luonnetta ja toimittajien kasvavaa tärkeyttä komponenttisuunnittelussa. Pohjoisamerikkalaiset mallit ovat yksinkertaisimpia koota.

Tutkimuksen rajoitteet: Kysymystä positiivisesta DFA/DFD korrelaatiosta ei näytetty empiirisesti toteen. Tarkan korrelaation löytäminen vaatii lisää numeerista tutkimusta.

Tutkimuksen vaikutukset: Autoteollisuuden laajamittainen moduulien käyttö vaatii tarvittavien kustannussäästöjen saavuttamiseksi toimittajilta valmiuksia DFA:n käyttöön. Amerikkalaisten autonvalmistajien osaaminen on tunnustettava;

niiden mallien käyttö voi tarjota myös alihankintateollisuudelle kyvyn luoda kustannustehokkaampia moduuleja.

Tutkimuksen kontribuutio: Aineistoon pohjautuvia tutkimuksia autoteollisuuden DFA-käytöstä (ja DFA:n/DFD:n korrelaatiosta) on tehty hyvin vähän. Tässä tutkimuksessa on toteutettu kattava vertailu DFA:n käytöstä autoteollisuudessa tuotemalleittain, vuosittain, tuotantoalueittain ja yrityksittäin.

Asiasanat
Design-for-Assembly, DFA, autoteollisuus, Design-for-Disassembly, DFD

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Is the Automotive Industry Using Design-for-Assembly Anymore?
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Abstract

Purpose: Soon, the car companies of the older industrialized countries will be challenged by the car companies of China and India. However, innovative use of design practices could provide the compete advantage to return the challenge.

Methodology: For certain definitions of repair, use of Design for Assembly and Disassembly can be extrapolated from repair data. From literature review and interviews with automotive experts, a certain degree of positive correlation between ease of assembly and ease of disassembly can be found.

This work explores repair data from 20 years and compares over 300 sedan models from Asia, Europe and USA – by statistical ANOVA analysis and on product and individual company basis.

Findings: The average car assembly time is growing: the average car uses universal components that do not approximate available automotive DFA redesign examples. This indicates the global nature of the supply chain and the importance of suppliers to provide component design. North American models are the easiest to assemble.

Research limitations: The question of positive DFA/DFD correlation is not empirically proven. Further numerical study seems necessary to establish exact correlation.

Practical implications: The automotive industry's use of modularity dictates that suppliers must be the next generation of cost-efficient DFA users. The expertise of the American car companies must be recognized; they can provide the knowledge the supply industry needs to create leaner modules.

Originality value: Very few quantitative studies on industry-wide DFA usage (and DFA/DFD correlation) currently exist. Furthermore, an up-to-date benchmark on expertise in DFA is produced.

Keywords
Design-for-Assembly, DFA, automotive industry, Design-for-Disassembly, DFD

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I would also like to thank my family for their constant support in my struggle towards education. When discussing with them, every problem easily produces several solutions and every day brings new opportunities of going forwards and upwards. Who could ever fall with such a brace to lean on?

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Mikael Ehrs

Contents

ACKNOWLEDGEMENTS VII

1 INTRODUCTION 1
  1.1 Objectives and Research Questions 2
  1.2 Research contribution and applications 3
  1.3 Structure of the study 4

2 LEAN DESIGN AND DESIGN FOR ASSEMBLY 6
  2.1 Lean design and current product development methods 6
    2.1.1 Concurrent engineering 7
    2.1.2 Modularity and product platforms 9
    2.1.3 Design for X 12
  2.2 Design for Assembly 14
  2.3 Historical Origin of DFA 16
  2.4 Development Generations 18
    2.4.1 First generation DFA 19
    2.4.2 Second generation DFA 21
    2.4.3 Third Generation of DFA 30
  2.5 Does DFA work? 31
  2.6 Is it used? 35

3 THE AUTOMOBILE INDUSTRY AND DFA 42
  3.1 A short background on the automobile industry and its situation today. 42
    3.1.1 Early history 42
    3.1.2 Situation before the 2008–2009 automotive industry crisis 49
    3.1.3 Situation during the 2008–2009 automotive crisis 57
  3.2 The Automotive Assembly Process Explained 69
  3.3 Why is DFA relevant to the auto industry? 74

4 THE CONNECTION BETWEEN ASSEMBLY AND REPAIR 84
  4.1 Design for Assembly guidelines 84
  4.2 Design for Maintainability guidelines 86
  4.3 Design for Disassembly 89
  4.4 Connecting DFA and DFD – Evidence from academic research 93
  4.5 Connecting DFA and DFD – Interview results 94

5 METHODS AND DATA COLLECTION 100
  5.1 Selecting Sources of Data 102
  5.2 Car Model Selection 106
  5.3 Car Model Selection 112
  5.4 Sub-Assembly Selection 116
  5.5 Data collection and limitations of the data 122

6 METHODS AND DATA ANALYSIS 124
  6.1 Statistical analysis 124
    6.2.1 Exploring the data 127
    6.1.2 Adapting the data to ANOVA analysis 130
    6.1.3 ANOVA analysis of Reciprocal Quadratic -transformed time measurements 131
    6.1.4 Exploring the smaller data 134
    6.1.5 Adapting the smaller data to analysis 136
    6.1.6 2nd ANOVA analysis of the Year variable 138
    6.1.7 Kruskal-Wallis analysis of the Class variable 139
    6.1.8 ANOVA analysis of the Region variable 140
  6.2 Company-level Analysis 141

7 DISCUSSION 151
  7.1 Possible conclusions 151
    7.1.1 A rising trend in annual repair time 151
    7.1.2 North American cars are the fastest to repair 157
    7.1.3 Chrysler and Kia produce the most repair/assembly friendly cars 158
    7.1.4 European cars (and Toyota's) are the slowest to repair 160
    7.1.5 High Quality and Repair/Assembly might not mix 160
  7.2 Limitations 162
  7.3 Suggestions for future research 164
  7.4 Research contribution 165

8 CONCLUSION 167

REFERENCES 170

APPENDICES 199

Figures

Figure 1. DFA redesign example, windscreen wiper motor 20
Figure 2. Boothroyd Dewhurst DFA redesign example – heavy-duty stapler. 27
Figure 3. World motor vehicle production, relative shares, 1950–2009 48
Figure 4. Motor vehicle production per country, 2005–2006 (units). 49
Figure 5. Passenger vehicle production per company/group, 2006 (units). 50
Figure 6. North American volume car market, market shares 2002. 51
Figure 7. European volume car market, market shares 2002. 53
Figure 8. Asian volume car market, marketshares 2002. 55
Figure 9. Motor vehicle production per country, 2005–2010 (units). 58
Figure 10. Passenger vehicle production per company/group, 2009 (units). 59

Figure 11. The automotive assembly process. 71
Figure 12. Technology trajectories. 76
Figure 13. Redesigned truck instrumentation panel. 80
Figure 14. Redesigned car seat. 82
Figure 15. World market for cars (2002). 100
Figure 16. Instrumentation panel, Mitchell guide. 119

Tables

Table 1. Boothroyd Dewhurst DFA evaluation table – old design. 25
Table 2. Boothroyd-Dewhurst DFA example, old design vs. new. 26
Table 3. Case study compilation results. 35
Table 4. Roundtable survey results. 39
Table 5. IMPV manufacturability survey results. 40
Table 6. World motor vehicle production, thousands, 1950–2009. 48
Table 7. Production cost structures of three Portuguese automotive industry suppliers. 78
Table 8. Design for Assembly guidelines. 85
Table 9. Design for Maintainability guidelines. 87
Table 10. Design for Disassembly guidelines. 91
Table 11. DFA-DFD guideline similarities. 92
Table 12. Incompatible models omitted from the 2010 comparison. 116
Table 13. Mitchell collision estimation guides’, sections. 117
Table 14. Final assembly selection. 121
Table 15. Corporate brands. 141
Table 16. Car model comparison, year 1990. 143
Table 17. Car model comparison, year 1995. 144
Table 18. Car model comparison, year 2000. 145
Table 19. Car model comparison, year 2005. 146
Table 20. Car model comparison, year 2010. 147
Table 21. Car model ranking lists, by corporation. 149
Table 22. Car model (relative) ranking lists, by corporation. 149

Abbreviations

DFA	Design for Assembly
DFM	Design for Manufacture
DFMA	Design for Manufacture and Assembly
R&D	Research and Development
DFX	Design for Excellence
DFD	Design for Disassembly
DFM	Design for Maintenance
DFR	Design for Repair
DFM	Design for Maintenance
IMVP	International Motor Vehicle Program
OEM	Original Equipment manufacturer

Formulas

(1) Cost of assembly..29
(2) Capital Cost 29

1 INTRODUCTION

The global auto industry is currently in a state of change. The old, established car companies are experiencing hard times due to the high oil prices, the poor global economy, rising material costs, the sudden shift to more environmental consumer preferences, etc. According to Maxton & Wormald (2004) and Holweg & Pil (2004) the traditional market for cars – loosely speaking "the Western world" (including Japan, South Korea, etc.) – is already mature. At the same time, numerous fresh car companies are starting to grow in the new industrial countries, notably China and India (see for instance Thoma & O'Sullivan 2011; Brandt & Thun 2010; Holweg, Tran, Davies, & Schramm 2011). These young companies are so far mostly catering to their domestic markets, but inevitably, these new entrants will eventually make the move out of Asia. At that point, they will without doubt put even further stress on the currently leading auto makers to rethink their business strategies and reduce costs in their own products.

It is a cold, hard fact that the established car companies cannot compete when it comes to labor costs. There is an alternative to this strategy, however: cost reduction by designing products that requires less labor to assemble. Especially the concept of Design for Assembly (DFA) should be worth a closer look (see for instance Mottonen, Harkonen, Belt, Haapasalo and Simila 2009; Koganti, Zaluzec, Chen& Defersha 2006; Sarmento, Marana, Ferreira–Batalha, & Stoeterau 2011).

Design for Assembly takes already existing products under examination and sees whether they can be restructured and redesigned to achieve a simpler assembly process. Components are combined; the number of fasteners is reduced; the way components are gripped, oriented and inserted is simplified – the reason for usage and existence of all items and assemblies are put into question. (Andreasen, Kähler & Lund 1988; Boothroyd, Dewhurst & Knight 2002) The resulting parts reduction and lower amount of assembly labor makes this technique highly interesting to industrial companies working on the assembly of mechanical and electronic products.

In a study by Boothroyd Dewhurst, Inc. (2004) – compiling the results of 117 product–design case studies at 56 partner manufacturers – their numbers showed that using the DFA techniques resulted in parts count reductions of more than 50 percent in 100 of the cases. Furthermore, an assembly time reduction of more than 60 percent was achieved in 65 of the cases. These figures indicate that there is a certain amount of value in the judicious application of Design for Assembly techniques.

But is Design for Assembly not already used in the automotive industry? The car companies themselves say yes – especially Chrysler and Ford invested heavily in DFA education during the 1980:s (Matterazzo & Ardayfio 1992; Ardayfio & Opra 1992; Causey 1999: 222–226). Design for Assembly is not a new invention – it has been around since the early 1960s – and today the techniques are a part of the elementary background and standard toolkit of the automotive design engineer. There seems to be no further improvements to be had in order to combat the rising influence of the new car companies. But is this really the case? The objective of this thesis will be to find out just that.

1.1 Objectives and Research Questions

The aim of this work will be to produce a study of the recent and present-day degree of usage of DFA techniques in the automotive sector. If Design for Assembly can translate into such important cost savings – are the car companies really using it? If benchmarking the companies against each other – where are the experts at Design for Assembly to be found? What companies should be emulated in order to reduce assembly cost? An objective comparison of assembly times seems necessary.

This study will provide an idea of the DFA-related situation in the automotive industry today. It will bring a much-needed update to the few manufacturability analyses conducted during the late 80s and early 90s (see for instance Womack, Jones & Roos 1990). The objective of this study is twofold – to investigate in which way the use of DFA has progressed in the auto industry over the last twenty years and to pinpoint what companies have been the most successful in achieving said progression. Furthermore it will bring to light the question of whether Design for Assembly and Design for Disassembly can be linked and compared.

1. *What are the trends in automotive assembly time, looking at the last 20 years?*
2. *What companies consistently produce the cars with lowest (and highest) assembly times?*
3. *Can DFA time data reliably be extrapolated from certain types of repair data?*

Finding objective data on the degree of usage of DFA in the automotive industry is difficult. To the present day, quite few surveys or quantitative investigations on the use of Design for Assembly have been completed and even fewer have been conducted looking expressly at the automotive industry. The automotive industry is nevertheless the most important industry for several of the largest economies in the world, and an important research area.

The study will be based on empirical analysis of numerical data gathered from an unorthodox source: car repair time manuals. The chosen manuals present repair time estimates for hundreds of different car models sold on the North American market, mainly from Asia, USA and Europe. In the following chapters a case will be made for how these repair times can be used as an indicator of the assembly time involved in creating such a car.

Assuming the validity of this line of reasoning, it seems probable that with a large enough database of these figures, similar car models can be compared and their use of “efficient” DFA design can be statistically analyzed. Based on this analysis, it should eventually be possible to say something about what trends have been operating on the car companies' assembly times during the last decades, and following this, the companies’ level of success in the field of DFA. The analysis will span the last two decades (1990–2010), recording data from five separate years at five-year intervals (1990, 1995, 2000, 2005, 2010).

It is possible that the study will show a clear trend of reduced assembly times as an effect of the automotive industry increasingly implementing the usage of DFA techniques over the last two decades, as diffusion of innovation and best practices results in design convergence. It is equally possible, however, that the study will show no such trend and that the car companies are not using assembly time reducing techniques to their fullest extent. If so, there may still be hope for the design driven cost reduction of the established car companies’ models, and continued room for international market competition between the established car companies and the new challengers.

1.2 Research contribution and applications

This comparative study stands to improve academic knowledge of several important issues in the automotive industry.

Firstly, to the present day, very few surveys or quantitative investigations on the use of Design for Assembly have been completed – those that have been made will be discussed later on in the text – but even fewer have been conducted looking expressly at the automotive industry. This work stands to improve that situation, and bring much-needed updates to those investigations that have been conducted.

Secondly, the issue of how Design for Assembly and Design for Disassembly correlate and impact each other will be discussed in the light of several different sources. Relevant literature is reviewed, design guidelines are compared and automotive experts and researchers are interviewed to draw conclusions. With a successful Design for Assembly redesign have any benefits on disassembly? This is a relevant question to answer considering the rising interests in disassembly and recycling seen during the last decade.

Thirdly, the question of where the world's foremost experts in automotive Design for Assembly can be found will be answered. This will provide a useful benchmark for those wishing to further investigate Design for Assembly practices in the automotive industry. It is also possible for the automotive industry companies themselves to use this information to see where the best practices in this area can be found.

1.3 Structure of the study

The second chapter will be overlooking current theories of design being pursued in the automotive industry and introduce the theory of Design for Assembly. The main concepts and DFA -techniques are presented, together with an outline of the historical impacts. The three generations of development: rule-based redesign, redesign based on quantifying the assembly steps of the product and finally computer aided Design for Assembly – all are presented briefly with examples. We will look at the usage of DFA in industries and its performance in real-life applications. Previous surveys on the same issues are investigated.

The third chapter will focus entirely on the automotive industry – why is Design for Assembly relevant to the assembly of a car and to the success of a company? A brief background on the automotive industries will be presented, looking at early development and the situation before and after the 2008–2009 automotive industry crisis. The automotive assembly process will also be investigated, looking especially close at the steps where human interaction is necessary.

In the fourth chapter the link between Design for Assembly, repair and Design for Disassembly will be explored, and we will hopefully establish that the connection between these concepts is strong enough that we can use automotive repair data to say something about the level of Design for Assembly used in the automotive industry. The Design for Disassembly and Design for Maintenance concepts are introduced.

In the fifth chapter the used methods for data collection and analysis are presented. The data collection section outlines all the choices made in terms of data sources, data selection, car selection, repair assembly selection, etc. Limitations to the data are also discussed.

In the sixth chapter we go through the data analysis, where the methods of statistical analysis are outlined, tested and implemented, after suitable transformations make the data acceptable for statistical analysis. Car models are also analyzed on an individual level, to see what companies have performed the best and worst in the comparison.

In the seventh chapter we discuss the results of the data analysis, and try to relate them to the industry's current situation. Can we see any clear links between a company's success in this comparison and its success in the market? Is Design for Assembly relevant to the major automakers of the world? Furthermore, we try to relate our findings to the theory presented earlier.

Chapter eight states the conclusions of the work, and gives suggestions for future actions.

2 LEAN DESIGN AND DESIGN FOR ASSEMBLY

In this section the leading theories in automotive product development are presented, to provide a setting for the more in-depth discussion on Design for Assembly methodology. A brief history of DFA leads up to a presentation (with examples) of DFA usage today.

2.1 Lean design and current product development methods

On its most basic level, the core idea of lean production – the value methodology that has been the guiding light of the automotive industry for the last fifty years – is the elimination of waste and continual improvement (See for instance Ohno 1988, Shingo 1984). However, lean design can be summarized as follows:

"*The main purpose of lean design is to use existing components and make sure that the final designs are compatible with existing processes so that the company's resources can be leveraged as much as possible.*" (Chen & Taylor 2009)

The ongoing process of product innovation and product refinement has very great importance in today's heavily competitive environment. The aim of the companies is to keep the period of time between product specification and production start as short as possible (Gonzalez-Zugasti, Otto & Baker 2000; Velos & Kumar 2002). After the wide-spread adaptation of lean production principles became the norm in the automotive industry, companies increasingly started looking to lean design as the next step in the development (Cusomano & Nobeoka 1998; Womack & Jones 2003; Hale & Kubiak 2007, etc.).

However, lean design is not such a well defined and documented area of expertise as lean production (Muffatto 1998). The parts of lean philosophy that are closest related to design practices mainly fall under the worker-process involvement umbrella: value analysis to forge a direct chain of information from customer into finished product; concurrent engineering to involve all parties from design to engineering to assembly in the creation process; etc.

According to Chen & Taylor (2009) value analysis, concurrent engineering, modularization and design for manufacturability form the basis of the lean design mechanism. These practices aim at minimizing costs and provide the ability to focus on critical value creation – value being defined as what the customer wants in terms of cost, product functions, etc. The concepts can be loosely defined as follows:

1. Value. Since end customers are less willing to pay for products that do not exactly fit their own needs, the product variety offered must be coordinated by in-depth analysis of what types of variety makes the biggest impact on profitability. (Jayaram & Vickery 2008; Schuh, Lenders & Hieber 2008)

2. Concurrent engineering. Given the increasing amount of product development projects and the decreasing time to achieve them in, an increasingly smooth co-operation much stand behind every achievement. The over-the-wall type of design cannot be used if the product must be made right the first time. (Olivella, Cuatrecasas & Gavilan 2008; Mehta & Shah 2005.)

3. Modularization. Product variety is a fundamental characteristic of lean production systems. For this to be economically viable, a maximum exploitation of economies of scale and scope are necessary, something which is simply impossible in a single project. This means reducing the number of unique components in each project and re-using technologies and components that have been developed in other projects. (Brown & Duguid 2002; Mehta & Shah 2005.)

4. Design for Manufacturing (Design for X). The increasing need for standardization of parts and a wish to minimize waste gave birth to techniques that aim at functional integration by design. Design for Manufacturing is a practice that aims at simplifying product design, minimizing parts count, and standardizing parts and processes. (Boothroyd et al. 2002, Mottonen, Harkonen, Belt & Haapasalo 2009.)

In the following sections we will look closer at the three last of these points, since they have an especially large impact on the research subject of this work. These methodologies form the framework in which the Design for Assembly study must be seen – the setting and background for the literary works this work bases itself on.

2.1.1 Concurrent engineering

Concurrent engineering is a way of doing rapid product development with less waste. It entails the early establishment of a cross-functional team that together designs the new product, process, and manufacturing activities, simultaneously (Rosario, Davis & Keys 2003; Valle & Vázquez-Bustelo 2009). The team members have backgrounds in different functional areas (design, manufacturing, production, marketing, etc.) (Gao, Manson & Kyratsis 2000). Together, they can identify potential difficulties very early on in the design process. The blending of cross-functional knowledge and team communication ensure that issues of manufacturing and sales feasibility are considered already at the creation stage of the product. (Hyeon, Parsei & Sullivan 1993; Koufteros, Vonderembse & Doll 2001.)

Winner, Pennell, Bertend and Slusarczuk (1988) define concurrent engineering as: "*a systematic approach to the integrated, concurrent design of products and related processes, including manufacturing and support. This approach is intended to cause the developers to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements*".

Concurrent engineering was originally put forward as a way of solving the problems connected with the traditional approach for developing new products – the throw-it-over-the-wall approach. Traditionally, the product development system has focused on structured processes with sequential, clearly-defined steps; the future product is defined (by management, market research), designed (by designers), produced (engineering) and released to the market (Iansiti 1995). If these activities all happen sequentially, and start when the previous step has finished, the end result is a product that lacks integration between its different functions and intentions.

Furthermore, continuous iterations of the process are necessary to correct the mistakes made early on, something which results in long development cycles and numerous expensive redesigns (Mutisya, Steyn & Sommerville 2008; Cordero 1991). Quality problems are another result of the traditional approach, since lack of communication, and misunderstanding of each other's intentions skew product design and production away from the customers' needs and wants (Ulrich, Sartorius, Pearson & Jakiela 1993; Umemoto, Endo & Machaco 2004; Cooper & Edgett 2003, etc).

Concurrent engineering on the other hand, based on the integrated approach to product development, employs parallel work solutions and coordinates the activities of different departments. With the early release of information from design, engineering can start working on some parts of the product while the final design is still being created (Rosario, Davis & Keys 2003). The aim is to make the product right the first time, and avoid costly iterations of the design process. It is especially important that any potential problems are identified before production begins, when costs of change are at their highest. (Hartley, Zirger & Kamath 1997.)

Communication aids in the form of software and automated design programs can support the cross-functional teams. The effective use of information technology enables team members to co-operate despite wide geographical spread. While Zirger & Hartley (1994) point out the benefits of co-location, virtual teams are commonly used to bring together the expertise of separate company function areas. (King & Majchrzak, 1996). Computer-aided design (CAD) and computer-aided manufacturing (CAM) software and allows designs to be shared and edited simultaneously. (Coman 2000; Ruffles 2000; Tucker & Hackney 2000; Ainscough, Neailey & Tennant 2003, etc.)

Benefits and drawbacks

Concurrent engineering has had a particular appeal to the automotive sector, since its strategy of regular model redesigns and overhauls requires short product development lead times (Humphrey 2003).

The main benefits of concurrent engineering are 1) improved customer value, 2) better quality, 3) shorter lead times and 4) cost reductions. (Corti & Portioli-Staudacher 2004; Portioli-Staudacher & Singh 1997; Bopana & Chon-Huat 1997; Gaalman, Slomp & Suresh 1999). Assembly of the product will certainly benefit from concurrent engineering, as manufacturing problems are taken into consideration during design. Also, several researchers mention the intangible benefits – involving all parts of the company's functional areas into the design process grows the commitment of the participants (Koufteros et al. 2001). This helps to achieve commitment and a sense of common goal in the process (Gupta & Wilemon 1990).

According to Clausing (1994), the actual design process will be a bit more time consuming under concurrent engineering than with the traditional methods. More issues are brought up during the process and the evaluation of each is more through. In general this will be more than compensated by the overall reductions in the new product design, as the time-consuming redesign iterations are kept at a minimum.

2.1.2 Modularity and product platforms

Modularity is also of the most important concepts in automotive design and production today (Garud, Kumaraswamy & Langlois 2003; Gershenson, Prasad & Zhang 2003; Hargadon & Eisenhardt 2000; Baldwin & Clark 2000). A modular product design means that the final product is assembled from a number of modules rather than discrete components – the modules or assemblies are in turn made up of sets of parts assembled (most often) by a supplier. Modular product design is considered a key enabler for mass customization (Partanen & Haapasalo 2004;

Duray, Ward, Milligan & Bery 2000), as modules can be assembled to create a large number of variations the final product (Sanchez 2002).

Baldwin & Clark (1997) define modularity as building a complex product or process from smaller sub systems that can be designed independently yet function together as a whole. Camuffo (2000) stresses that modularity is an ambiguously used term in the auto industry – a broad concept, applied to a number of systems (product design, manufacturing, work organisation, etc)

The SMART example

In Doran, Hill, Hwang and Jacob 2007 we can see a good example of the use of high-level modularization in the automotive industry: the design and production of the "Smart" car model. It is the result of a collaboration between Mercedes-Benz and watchmaker Swatch. The Smart car is revolutionary in that the bulk of the value-adding activities have been shifted to upstream suppliers: only about twenty percent of the production value of the car is added at the final Smart car assembly plant. The suppliers create and develop their modules in tight collaboration with the OEM (Original Equipment Manufacturer). Only about 25 module supplier are involved in the creation of the car, as opposed to the 200–300 components suppliers normally involved in the sourcing of a car's components. Examples of modules include dashboard systems, body structure, breaking control systems and seating modules

Benefits and drawbacks

In general, the automotive sector has been experienced declining profit per vehicle, shorter product life cycles and tougher consumer demands on variety, all throughout the last few decades (Maxton & Wormald 2004, Holweg & Pil 2004, Womack et al. 1990, etc.) Velos & Kumar (2002) point out that modularity has been seen by the automotive industry as a way to cope with these circumstances.

Benefits of modularity include increasing the range of product variations, fast upgrading of products, reducing the number of suppliers to interact with and reducing costs of development and production (Sanchez 2002; Mikkola & Gassmann 2003). Sanchez & Collins (2001) and Ernst & Kamrad (2000) do, however, suggest that the most tangible benefit of modularity is the ability to configure new product variations quickly and at low cost. This is achieved by reusing modules in new products' architectures (Weng 1999; Partanen & Haapasalo 2004) In addition, a company with a well-specified interfaces architecture in their products can quickly substitute defective or obsolete modules without affecting manufacturing negatively.

From the product life cycle point of view, Primo & Amundson (2002) see the reuse of high quality modules as a great possibility for the remanufacturing industry. Mukhopadhyay & Setoputro (2005) see the possibility that even a build-to-order product could more easily be accepted back by a company (returned by the customer) if only the product can then be easily dismantled and the modules reused.

However, some authors do argue that modularity might also make the product less distinct in the eyes of the customer. Kim & Chhajed (2000) found that if common modules are used in both high-end and low-end products, they reduce the perceived difference in quality between the products – this can have the benefit of raising the customer's belief in low-end brands but will invariably detract from the high-end product's uniqueness.

Product platforms

A continuation of modular design, the wider concept of product platforms (or product families) is used to describe a strategy of planning multiple generations of products based on largely the same components and modules. If the core product is flexible enough in its modular design, many derivative or enhanced variants can be created from the basic product. (Muffatto 1999.)

Muffatto & Roveda (2000) define product platforms as "*a set of subsystems and interfaces intentionally planned and developed to form a common structure from which a stream of derivative products can be efficiently developed and produced*."

The most desired effect of implementing a platform strategy is naturally to achieve risk reduction and economies of scale in the sourcing of the common modules (Ethiraj & Levinthal 2004; Xu, Lu & Li 2012). Increased commonality (a measure of the extent to which product variants share the resources) tends to lessen the risks of supply chain management, as fewer components are sourced from fewer suppliers (Cucchiella & Gastaldi 2006). Product platforms are furthermore often cited as being a prerequisite to implementing mass customization – a system under which a core product can easily be configured according to the customer's needs. The end product can be relatively unique, but nevertheless created from a pre-defined set of components/modules (Meyer & Lehnerd 1997; Salvador, Forza & Rungtusanatham 2000; Huang, Zhang & Liang 2005).

Benefits and Drawbacks

The main benefit of product platforms is that they provide product variety at reduced costs (Gonzalez-Zugasti, Otto & Baker 2000; Marion, Thevenot & Simpson 2007; Park & Simpson 2008). Having a high degree of commonality means simplified planning and scheduling (Berry, Tallon & Boe 1992), shorter lead times in new product development (Gonzalez-Zugasti et al. 2000; Krishnan & Gupta 2001), smaller inventories and less Work-In-Progress (Vakharia, Parmenter & Sanchez 1996), less uncertainty around untested components (Rosenthal & Tatikonda 1992), etc.

In addition, the possibility of catering to a wider range of customer is also made available. Muffatto & Roveda (2000) use the example of the automotive industry, and its attempts to create “world cars”. These are car models that are planned to be able to gain public support around the world; with regional customization the common core product should be acceptable in a multitude of countries (Maxton & Wormald 2004).This sort of a consumer market base is something that most car-makers have only been able to dream about before the adaptation of platform strategies.

Of course, there are also drawbacks in using platforms to create variety. The commonality requirement puts constraints on design, and may result in products that feel too similar in the mind of the public. Perceptions of the products' quality can also be negatively affected. (Kim & Chhajed 2001; Krishnan & Gupta 2001; Yu, Gonzalez-Zugasti & Otto 1999.)

2.1.3 Design for X

As we saw during in the previous sections, an important trend in new product development involves taking the extended chain of production into account when designing a product – a key motivating factor in both concurrent engineering and modularity (Cooper, Edgett & Kleinschmidt 2004; Gupta, Pawara & Smart 2007). It is always easier to modify a design at the beginning of the development process and taking an all-inclusive approach to the first steps of design will reduce both unnecessary changes during the process and have a positive effect on the total life-cycle costs of the product – even after it has left the factory.

Design for X (often referred to as Design for Excellence) is a catch-all term for the different design methodologies that have sprung out of the modifying-designs-early way of thinking (Mottonen, Harkonen, Belt, Haapasalo & Simila 2009). DFX is a very general term – the X can stand for assembly, manufacture, quality, repair, disassembly, six sigma, etc (Tan, Matzen, McAloone & Evans 2010). There is no one single methodology that claims to be able to achieve all these at the same time even though the many different Design-for techniques have a common root. DFX (the general term) "*emphasizes consideration of all design* *goals and related constraints in the early design stage*" (Kuo, Huang & Zhang 2001).

According to Kuo et al. (2001), the concept was first used in the 1970s, but the research into the subject has accelerated since the late 1990s (Rosario & Knight 1989; Huang & Mak 1997). DFX is one of the more popular concepts within quality management (Jiang, Liang, Ding & Wang 2007) and environmental issues (Graedel 2008; Kurk & Eagan 2008; Bras 1997; Ehrenfeld & Lenox, 1997). The aim of Design for Environment is to reduce the impact of the product's production, use and end-of life on the environment.

We can find endless permutations on the theme of "Design-for" methodologies, even though Design for Assembly and Design for manufacturing are commonly regarded as the first techniques adapted in industries (with origins as early as the 1940s (Stoll 1988; Chang, Lin, Chang & Chen 2007; Huang 1996)). Evidence of the expansion of the field can be seen in literature: Design-for mass customization (Tseng & Jiao 1998), modularity (Jose & Tollenaere 2005), cost (Rungtusanatham & Forza, 2005), sustainability (Gehin, Zwolinski & Brissaud 2008); logistics (Dowlatshahi 1999); safety and reliability (Dowlatshahi 2000), platforms (Jiao, Simpson & Siddique 2007), remanufacturing (Charter & Gray, 2008), environment (Kumar & Fullenkamp, 2005), service (Lele 1997), supportability (Goffin 2000), maintainability (Takata, Kirnura, van Houten, Westkamper, Shpitalni, Ceglarek & Lee 2004), etc.

Benefits and drawbacks

In general, the aims of DFX is to reduce time-to-market, lower cost and increase the quality of products (Gungor & Gupta, 1999). But since there are so very many different methodologies under the DFX umbrella, it is hard to define a unified set of benefits that result from such design. Maltzman, Rembis, Donisi, Farley, Sanchez & Ho (2005) have studied the benefits to quality and customer satisfaction, and Zuidwijk & Krikke (2008) reusability. The product life-cycle aspects have recently become more important to researchers and companies, and the benefits to these types of redesign have been studied in for instance Huang, Kuo & Zhang (2001); Ferrão & Amaral (2006); Shu & Flowers (1995); Ferrão, Reis & Amaral (2002), Ritzén (2000), etc.

However, implementing a successful DFX strategy is neither easy nor automatic (Sheu & Chen 2007). Effective implementation of DFX requires an environment of cooperative work and good internal communication (Skander, Roucoules & Meyer 2008), supported by guidelines, checklists and software tools (Gungor &

Gupta 1999; Bralla 1996; Huang & Mak 2003; Eversheim & Baumann 1991). In short, a lean design environment, as described in the earlier sections.

2.2 Design for Assembly

> "*A product cannot be regarded in isolation when we are discussing assembly problematics. A product is normally divided into a series of product variants; certain sub-systems in the product ca appear naturally in other subsystems or can be produced because of group-technological similarities with other components. Thus design for ease of assembly can be said to be the process of achieving the insertion of a single product into a well-structured product, building element and component program*." (Andreasen, Kähler & Lund 1988: 68)

In this section we look closer at Design for Assembly – technically a part of the larger concept of Design for X, but also one of the first Design-for methodologies invented. It is therefore more clearly defined than several of the other DFX-offshoots and covered by large amounts of academic literature.

But what is Design for assembly? In practice Design for Assembly analysis is generally performed by a cross-functional team consisting of designers, engineers and assembly staff, to improve consistence of purpose. First of all, the team looks at the different functions the product (or proposed product draft) – can the product itself may be made simpler, and functions unnecessary to the customer be removed? After this, the product under investigation is opened up and the function of every individual component is mapped and queried. Can we remove certain components and still keep the product functioning as well as before? The possibility of combining several components to perform several functions is put on the table – for instance, supporting walls can often be redesigned to provide integral support, previously provided by separate components. The amount and type of fasteners used is debated – can we safely reduce the number, or can more easily fastened types be used? (Swift 1981; Andreasen, Kähler & Lund 1988; Bakerjian 1992).

Any amount of other, small improvements can be brought forth at this point: adding chamfers that self-align the screws upon insertion, making components symmetrical this so that their orientation upon insertion does not matter, eliminating the usage of especially small and delicate components hard to handle, etc. (see Edwards 2002; Rampersad 1996; Boothroyd et al. 2002; Bralla 1999) – a more exhaustive list of design guidelines is presented in Chapter 3. Final the materials themselves should be challenged, to see whether using a more simple production technique can be used – for instance, injection molded plastics instead of welded metal (Constance 1992). The end result is hopefully a product with fewer components, a more standardized set of fasteners and materials, and with a substantially lower assembly time.

The link between these steps and product cost reductions is clear. First of all, with a product that takes less time to assemble, workers can produce more of the product, lowering the average price of production. The same is true for automated production, of course, increasing the throughput of the factory (Eversheim & Baumann 1991). Also, with a simpler product fewer jigs, fixtures, specialized tools, etc. are necessary. With increased standardization, the changeover times between products are reduced. (Joneja 2003).

In terms of quality, a product designed with wider tolerances will be less sensitive to mistakes in the assembly process, resulting in lower rates of scrap, fewer faulty products reaching the customer, fewer claims, etc. As the followers of the Six Sigma quality methodology will assure, it is difficult to make a prefect product: even a microscopically small defect rate in one component will cumulate or multiply when used together with other components (Bañuelas & Antony 2003, Bañuelas & Antony 2004). Thus, redesigning the product to use fewer parts (with wider tolerances) will increase the chances of a first rate product, at the first try.

Andreasen, Kähler & Lund (1988: 67) define four improvements that result from the design for assembly methods:

1. Improvement of the effectiveness of assembly, i.e. increased productivity in relation to manpower and investment resources.

2. Improvement of product quality – i.e. improved product value from the buyer's standpoint in relation to the product's price.

3. Improvement of the assembly system's profitability, i.e. increased utilization of equipment.

4. Improvement of working environment within the assembly system.

Improved quality comes from several directions of the DFA process. Firstly, the cross functional team aspect gives a more consistent product. Secondly, the serious querying of the product functionalities might lead to a simpler product, also to a product that is more specific to the customer's needs. Thirdly, the probability of defective products is reduced because of assembly problems (such as misalignment of components) and the new product will of course contain fewer components that can break.

The improvement of the assembly system's profitability comes partially from the faster flow of assembly through the plant, and partially through better usage of the already existing tools and machines: several of the redesign guidelines concern the standardization of materials, fasteners and tools. The last point, improving the working environment within the assembly system, becomes obvious when you look at the ergonomics of the new product. According to the guidelines (see Chapter 4), the designer avoids materials that tangle or nest, that are flexible and fragile, that require careful orientation, that are heavy to lift, and so on. The assembly worker is meant to see the greatest benefit of the redesign personally.

2.3 Historical Origin of DFA

According to Causey (1999: 222–226) Design for Assembly was the initial result of the wave of new-style automated manufacturing that swept the industries in the late fifties and early sixties. The new robotic assembly devices were beneficial to production rates, but demanded a new way of considering assembly and manufacturability.

Consider the simple task of screwing together two components with a couple of screws. The mechanical solutions that allow a robot to do so are very complex and not very economical. The robot needs one (delicate) appendage to move the screw into place, and another (strong and revolving) appendage to fasten the screw. The treads of the screw must furthermore be perfectly aligned with the hole or the component might become scrap when the robot powers the screw in. (Scarr, Jackson & McMasters 1986). The change-over wastes time, the robot is more expensive, the scrap rate is up – in short, a bad way to fasten component.

When realizing that the new design principles were failing them, industrial companies began defining new standards for automated production. One of the first recognized works that dealt with this issue exclusively was General Electric's *The Manufacturing Producibility Handbook* (1960) (Causey 1999: 222–226). The understanding of the topic and its practical use did not follow any beaten path, however – many companies are said to have worked on new principles internally, principles that in hindsight can be called DFA methodology.

The Design for Assembly methodologies have since evolved to consider both automatic and manual assembly. The original discussions about the link between design and industrial, high-speed assembly helped bring new issues to the fore – why design should henceforth be seen as a team issue and why it should take into consideration a complex mix of different considerations (Gupta, Regli, Das & Nau 1997).

In the beginning the two concepts Design for Assembly and Design for Manufacturing were generally held to be the same thing. This is partially the case also today – the two terms are used relatively synonymously. Boothroyd Dewhurst Inc. (DFMA 2011a; DFMA 2011:b) suggests a division: Design for Assembly involves the process of redesigning the product and components to reduce assembly time, while Design for Manufacturing focuses more on the correct choice of material and production method to best fit the circumstances. The collective term Design for Manufacturing and Assembly is a registered trademark of Boothroyd Dewhurst Inc., but is often used to describe the whole process of redesign for assembly, including material selection.

Enabling the development

According to Joneja (2003) two new occurrences in production engineering in the 1970s made it possible to evolve the DFA regime: injection molded plastic production and the concept of concurrent engineering.

The first, injection molding of plastic, meant that old components could – to an increasing degree – be replaced witch cheap, multi-form plastic pieces that were easy to produce without using much manual labor (welding, for instance). This meant a veritable revolution in the way products were made, a revolution that furthermore promised remarkable cost-reductions.

Secondly, companies were actively trying to speed up their time to the market, and one of the great time-wasters in the product development process was the forwards-backwards lobbing of blueprints between the designer and engineering (the designer had to approve of the changes added by engineers at a later stage). However, the formation of cross-functional product teams proved to be an effective way around this. (Gupta, Regli, Das & Nau 1997; Prasad 1996; Cutkosky & Tenenbaum 1992) The manufacturability of the product improved as it was no longer implemented as an afterthought.

According to Gupta, Regli, Das & Nau (1997) the teamwork aspect of the design process cannot be overstated. In its loosest definition, the origin of the design for assembly and manufacturing may in fact lie as soon as the World War II, when the high pressure to develop new and more advanced weaponry forced designers and engineers to work together under a common motivation (Ziemke & Spann 1993). Many of the successful weapons developed during the wartime were in fact designed by small, tight, multi-disciplinary teams, striving for a common goal. During the later peace-time industrial growth, these forms of co-operation were forgotten in the face of scientific management, with clearly defined departmental structures and a hierarchical decision flow.

2.4 Development Generations

As Causey (1999: 222–223) states, there were three overall generations in the evolution of DFA principles, (with a certain degree of overlap, time-wise). The first generation (1960s to late 1970s) was qualitative in nature. With the help of design rules (more about these in Chapter 4) a designer or a team could redesign a product to increase its manufacturability. (General Electric 1960; Boothroyd, Poli & March 1978; Stoll 1988; Scarr et al. 1986) This method depended heavily upon the individual, and the individual’s skill in applying the guidelines to the process. A labor intensive method, but nevertheless valid – this was how the earliest assembly designers worked, and how many solutions are reached still today.

The second generation (1970s to present day) consists of the quantitative methods – the Boothroyd Dewhurst method, The Hitachi Assemblability Evaluation Method, The Lucas DFA Technique, Toshiba Design for Automatic Assembly, MOSIM etc. (Causey 1999: 222–223; Andreasen et al. 1988; Boothroyd & Radovanovic 1989; Takahashi & Senba 1986; Angermüller & Moritzen 1990). These methods brought quantitative measurement of assemblability into the design improvements. According to these methods, each part of the product is assigned values based upon their manufacturability. Problem areas are identified and the product is redesigned, maximizing the product's overall manufacturability. (Ardayfio, Paganini, Swanson & Wioskowski 1998; Matterazzo & Ardayfio 1992; Kuo et al. 2001) Naturally, also this method relies upon the skill and knowledge of the person redesigning the product.

The third generation (1990s to present day) is a step in the direction away from that reliance. If a computer is taught the systematic method of manufacturability analysis, and furthermore programmed with the more intangible general guidelines (whenever they can be defined in terms that a computer can understand), the computer can be made to perform certain parts of the design process without human guidance (Coma, Mascle & Véron 2003; Sanders, Tan, Rogers & Tewkesbury 2009; Tan 2006) This is a monumental task, of course, and one that is still under rich development. But nevertheless, computers have the added advantage of being able to iterate designs considerably faster than a human, and can as such have the capability to come closer to an optimal solution – by brute force if nothing else. Some of these new methods will be explored in Chapter 2.4.3.

2.4.1 First generation DFA

The first generation of the Design for Assembly relied completely on the skills of the individual designer. To help, lists of design guidelines were created, with useful principles to guide the inexperienced industrial designer. These guidelines would help the designer see the priorities of Design for Assembly and the point in the direction of right solutions. In Table 8, Chapter 4, we will see a compiled list of the Design for Assembly guidelines that are mentioned most often – if we start looking at specific types of products, we can find many more.

The guidelines concern such things as a using the minimum amount of components to fulfill a function, using standardized materials, tools and components for easier assembly, designing the individual components for self-alignment and easy insertion, avoiding parts that were especially small, delicate, sharp, tangling, heavy etc – all so the human worker or the automated assembly machine can have an easier time assembling the product.

In general, the first DFA guidelines in the 1970's often emphasized making the single components more simple (Boothroyd et al. 2002:3). However, the best gains are generally made when single parts are combined or eliminated completely. In reality, there are also several "cumulative" benefits to reducing the number of parts – benefits such as simpler handling, less storage, cheaper tooling, etc.

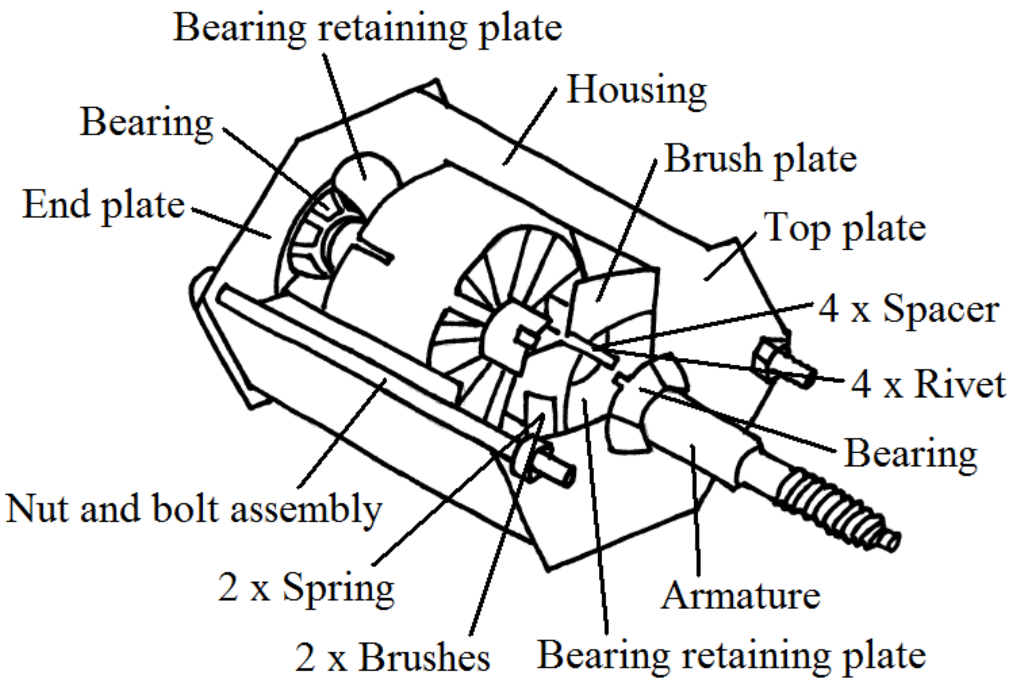
One of the most central postulates behind the DFA methodology is that the designer should challenge the existence of the product at its most basic level.

"*There is only a limited rationalization effect to be gained when one evaluates only a product's components with a view to easier assembly. A much greater effect can be achieved by tackling the product's structure or considering the product assortment more thoroughly in conjunction with the setting of goals for a rationalization of assembly.*" Andreasen et al. (1988:130)

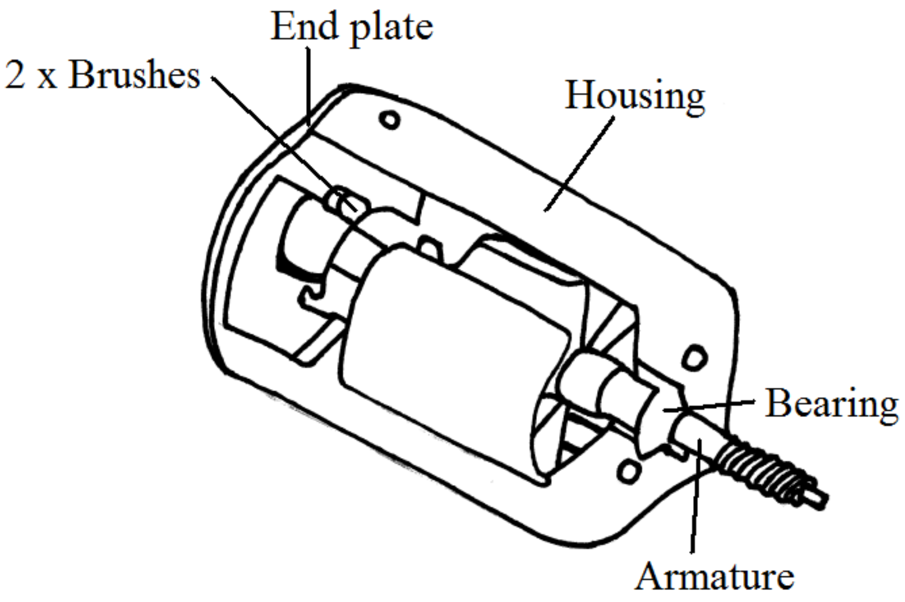
A Redesign Example

An interesting case study is provided by the Materials and Process Performance Research team of the University of Hull – the redesign of an automotive windscreen wiper according to DFA principles. The two designs, old and new are shown in Figure 1.

Before



After



(University of Hull 2011)

Figure 1. DFA redesign example, windscreen wiper motor.

The redesign is radical, but solves many of the problems connected with the old design. The old motor had a number of alignment problems and required many two-handed assembly operations. Furthermore, because of the small size of the motor, several of the components used earlier were small enough to be difficult to handle and easy to drop. Out of the total 29 parts, only six had a clear function related to the operation of the motor.

In the new design there are only six components, all of which have a function. For instance, the top plate and the housing have now been merged. There is only one sturdy bearing instead of two (also removing the need for rivets and the bearing retaining plate at the end). The brushes have been moved to the other end of the housing, making the armature more stable around its one bearing. The brushes are spring-loaded themselves, negating the need for separate springs.

According to the design rules in Table 8, Chapter 4, the redesign fulfills many important guidelines: 1) the number of components has been reduced to a minimum, 2) the functions performed by each component has been maximized, 3) the types of material used have been reduced 4) fasteners such as rivets have been removed, 5) parts that are very small have been avoided 6) flexible parts (springs) and 7) tangling parts (springs) have been removed, 8) a base component has been supplied to mount assemblies on (housing), 9) the product can be assembled from above, in a stack, 10) the product is now asymmetrical to make the correct assembly direction obvious and 11) several sharp angles and corners have been removed.

2.4.2 Second generation DFA

The second-generation DFA methods were created for a logical reason: without a systematic and quantifiable method of analysis, these are no ways to quantify how much better one new redesign is to another new redesign (Boothroyd et al. 2002:3). Using a quantitative approach, the designer can try out several solutions and quickly see how they measure up against each other. Furthermore, the design rules can guide the designer in homing in on problematic areas more specifically.

These methods are by no mean an automatization of the redesign process – one cannot get around the fact that hard work and thorough evaluation is necessary to find the different ways certain assemblies can be modified to yield a more effective design. However, the numbers can help the designer in directing his or her efforts in the most beneficial direction.

Much in the same way as the first generation methods, the second-generation techniques were created by many parties more or less simultaneously. The three most well known are probably the Boothroyd Dewurst DFMA method, the Hitachi Assemblability Evaluation Method and the Lucas DFA Technique, which are explained more closely below. There are, however, several other second-generation Design for Assembly techniques proposed by researchers and companies:

- The Sony Corporation developed a method for analyzing design for assembly cost effectiveness, using keywords and a visual hundred point rating system for each operation (Yamigawa 1988).
- FUJITSU developed the Productivity Evaluation System (PES) (Miyazawa 1993)
- Angermüller & Moritzen (1990) developed a MOSIM, A knowledge-based system supporting product design for mechanical assembly
- Warnecke & Bassler (1988) developed the Assembly-Oriented Product Design method, where each part is given a rating based on its functional value and parts with the lowest functional value (separate fasteners, etc.) are assigned out (whenever possible).
- Poli & Knight (1984) developed a spreadsheet method to rate designs on ease of automatic assembly.

The Boothroyd Dewurst method

The Boothroyd Dewurst Design for Manufacturing and Assembly method is perhaps the most well-known and widely used quantitative DFA methodology. It was primarily developed during a joint research project between the University of Massachusetts (USA) and the University of Salford (UK) in the late 1970s. (Hsu, Fuh, Zhang 1998; Andreasen et al. 1988:150)

The Boothroyd Dewhurst method aims to first reduce the number of components and then ensure that the remaining components are as easy to assemble as possible (combining two components, for instance, eliminates one assembly operation) (Ardayfio, Paganini, Swanson & Wioskowski 1998; Matterazzo & Ardayfio 1992). First of all the designer uses three basic questions to cast doubt on the necessity of each separate component. The questions are:

1. Does the part move relative to all other parts already assembled?
2. Must the part be of a different material or be isolated from all other parts already assembled?
3. Must the part be separate because otherwise necessary assembly or disassembly operations would become impossible?

For a component to continue its existence it should play a key part in the functioning of the product. The designer is required to provide reasons why the part cannot be eliminated or combined with others. Secondly, the assembly time is estimated using a database of time standards developed specifically for the purpose. These depend on what motions the attachment of the component entails – two-handed grip, one-handed, etc. A DFA index (a percentage value known as design efficiency) is obtained by comparing the assembly time with the theoretical minimum of parts. On the basis of this figure, assembly areas that can lead to manufacturing problems are identified. Any iteration after the first design efficiency index is calculated will have to top the original index number, or be discarded directly. (Kuo et al. 2001).

A Boothroyd Dewhurst method example

In Stone et al. (2004), we see a redesign example where the Boothroyd Dewhurst method is used to improve an ordinary household tool – a heavy-duty stapler. The unit consists of a casing, a handle and a spring-loaded mechanism inside to propel the staple into the material it is used on. A very simple and classical product but nevertheless one that can be improved substantially in terms of assembly.

In Table 1 we see the assemblability evaluation of the old design. In the table, column 2 depicts how many times a certain operation must be carried out (two rivets, thus two riveting operations) and column 3 is a two-digit handling process code from a manual handling chart (part of the DFMA material) with predetermined classifications of handling and operation methods, such as 'one-handed operation', 'one-handed operation with grasping aid', etc. Orientation is classified by the rotation necessary to install the component.

Column 4 is simply the handling time in seconds, also obtained from the manual handling chart on the basis of the handling code. Column 5 is a two-digit insertion process code, obtained from the manual insertion chart, based on the component's insertion technique. Column 6 gives the insertion time, based on the insertion techniques determined in column 5.

Finally we have column 7, which give the total operation time (the sum on handling time and insertion time, multiplied with the number of operations, and column 8 which shows the theoretical minimum of parts to be used in an assembly.

Filling column 8 is done by asking the three questions:

1. Does the part move relative to all other parts already assembled?
2. Must the part be of a different material or be isolated from all other parts already assembled?
3. Must the part be separate because otherwise necessary assembly or disassembly operations would become impossible?

If any of the three questions can be answered with “yes”, one point is added to the column (thus if all three questions are answered with yes, a '3' goes into column 8).

At the bottom of the table the manual assembly design efficiency value is calculated using the formula:

MANUAL DESIGN EFFICIENCY (%) = 3 x (THEORETICAL MINIMUM NUMBER OF PARTS / TOTAL MANUAL ASSEMBLY TIME).

Using this theoretical measure as a metric, redesign of a component becomes more systematic and a designer can more easily see where the difficult, time consuming components/operations lie.

Table 1. Boothroyd Dewhurst DFA evaluation table – old design.

1	2	3	4	5	6	7	8	9
Part no.	**Operation no.**	**Manual handling code.**	**Manual handling time (s)**	**Insertion code**	**Insertion time (s)**	**Total operation time (s)**	**Theoretical meini-mum parts**	**Part name**
1	1	30	1,95	00	1,5	3,45	1	Plastic support
2	1	30	1,95	30	2,0	3,95	0	Hammer guide
3	1	23	2,36	30	2,0	4,36	1	Hammer
4	1	30	1,95	06	5,5	7,45	1	Stapler advance mecanism
5	1	33	2,51	06	5,5	8,01	1	Left casing
6	2	15	2,25	0,	3,5	11,50	0	Rivet
7	1	10	1,50	31	5,0	6,50	1	Bottom leaf spring
8	1	10	1,50	00	1,5	3,00	0	Top leaf spring
9	1	30	1,95	00	1,5	3,45	1	Left lifter
10	1	00	1,13	06	5,5	6,63	1	Plastic pin
11	1	33	2,51	01	2,5	5,01	1	Right lifter
12	1	30	1,95	07	6,5	8,45	1	Plastic handle
13	1	30	1,95	30	2,0	3,95	0	Metal handle
14	1	15	2,25	30	2,0	4,25	1	Pin
15	1	15	2,25	30	2,0	4,25	0	Stud
16	2	30	1,95	06	5,5	14,90	0	Lifter cover
17	1	30	1,95	06	5,5	7,45	0	Spring mount
18	2	05	1,84	06	5,5	14,68	2	Springs
19	1	35	3,00	06	5,5	8,50	0	Metal spring holder
20	1	33	2,51	06	5,5	8,01	1	Right casing
21	1	15	2,25	38	6,0	8,25	0	Pin
22	1	39	4,00	31	5,0	9,00	0	Circlip
23	2	–	–	35	7,0	14,00	0	Riveting (rivet row 6)
24	1	33	2,51	08	6,5	9,01	0	Front casing
25	1	15	2,25	38	6,0	8,25	0	Pin
26	1	39	4,00	31	5,0	9,00	0	Circlip
27	1	23	2,36	31	5,0	7,36	1	Locking pin
					Totals	204,18	14	

Total number of parts is 29

The manual design efficiency is given by EM = 3x14/204,18 = 20,60%

The Stapler

The authors consider the following changes possible in the stapler:

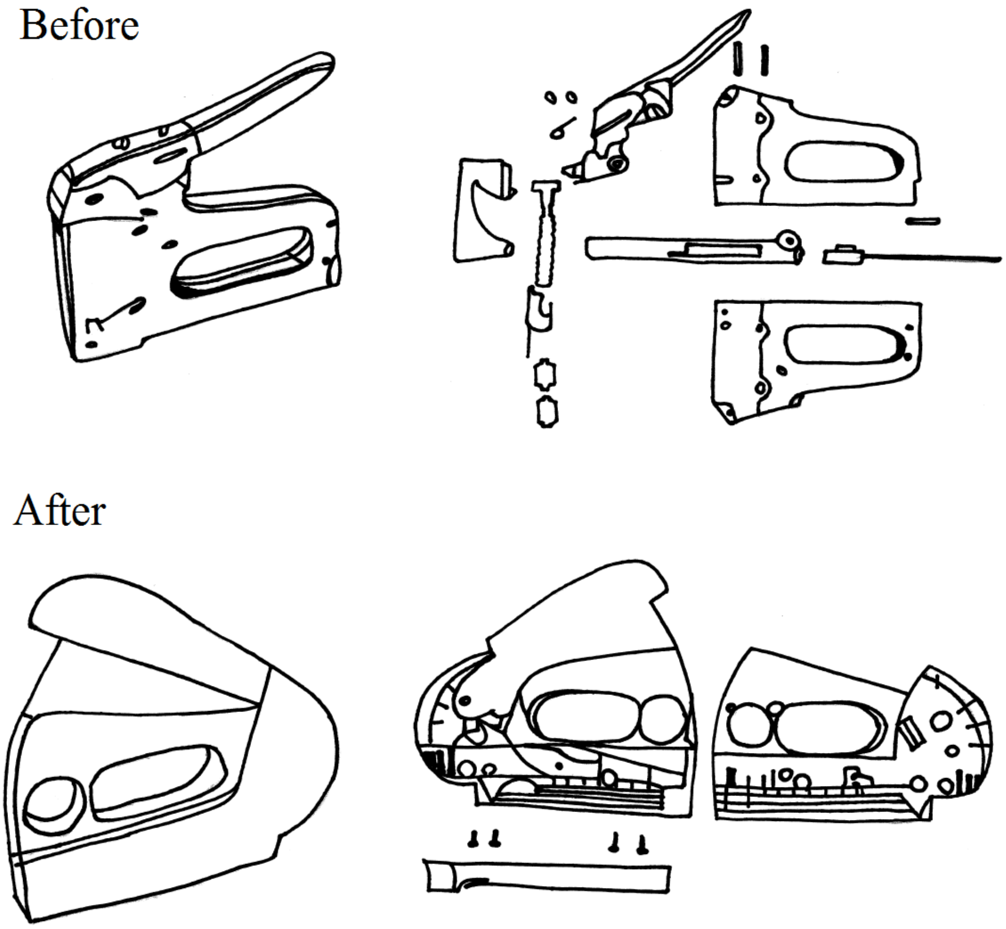
1. Combining the hammer guide with the plastic support.
2. The casings could be attached by snap fits to the plastic support
3. The two leaf springs could be combined into one leaf
4. Slots in the plastic pin could eliminate the lifter cover
5. The spring holder could be combined with the handle assembly
6. The spring mount could be integrated with the casings.

These changes would reduce the stapler components according to what is displayed in Table 2. The old stapler had a parts count of 29 and an assembly time of 204, 18 seconds (3,4 minutes). The new stapler design has a parts count of 11 and an assembly time of 88,08 seconds (1,5 minutes)

Table 2. Boothroyd-Dewhurst DFA example, old design vs. new.

Module	**Existing design**			**Proposed concept**		
	Component descriptions	**Part count**	**Time**	**Component descriptions**	**Part count**	**Time**
Staple	Plastic support	1	3,45	Casings	2	7,45
	Staple advance mechanism	1	7,45	Staple advance mechanism	1	16,02
Rotation-translation 1	Metal handle	1	3,95			
	Leaf springs	2	9,50	Hammer with integral leaf spring and projections	1	6,00
	Hammer	1	4,36			
	Hammer guide	1	5,01			
	Left lifter	1	5,01			
	Right lifter	1	6,63			
	Plastic pin	1	9,01			
	Front casing	1	4,25			
	Stud	1	4,25			
	Lifter covers	2	14,90			
Rotation-translation 2	Springs	2	14,68	Handle with integral leaf spring	1	14,00
	Spring mount	1	7,45			
	Metal spring holder	1	8,50			
	Casings	2	16,02			
Grip	Plastic handle	1	8,45	Handle with integral leaf spring	0	
				Casings	0	
Pin	Pin	1	4,25	Pin	1	4,25
Lock	Locking pin	1	7,36	Locking Pin	1	7,36
Other parts	Rivets and riveting	2	25,50	Screws	4	33,00
	Pins	2	16,50			
	Circlips	2	18,00			
		29	204,18		11	88,08

In Figure 2 we see a rendition of what the two different designs would look like, compared to each other.



(Stone et al. 2004)

Figure 2. Boothroyd Dewhurst DFA redesign example – heavy-duty stapler.

The Hitachi Assemblability Evaluation Method

According to Miyakawa & Ohashi (1986) the Hitachi Assemblability Evaluation Method (or AEM) uses so-called *Cost Ratio Indices* to pinpoint candidate components for redesign. Initial drawings or concepts of the product under scrutiny are used by the designer to fill in the AEM form (component names and numbers) in a logical assembly sequence. The assembly operations are then analyzed and classed, using about 20 different AEM symbols. On the basis of these, the final assemblability evaluation score, or assembly cost ratio, can be calculated. If the final scores are lower than the 'target values', the product is redesigned. The complete analysis sequence is :

1. Preparations
   - Prepare the products to be evaluated, such as conceptual drawings, design drawings, assembly drawings, samples, etc.
   - Prepare the assemblability evaluation calculation form.
2. Determine attachment sequence
   - Enter the part names and the number of parts on the evaluation form in the same order as the attaching sequence.
   - Determine the attaching sequence of the subassembly units.
3. Determine attaching method
   - Determine the parts attaching procedures.
   - Enter the symbols for each part of the evaluation form.
4. Calculate evaluation indices
   - Calculate the *product assemblability evaluation score*, the *part evaluation indices score* and the *assembly cost ratio*.
5. Evaluation index judgment
   - Compare calculated indices to the target values. It is desirable that the *product assemblability evaluation score* be over 80 points. It is desirable that the *assembly cost ratio* be below 0,7.
6. Improve product design (if necessary)
   - Find subassemblies and parts having relatively small p-values, then attempt to reduce the number of attachment movements.
   - Attempt to reduce the number of parts.
   - A reduction in the number of parts sometimes results in a small *product assemblability evaluation* score. In that case, reduction in the *assembly cost ratio* is preferred to a smaller *product assemblability evaluation score*.
   - When the design is improved, gradual improvements in the *product assemblability evaluation score* (20 to 30 points) are desirable.
   - Prepare proposed improvements.

The Lucas DFA Technique

The Lucas Technique is also one of the more well-known DFA methods. According to According to Andreasen et al. (1988:156) the Lucas system is mixture of knowledge engineering and CAD modeling. The system uses the same classification method for automatized and manual assembly. The analysis goes through the following steps:

1. Product design – important strategic choices are made as to the individuality of the product and standardization possibilities.

2. Functional analysis – components are divided into groups depending on their functional importance. Unimportant functional components are prime candidates to be cut in redesign, or combined into one larger or more complex component.

3. Feeding analysis – each component is assigned a feeding technology symbol and assigned a value from a feeding cost index. Individual components must be compatible with the intended manufacturing method.

4. Gripping analysis – the components are evaluated on their ease of gripping and graded on an index. This is especially important when considering automated assembly.

5. Insertion process analysis – the designer creates an assembly sequence flowchart and grades each assembly process according to a cost index. If disproportionately expensive assembly processes are necessary for certain components, they are prime candidates for redesign.

6. Assessment – the total cost index vales are used as a basis to brainstorm up new proposals around the components and the product.

The Lucas method's cost indices are calculated by using the following formulas, and then by minimizing the cost of assembly total:

(1) Cost of assembly	$COSTOFASSEMBLY(C) \approx \frac{C_p}{N_t} + \frac{C_a}{N_a} + C_m$
(2) Capital Cost	$C_p \approx \sum^{N_p} (C_f + C_g + C_i)$

Cp: Total capital costs of automated system
Nt: Total number of assemblies produced in the system lifetime
Ca: The annual costs of operating the system
Na: The annual production of assemblies
Cm: The cost of labor per assembly
Np: The number of parts in the assembly
Cf: The feeding costs of an individual part
Cg: The gripping costs of an individual part
Ci: The inserting costs of an individual part
(Andreasen et al. 1988:156)

2.4.3 Third Generation of DFA

The third generation of the Design for Assembly makes the jump from pen and paper to software – trying to create a program that can take on a part of (or why not the entire) process of redesigning the product according to DFA principles. Taking the first steps on this path is relatively easy – creating programs that can aid the designer in the design process – but going all the way to creating a program that can create a new design on its own is a very complicated task (Hsu, Fuh & Zhang 1998).

Computerizing the second generation methods

Boothroyd Dewhurst Inc. offer softwares that computerize their DFMA process. Their DFA software helps the designer optimize their product design, and the DFM software gives fast cost estimates of how much the new design will cost to produce. The DFM software can also help with the choice of material, and show you whether certain production processes are incompatible with the envisioned design (DFMA 2011a, DFMA 2011b). Boothroyd et al. (2002:2) state that one of the main problems separating 'optimal' design from the real world, is that designers (naturally) will conceive their products in terms of components and materials that they are the most familiar with. This means that they may easily overlook a component or material that would in the end have produced a cheaper, better product.

According to Choi & Guda (2000), the Boothroyd Dewhurst computer software functions in much the same way as the pen-and-paper method. The user is led through the process of deciding the sequence of assembly, building a structure chart and answering the three DFA questions for each component. Several more questions are added to pinpoint the design of the product further. The user is asked to choose what simple, geometrical shapes most closely resemble the real-world shapes of the components. Irregular shapes are not considered, so some approximation is inevitable.

The authors contrast the Boothroyd Dewhurst DFMA software with a computer aided production engineering tool named Dynamo (Technomatix Technologies). This program relies on 3D modeling of the product and its production line, and is more concerned with "*finding an optimal sequence of assembly for a given design*". In the authors’ opinion the Boothroyd Dewhurst DFA program could benefit from incorporating more visualization into its software – letting the designer play with his or her design in a combined DFA/Virtual prototype setting. As it is, the designer would be better served by using both programs simultaneously.

Going beyond

A number of attempts have been made to automatize the DFA process beyond simply computerizing the Boothroyd Dewhurst method. Li & Hwang (1992) use a semi-automated system modeled on the Boothryd Dewhusrt method, which systematically finds all feasible assembly sequences for a product. Ong and Lye (1992) and Rosario (1988) use a part's CAD model to calculate optimal overall dimensions and rotational symmetries. Lucas Engineering have created a knowledge-based design system to define an assembly-sequence and analyzing each components for ease of part-handling and assembly (Shehab & Abdalla 2006). Coma et al. (2003) present a geometric tool software solution for automated Design for Assembly assessment where each component is first analyzed to identify mass dimensions and symmetries and secondly to identify form – after this the optimal mechanical assembly method can be pinpointed.

The closest thing to an all-round solution is perhaps the multi-faceted expert systems such as the one presented by Sanders, Tan, Rogers and Tewkesbury (2009): software combining four expert systems (computer-aided design (CAD), automated assembly analysis, manual assembly analysis and design analysis). The four systems are able to take data from each other, and thus make the design process more seamless. The program can analyze a design and provide ideas for designers, and it can do so on the basis of existing CAD drawings. Furthermore, the system can estimate assembly times and costs for manual or automatic assembly, suggesting optimal assembly techniques along the way. This is not the self-designing program that would crown third generation DFA, but nevertheless a functional DFA software that will help the designer speed up the process significantly.

2.5 Does DFA work?

There are numerous academic articles and industrial news sources that present successful redesign case studies, case studies where real-world products have been remodeled to significantly reduce parts count and assembly time. Below, a few are presented together with a case study compilation carried out by Boothroyd Dewhurst Inc. on their own customer base. This to give us an idea of what benefits have been achieved using efficient industrial design methods.

We should do well to remember, however, that any articles written about DFA case studies will be predominantly positive simply because of human psychology – it is unlikely that anyone will publish an article about unsuccessful redesign, or at least about very marginal results from the redesign venture. Small results are most often deemed lacking in news-value.

Case studies

We already remember the two studies presented in connection with the DFA techniques earlier on – Stone et al. (2004) described the redesign of a heavy duty industrial stapler, and the University of Hull present an improved windshield wiper motor. In the case of the stapler, the authors suggest that it is possible to reduce the part count from 29 to 11 (a reduction of 62%). In terms of assembly time, the old model consumed 204,18 seconds while the new model would use only 88,08 seconds (a reduction of 57%). The windshield wiper motor achieved a parts reduction from 29 to 6 (a reduction of 79%).

Ardayfio, Paganini, Swanson & Wioskowski (1998); Matterazzo & Ardayfio (1992), Ardayfio & Opra (1992), Ardayfio, Dembsey, Kreucher & Schmitt (1998); Sarmento, Marana, Ferreira-Batalha & Stoeterau (2011) da Conceicao & da Silva (2010) present successful case studies of Automotive Fuel Intake Covers, Automotive Electrical and Electronic Systems, Front Suspensions, Convertible-Top Vehicles, Brake and Clutch Pedal System at Ford Motor Company, GM, Chrysler and Delphi Automotive Systems.

Boothroyd et al. (2002), though hardly impartial in the matter, produce an impressive list of successful projects, where the DFA techniques have produces significant positive results: Donnell Douglas used DFMA methodology to redesign the F/A Hornet jet fighter, resulting in a bigger, lighter product with 42% fewer parts. Dell Computer Corporation used DFA tools to design and manufacture a new desktop computer chassis, with savings reported as a 32% reduction in assembly time, a 44% reduction in service time, a part count reduction of 50%, and a direct labor cost reduction of 80%. Motorola, on the redesign of their walkie-talkie vehicular adapters, realized assembly time reductions of 87%, from 2742 seconds (45,7 minutes) initially to only 354 seconds (5,9 minutes) when finished. Ciba Corning Diagnostics Corp, a medical company building blood-gas analyzers, reduced their overall number of parts by 48% and cost by 22 %. Magna Interior Systems Seating Group, a company making seats for the car industry pulled down total parts count form 105 to 19 and assembly time form 1445 seconds to 258. Whirlpool used the method to make their new microwave oven faster to assemble (by 26%) despite adding a new forced convection technology to it, in addition to the old functionality. At Ingersoll-Rand Corporation's portable compressor division, the DFMA software was used to redesign an oil cooler and a radiator assembly to achieve a parts count reduction from 80 parts to 29 (64%) and an assembly time reduction from 18,5 minutes to 6,5 minutes (65%). In a later attempt, the same company redesigned a control and instrument panel assembly to achieve a parts count reduction from 36 to 24 (33%) and an assembly time reduction from 8.5 minutes to 6.1 minutes (28%).

Port (1989) relates two successful case studies: IBM's redesign of their ProPrinter and NCR's cash register terminal. The IBM printer (automated assembly) was redesigned to result in a parts count reduction from 152 to 91 (40%) and an assembly time reduction from 30 minutes to three minutes (90%). Furthermore, the printer could now be manually assembled, because of its more simplistic design. The cash registered achieved a parts count reduction of 80% and an assembly time reduction of 75% through the DFA analysis. As an added bonus of the reduced part count, the number of suppliers needed went down by 65%.

Stone et al. (2004) presents the redesign of an ordinary kitchen wok. As for the wok, parts count dropped from 33 to 13 (a reduction of 61%) and assembly time from 233.48 seconds to 91 seconds (a reduction of 61%). Causey (1999), using the DFMA methodology, suggests redesigns to a normal flashlight achieving a part count reduction from 14 to 7 (50%). Stevens & Eijsink (1994) describe the redesign of a wall-mounted emergency fire hose reel. According to their calculations, their redesign reduces parts count from 59 to 27 (a reduction of 54%) and manual assembly time from 525 seconds to 264 seconds (a reduction of 50%).

There is no shortage of impressive cost reductions to be seen in literature – the presented studies are just a sample from the top of the pile and there exists a multitude of similar case studies in design literature and journals. The following example is especially interesting in that it describes the usage of Design for Assembly methods already during the creation stage of a new product – a new product only exists in potentia, but cost estimates and assembly simulation can still be done during the development phase to see whether the new design shows promise or not.

Hydrogen fuel cells: using DFA before production

In an article for Design Engineering news (2007) we can read about a project undertaken by the technical consulting firm Directed Technologies Inc. on behalf the U.S. Department of Energy, to create a hydrogen fuel cell. The fuel cell should be a tangible alternative energy solution, with set technical and financial goals for each step of the project. The final target (for 2015) is set at 15 dollars per kilowatt, an ambitious goal, considering that the 2006 cost target was set at 70 dollars per kilowatt.

Importantly, the goal of the project is to consider all possible solutions (systematic, material, operational, etc.) that might lead to cost reduction compared to the current products. DFMA software is used to rapidly calculate estimates of manufacturing and assembly costs with only light initial information.

The hydrogen fuel cell stacks consist of several hundred plates with differing electrical charge that act as anode and cathode, as well as a similar amount of semi-permeable membranes that guide the electrons and protons in a desired route. The design of the plate for optimal processing surface to minimum manufacturing cost is therefore of great interest to the designing engineers.

After several different iterations, considering the effects of process, plate design, plate material and production batch sizes, it was concluded that stamped steel plates would function better than injection moulded composite plates, and that pieces stamped from a roll of steel with the exact width of the plate would produce zero waste at an 80 plate per minute rate. By changing their designs in this manner, the designers have been able to bring the projected cost of the fuel cells down to $25/kW.

Survey work

There are very few surveys made on the subject of how often redesign projects have been successful, as opposed to only achieving moderate or marginal improvements. The closest thing we can come to an industry-wide benchmark of the situation in companies where Design for Assembly is used is another study by Boothroyd Dewhurst, Inc. (2004). Again, we must be aware that private company is not the best source of objective data, but since similar studies are almost nonexistent, we have to consider it the best source available.

The Boothroyd Dewhurst study compiled the results of 117 product-design case studies by 56 manufacturers, conducted over the last 15 years. The their numbers showed, for instance, that using the DFMA techniques resulted in an average parts count reduction of 54% in 100 of the cases studies. Similarly, an average assembly time reduction of 60% was calculated on the basis of 65 case studies. The full survey is presented in Table 3. The figures indicate that there is a considerable amount of value in the judicious application of Design for Assembly techniques.

Table 3. Case study compilation results.

Category	**Number of cases**	**Average reduction (%)**
Part count	100	54
Assembly time	65	60
Product cost	31	50
Assembly cost	20	45
Assembly operations	23	53
Separate fasteners	20	60
Weight	11	22
Labor costs	8	42
Manufacturing cycle	7	63
Part costs	8	52
Unique parts	8	45
Assembly tools	6	73
Material cost	4	32
Number of suppliers	4	51
Manufacturing steps	3	45
Assembly defects	3	68

2.6 Is it used?

Even though there are numerous case studies on the improvements that DFA can generate, surveys on the extent of its usage in various industries are few. Presented below are five different surveys connected to DFA in various settings – they vary strongly in scope and setting, but each can give us a few insights into the usage and problems surrounding DFA. They also represent a large part of the surveys ever done on DFA usage and methodology, unfortunately.

Dean & Salstrom (1990) present a survey of the extent of familiarity with and use of Design for Manufacturing (DFM) tools and techniques in San Francisco Bay area firms, and Huang & Mak (1998) make a similar investigation in Design for Manufacture in the UK furniture manufacturing industry. Boothroyd-Dewhurst Inc. presents a roundtable survey conducted at their customer conference (2009), and Sirat, Tap & Shaharoun (2000) a survey on the extent of DFA application in Malaysian industries. The most relevant study of manufacturability concerning the automotive industry is presented in The Machine That Changed the World by Womack, Jones & Roos (1990: 96–97). There, the well-known authors on Lean production present the results of an MIT International Motor Vehicle Program survey where a set of car manufacturers were asked to rank each other in terms of manufacturability.

DFM in San Francisco firms

Dean & Salstrom (1990) conducted a survey on the usage of and familiarity with Design for Manufacturing techniques in the San Fransisco Bay area. The American industries were at the time suffering hardening competition from mainly Japanese producers, and according to the authors, the heavy investment in robotics, flexible manufacturing systems and computer-aided design had not provided as large a competitive advantage as had been hoped. Therefore, a greater linkage between design and manufacturing (and especially the automatic assembly methods used) was desirable. The aim was to see whether companies recognized the benefits of industrial design and furthermore to determine the extent to which companies had already implemented DFM tools.

The authors conducted their survey by questionnaire, handing out their inquiry forms during the course of three different conferences. They thereby received a good number of responses – 98 completed questionnaires, in which 60 of the respondents stated they were ‘management’. Out of the 90, 58 were in manufacturing and 28 in design.

The survey identified six benefits to implementing DFM (percentage in brackets): 1) Higher quality (88%), 2) Lower total costs (88%), 3) Fewer engineering change orders (70%), Improved morale (54%), Increased market share (51%), Increased creativity (31%).

The survey also identified seven main problems to implementing a successful DFM program. The problems were: 1) Lack of management commitment (62%), 2) Resistance from design engineers (53%), 3) No budget to implement DFM tools (37%), 4) DFM tools have long term benefits but I have short term problems (29%), 5) Difficult to implement DFM tools (29%), 6) Lack of tangible benefits (9%), 7) DFM tools hinder creativity (6%).

As for the usage of DFM in the companies, the majority of respondents gave a moderate answer (agree, neither, disagree – as opposed to strongly agree or strongly disagree) on the question whether their companies did a good job implementing DFM. The majority answered the question whether their companies have formal DFM implementation programs negatively. On the other hand, the absolute majority of respondents with a ‘strongly agree’ on the question whether the potential benefits from DFM are very high.

Interestingly enough, a difference between the responses of manufacturing and design personnel showed that the design personnel were more positive in their belief that their DFM programs were succeeding than the manufacturing personnel, in almost every category. This sort of a discrepancy seemed to indicate that complete "concurrentness" in the design phase had not been achieved.

DFM in the UK furniture industry

Huang & Mak (1998), both of the University of Hong Kong, carried out a survey to ascertain the familiarity with and usage of Design for Manufacture in the UK furniture industry. The aim of the study was to "establish the relevance of DFM to the furniture manufacturing industry and what special needs this particular sector has."

This was a questionnaire survey, with 200 questionnaires sent and a response percentage of about 15%. The respondents were mainly senior personnel such as managing directors, design managers, etc. and the questionnaire inquired whether

1. DFM (and other techniques such as value analysis and Quality Function Deployment) were currently being used in the company
2. How the company would choose to implement such techniques
3. The perceived benefits and potential to implementing such techniques
4. Current problems in the manufacturing process.

The survey concluded that while there was a relatively high degree of knowledge about the DFM methodology (as well as other value and quality management theories) there was not, generally, a great degree of implementation of the techniques. The benefits of DFM were seen as speeding up product manufacture, improving product quality and reducing product cost, as well as necessitating less engineering changes, being able to compete better in the market, etc.

However, the real barrier to implementing DFM was seen as not having enough budget to spend on such systematic changes. External consultants were considered too expensive, but several firms were open to the possibility of sending their engineers on short workshops on the subject. However, according to the authors, a lack of true understanding about the methods and benefits of DFM could well be another reason why the methods have not been implemented to a greater degree in the furniture industry.

DFA in Malaysian industries

Sirat, Tap & Shaharoun (2000) of the Universiti Teknologi Malaysia present the results of a survey they conducted to find the extent of DFA application in Malaysian industries. The questionnaire was sent to about 200 companies in Malaysia (with a response percentage of 19%) and was answered by senior personnel in the companies (Managing directors, R&D managers, etc.).

The survey concluded that the level of DFA awareness is relatively low. The number of companies that replied they have never heard of DFA was 26%, while a further 26% answered that they did not understand DFA (partially or fully). There was in fact only three of the companies that answered stated that they were actively using DFA in their production practices. These were all in the ‘large company category’, and used the Hitachi method, the DFMA method, or a method created in-house.

The authors feel that there is a large potential for wider usage of DFA, and that the reason for the low adaptation degree is mainly the lack of knowledge about the method. DFA is not as well-known in Malaysia as the larger industrial management methodologies such as Just-In-Time production, Total Quality Management, etc. The respondents were generally interested in the benefits DFA are able to bring, though – reduced lead time and assembly times being the most popular areas of interest to the respondents.

Boothroyd Dewhurst's customer review

In a survey conducted at a company quality seminar, Boothroyd Dewhurst asked their customers what benefits they see in DFMA and what kind of benefits they feel they have gotten from implementing the method. Only 19 customer representatives were present, but of the companies involved, many are fairly well-known: Motorola, Dell corp., GE, Harley-Davidson, KPMG, TRW automotive, Raytheon, Magna Intierior Automotive Seating, Boeing, etc.

The quantitative results of the survey are presented in Table 4.

Table 4. Roundtable survey results.

Which of these categories do you believe contribute to product development costs that could be avoided by analyzing product deigns with DFMA?

	responses	%
Testing and prototyping	10	52.6%
Engineering change notices	13	68.4%
Production throughput	17	89.5%
Factory floor space	13	68.4%
Quality inspection	15	78.9%
Inventory	13	68.4%
Shipping	8	42.1%
Supply chain management	13	68.4%
Warranty and service	10	52.6%
Order entry and part tracking	9	47.4%
Assembly documentation	13	68.4%
ERP, BOM, and MRP admin	10	52.6%
CAD and PDM	7	36.8%
End-of-life considerations	4	21.1%
Other assembly	2	10.5%

For which of these categories has your company measured savings in overhead costs related to DFA part-count reduction?

	responses	%
Testing and prototyping	6	31.6%
Engineering change notices	7	36.8%
Production throughput	13	68.4%
Factory floor space	9	47.4%
Quality inspection	6	31.6%
Inventory	7	36.8%
Shipping	6	31.6%
Supply chain management	8	42.1%
Warranty and service	3	15.8%
Order entry and part tracking	6	31.6%
Assembly documentation	7	36.8%
ERP, BOM, and MRP admin	5	26.3%
CAD and PDM	4	21.1%
End of life considerations	1	5.3%
Other assembly	1	5.3%

(IndustryWeek 2007)

The MIT IMVP assemblability study

The most interesting survey from an automotive industry perspective is one carried out by the International Motor Vehicle Program (Womack et al. 1990: 96–97). The survey was carried out by questionnaires sent to 19 major auto assembling companies. The firms were asked to rank their competitors "*according to how good you think each company is at designing products that are easy for an assembly plant to build*". It is widely known that car producing companies regularly buy cars form their competitors, disassemble them and study their build, their functionality and their innovations. Therefore it is only logical to presume that the other car companies should know what companies are the best at producing manufacturable cars (in essence Design for Assembly).

Eight companies answered the survey and the findings are presented in Table 5:

Table 5. IMPV manufacturability survey results.

Producer	**Average rank**	**Range of rankings**
Toyota	2,2	1–3
Honda	3,9	1–8
Mazda	4,8	3–6
Fiat	5,3	2–11
Nissan	5,4	4–7
Ford	5,6	2–8
Volkswagen	6,4	3–9
Mitsubishi	6,6	2–10
Suzuki	8,7	5–11
General Motors	10,2	7–13
Hyundai	11,3	9–13
Renault	12,7	10–15
Chrysler	13,5	9–17
BMW	13,9	12–17
Volvo	13,9	10–17
PSA	14,0	11–16
Saab	16,4	13–18
Daimler–Benz	16,6	14–18
Jaguar	18,6	17–19

We can see that the Asian (Japanese) producers rank highly on this list – probably because of their prowess in Lean production/design. The highest ranking American company is Ford (at fifth place), beaten surprisingly enough by Fiat, ranking fourth on the list.

In connection with this survey, Womack et al. (1990:96) also presented GM's productivity comparison between two American assembly plants: GM's Fairfax plant (producing the Pontiac Grand Prix) and Ford's Atlanta plant (producing Taurus and Mercury Sable). The comparison was done by disassembling both kinds of cars and assembling them with the aid of the manufacturer's assembly manuals. The conclusion of the comparison was that the Ford plant was significantly more productive, and that the design of the Taurus accounted for 41% of this productivity gaps. The Taurus used fewer parts, and the pieces fit together more easily. The other causes for the difference were set as: Factory practices (48%), Sourcing (9%) and Processing (2%). This indicates that a careful design can have significant impact on the production's costs and throughput.

Reasons why DFA may not be used

Boothroyd et al. (2002: 16–21) have identified several reasons why DFA is not more commonly used in general:

No time. The designers may feel that they have no time to put on simplifying design, when it works already.

Resistance from the designers. The DFA initiative often comes from the outside, and a designer may take this as direct critique of his or her work. The designers are crucial to the effort since they are in a unique position to build DFA into the product from the beginning.

Low assembly cost. If the assembly costs are already marginal to the material and manufacturing costs of the product, there may be no reason to run the DFA process.

Low volume. When products are produced in small rounds, a DFA process will not form any economy of scale benefits, even if it is successful. There is a possibility of increased quality because of clearer parts orientation and so on, but the benefits are less prominent.

3 THE AUTOMOBILE INDUSTRY AND DFA

In this section we will go though the recent situation of the automotive industry and the events that led up to the current day; we'll look at the automotive assembly process and its usage of robotic and human labor; and finally look at why DFA is relevant to the automotive industry – why DFA can have an impact on the future business situation of the established car companies.

3.1 A short background on the automobile industry and its situation today.

This section is split into three parts – early automotive history, the situation up until the automotive crisis of 2008–2009 and the situation afterwards. There have been many crises in the automotive industry over the last sixty years, but this latest one is especially important to the subject of this work. This crisis exposed the structural weaknesses of the old automotive companies and allowed the new automakers of especially China to raise their heads and see the possibility of direct competition. As we will see later on in Sections 3.1.2 and 3.1.3, it was during this time period that China passed Europe as the largest automobile producing region in the world. Furthermore, during the crisis the Chinese automakers were able to turn the tables on everyone and start making acquisitions among the struggling Western car companies and suppliers (e.g. Volvo).

3.1.1 Early history

Mass production

The automotive society as we know it today started in the United States, with Henry Ford and his principles of assembly line production. The Model T Ford was in fact a revolution in manufacturability and assimilability. According to Womack et al. (1990: 27), the greatest, most revolutionizing concept that Ford came up with was not necessarily the moving assembly line or the specialization of labor, but rather the interchangeability of components, to a level that assembly line assembly work could become possible. The first cars (Daimler, Benz, etc) were all more or less unique, handcrafted, and could not as such be assembled by just anyone (Ford Motor Company 2010).

According to Hounshell (1984) Ford perfected his new production technique in steps. First by having all necessary components delivered to an assembly station before they were needed, later by making the assemblers perform only a single task on the product. And finally, the culmination of the mass production system, a moving assembly line that meant that workers no longer had to waste time by walking between their assemblies – the assemblies came to them.

The Model T Ford came in nine body styles (two-seat roadster, four-seat touring car, four seat covered sedan, two seat-truck, etc) but they were all based on the same chassis and the same mechanical parts. At the peak year of Model T production (1923), Ford produced over two million Model T chassis, a figure that was in fact the high-water mark for standardized mass production (Womack et al. 1990:37)

The T-Ford based its popularity on low prices, not especially much on high level of quality or on a wide range of selection. Towards the end of the T-Ford's production life span (1908–1927) (Ford Motor Company 2010) the competition from other companies finally broke its monopoly simply by offering more modern and interesting cars, at prices not much higher than the Ford's.

According to Hounshell (1984) the beginning of today's selection-of-choice auto industry started in General Motors. This company was the first automotive company to establish a wide selection of car brands and models to allow the customer freedom of choice in his or her purchase. With the introduction of GM's five brand product range (from Chevrolet at the cheapest end to Cadillac at the most expensive), GM was able to create a stairway of progression for its customer, and make the car into a symbol of status.

In Europe, the craft manufacturing tradition was not given up easily – Henry Ford experienced considerable resistance when trying to implement his mass-production system in Great Britain (Womack et al. 1990: 24–25). After the two World Wars, however, much of the old society had been swept away forcedly by the ravages of war. The resistance to mass-production was at an end, and the economic upswing of Europe during the post-war era can probably be ascribed to a full embrace of these new methods of production (not only in the automobile industry, of course (Womack et al. 1990: 24–25).

As Womack et al. (1990:43) continues, the American car industry had its golden days in the 1950's, with booming post-war economies, especially marvelous and impressive car models and a strong mass production technique. The Big Three (GM, Ford and Chrysler) accounted for the absolute majority of cars produced in the world. Already in 1955, however, the European manufacturers were beginning to make serious instep into the competition. André Citröen, Louis Renault, Fiat's Giovanni Agnelli, Herbert Austin and William Morris among others had visited Ford's plants and learned the new concepts of mass production – only the war effort hindered them from translating their automotive knowhow to the new system. The total output of the European auto industry would grow considerably during the 1960's and 70's, rivaling that of the United States.

The Europeans specialized in smaller, compact economy cars, and sportier fun-to-drive cars, that broke off from the old model. A new kind of sporty luxury car won instep on the old luxury sedans. Many new mechanical innovations such as the front-wheel drive car, disc brakes, fuel injection and unitized bodies (no separate frame) were invented in Europe in the 1960's and 70's. For a period of time between 1950 and 1970, the Europeans were the main competitors of the American car industry, both quite undisturbed by other entrants.

Lean Production

The late 1960's showed the start of a new kind of revolution in the automotive industry: the Lean production methods. According to Holweg (2007), Eiji Toyoda (member of the founding family of Toyota) visited a Ford plant in the 1930s, to learn about the mass production methods of the automotive industry. However, he concluded that there would be problems implementing such a system in Japan. Firstly, the domestic market was small and demand was split in many ways. Secondly, the native work force was too proud to work well in a mass production system. And thirdly, Japan was poor and starved for capital after the war, so no large production machineries could be bought. In addition to this, the outside world was actively looking to enter the Japanese market, to fill it with their own automotive products. Womack et al. (1990: 49–50).

So the response of Eiji and his now legendary chief engineer Taiichi Ohno was to change the production system to fit the circumstances. They wanted to work in smaller batches and produce many different models to satisfy the varied demand (Ohno 1988). However, the first and biggest problem they ran into was the usage of dies for stamping out the forms of the car's steel components. These dies took a very long time to change in the machines, and thus it was more economical to run long production series in between changes. But Ohno set to eliminating this problem by mechanizing and effectivizing the changeover process, and could, by the late 1950's change dies in three minutes. (Toyota 2010.)

The most interesting thing about this achievement was the discovery that production in small batches, now made possible, was actually more profitable than large-batch production (Shingo 1984). The large inventories of components and partly finished goods that the long production series required could be eliminated, and mistakes in the production machinery, process, components, etc. could be spotted almost instantly, and thus with less wastage.

The benefits of these findings were multiplied by many other new and revolutionizing practices. As a result of a strengthening of the worker’s unions after the war, the workers of Toyota had moved on to life-long employment with the same company. However, the workers were in return expected to be flexible in their work functions and more importantly, use their own initiative in offering improvements to the production processes (Ohno 1988) The famous concept of Kaizen (approximately “continuous improvement” in Japanese) was born. Kaizen means, among other things, the use of quality circles to let the workers share their ideas for quality improvement and waste avoidance, to engage all workers in offering up ideas for improving the company’s processes, and to use a tangible part of one’s work time to implement these improvements (Monden 1983).

Since Ohno reasoned that the cost of errors will multiply the longer down the production line they go, the most cost effective thing would be to avoid all production error from the beginning (by improving the processes) or at least spotting errors whenever they occur (Ohno 1988). The workers were given possibility and responsibility to halt the production assembly line whenever quality problems or machinery errors were noticed (the Andon-system).

Continuing this line of thinking, it was only logical that also the component suppliers would become involved in this hunt for errors and waste. Toyota grew stronger ties to their suppliers and started educating them in the practices taught inside the company. The suppliers were given considerable leeway in suggesting changes and improvements in the design of their components. A certain degree of cross-equity-ownership made the ties stronger still. (Womack et al. 1990)

But the final step in building what would later become known to the rest of the world as the Toyota Production System was something that completely changed the entire structure of the production flow. According to Shingo (1984), the concepts of "pull-manufacturing" and "Just-In-Time production" were implemented to co-ordinate the flow of goods down the supply chain. The idea of pull manufacturing dictated that the ultimate expression of small batch production is not to produce anything until an impulse is give from the end of the supply chain, when a customer buys a product. Then the production is started, with the impulse working its way up the chain of production, and each work station kicking into life when the work station beneath it requires replenishment. Inventory of half-finished assemblies between the work stations are minimized. The now famous Kanban-system is simply a system of cards used to make this flow of production impulses work in the most simple and visual way.

If expanding this concept to encompass the entire supply chain, including suppliers, you get the Just-In-Time system, where the entire supply chain is supposed to work as one big machine, in sync with each other and in sync with the Takt-time, that sets the pace of production. The result – a production system that produces a wide variety of products, at an unmatched level of quality and at prices lower than the old mass-production system.

The Japanese production miracle

By the end of the 1960's the world market's tastes had begun to shift. There was a growing demand for variety in car models: cars were by now a fixed part of the working life for almost everyone in the Western world and the increasing standards of income had started making it possible for households to buy two cars. Furthermore, with the growing complexity of the cars mechanical systems, reliability was becoming a much more important issue. In this climate, the Toyota Production System was set to shine.

When finally the two oil crises struck in 1973 and 1979, the cheap, energy-efficient Japanese cars won over all obstacles and formally flooded into the United States, where the effect of the rising petrol prices was felt the most. The CAFE (Corporate Average Fuel Economy) consumption standards were imposed by the American government to ensure that the American car fleet would no longer be as dependent on foreign important oil (Gerald & Lave 2005). This meant a large redesign of American car models, from predominantly rear wheel drive large fuel hungry versions to relatively more energy-efficient smaller front-wheel-drive versions. The Japanese cars already fit in the profile without redesign, however.

In all honesty, the Americans who cried 'invasion' during this time, did have some truth to their claims: the wage levels were lower in Japan at the time and large car export was encouraged by the government of Japan through tax breaks and low interest rates. But even with these factors discounted, the price/quality ratio of the Japanese cars spoke volumes about the strength of their production methods (Holweg 2007).

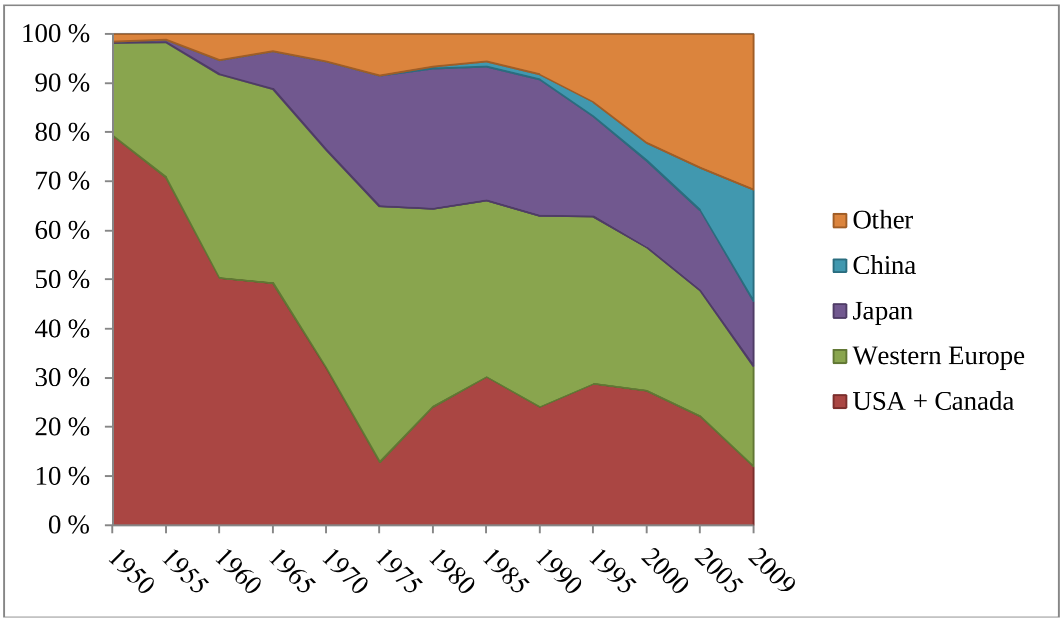
According to Womack et al. (1990:260), the South Korea example later showed that cheap wages could not outweigh the quality aspects of the Japanese production system. The Hyundai Excel was broadly speaking a copy of the Mitsubishi Colt, built on license from Mitsubishi. As the Japanese Yen was starting to get more expensive in the middle of the 1980's, Hyundai saw their chance to grab market share in the United States, in the low-price segment. This worked very well, but as soon as the Korean currency started appreciating a few years later, the cost advantage was no longer there. Hyundai used more hours to build a car than their Japanese counterparts, and their defects rate was up to six times higher.

In Figure 3, we can see the world's vehicle production, and its development over time (U.S. Department of Energy 2008; Ward's Motor Vehicle Facts and Figures 2009). In Table 6 we see the same development in numbers for greater clarity. The annual production of motor vehicles has been rising constantly since the 1950s but the figure shows percentage shares – the maximum is always on hundred percent.

The early history is laid out clearly according to what we have just gone through – in the beginning North America dominates the world market almost completely. Then the European producers pick up the competition and keep the shares of production relatively stable over a period of growth in the late fifties and early sixties. The Japanese car makers start making an entry to the market at this point, and quickly grow to become the third major automobile producing region.

Again we have a period of relative stability and growth before the oil crises of 1973 and 1979 strike. The European and Japanese producers are not hit equally hard because of their already more fuel-efficient cars – it is the American automakers that suffer the worst effects. During the 80s and early 90s, we see a quite stable situation where North America's, Europe's and Japan's vehicle production grow, and grow together. Lean production methods are to some degree adopted over the board. The growth of South Korea's vehicle production is incorporated in the increase of "Other" towards the late 80s, early 90s.

The next two chapters will describe the situation during the last 10 years only – but 10 years that have seen enough change to last for several decades. As the figure indicates, the serious rise of production in many other countries, and the exponential vehicle production growth of China dominate the picture at the moment. The automotive crisis of 2008–2009 introduced further structural changes into an already dynamically changing situation.



(Ward's Motor Vehicle Facts and Figures 2009)

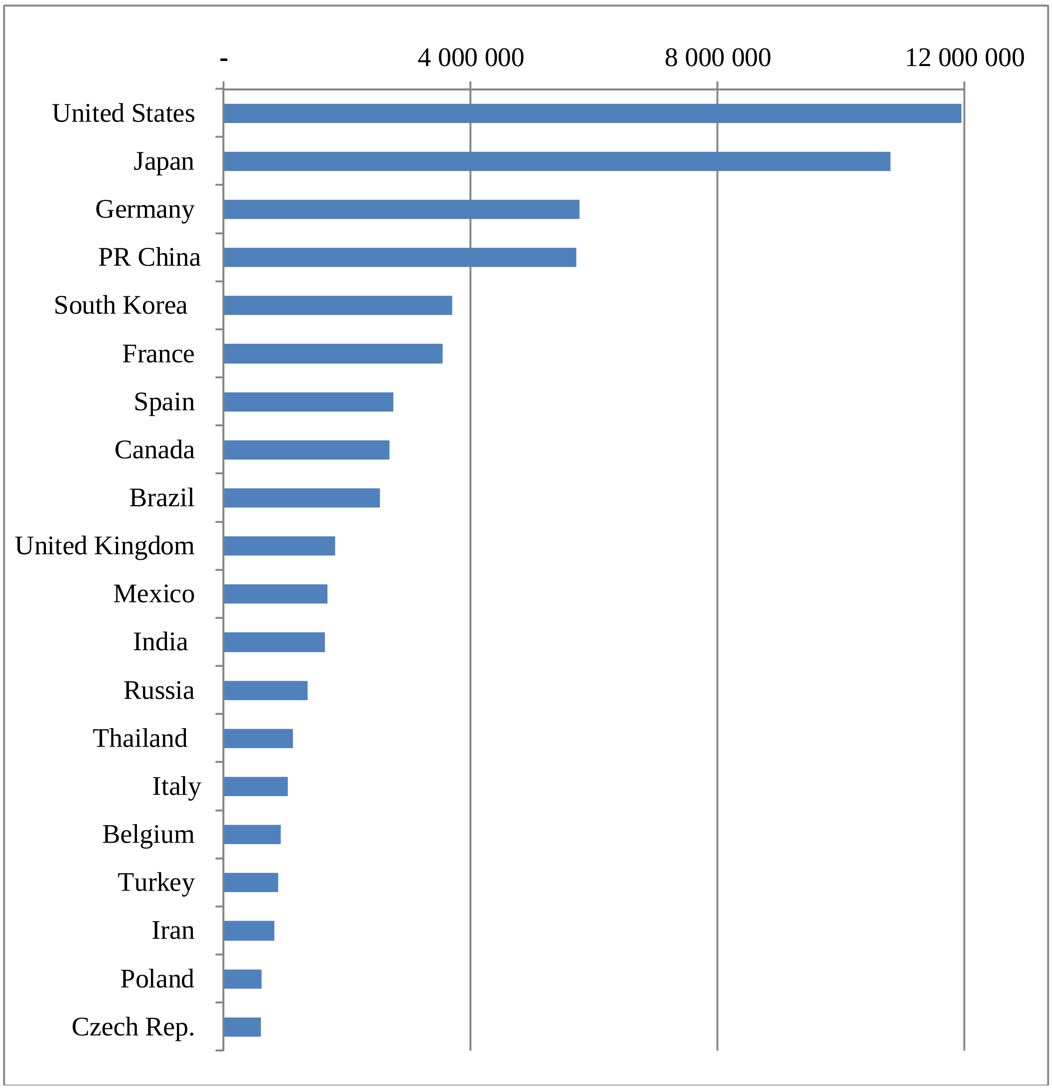
Figure 3. World motor vehicle production, relative shares, 1950–2009.

Table 6. World motor vehicle production, thousands, 1950–2009.

Year	**USA + Canada**	**Western Europe**	**Japan**	**China**	**Other**	**World Total**
1950	840	199	3	0	16	1 058
1955	965	374	7	0	16	1 363
1960	831	684	48	0	87	1 649
1965	1199	958	188	0	83	2 427
1970	944	1 305	529	0	164	2 942
1975	338	1 358	694	0	221	3 311
1980	933	1 550	1 104	14	255	3 857
1985	1358	1 611	1 227	44	250	4 491
1990	1171	1 887	1 349	51	399	4 856
1995	1440	1 705	1 020	143	691	4 998
2000	1573	1 675	1 015	207	1 273	5 743
2005	1464	1 681	1 078	567	1 788	6 577
2009	720	1 230	794	1 365	1 901	6 009
World Vehicle Production (Thousands)						

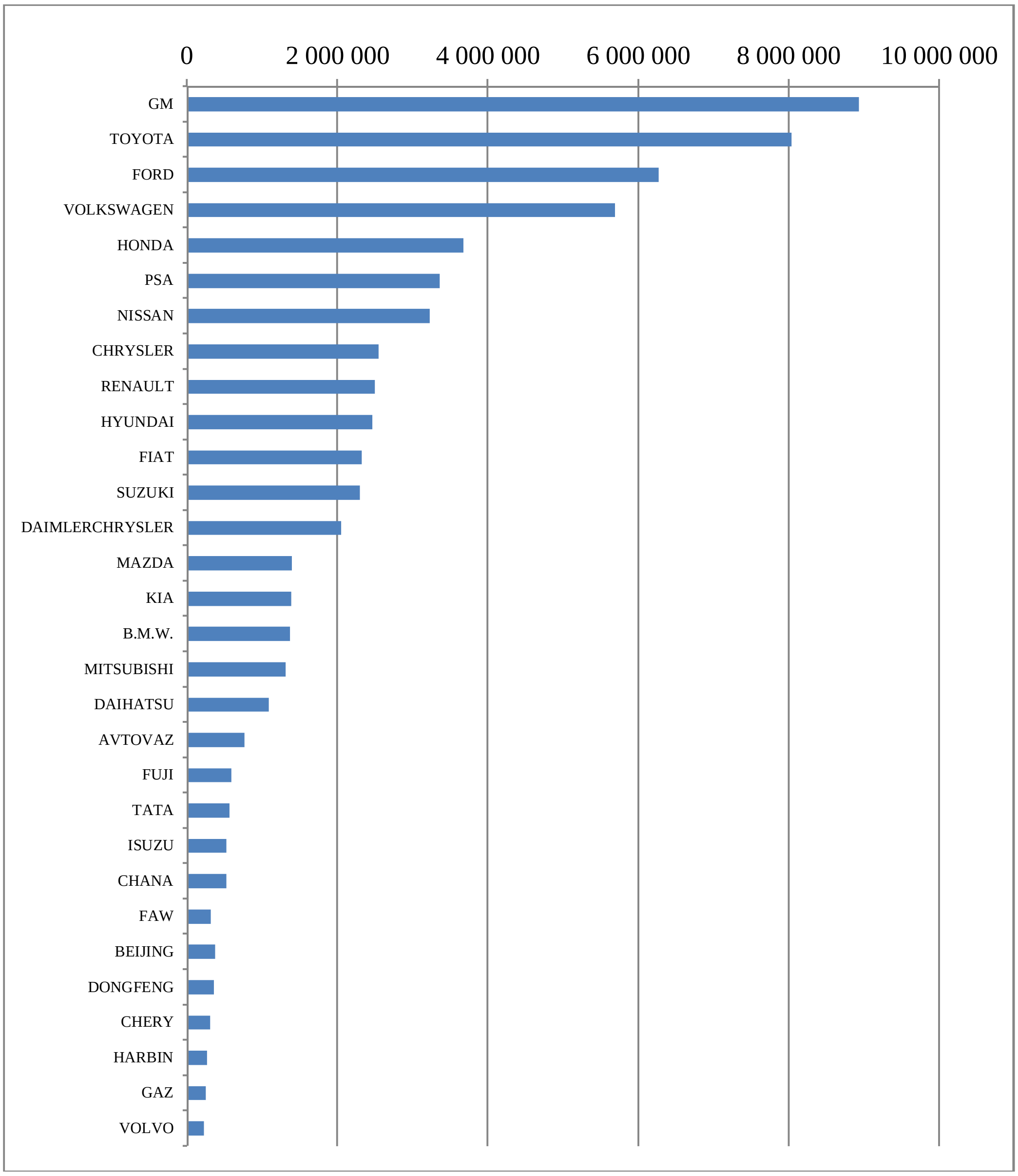
(Ward's Motor Vehicle Facts and Figures 2009)

3.1.2 Situation before the 2008–2009 automotive industry crisis



(OICA 2005)

Figure 4. Motor vehicle production per country, 2005–2006 (units).



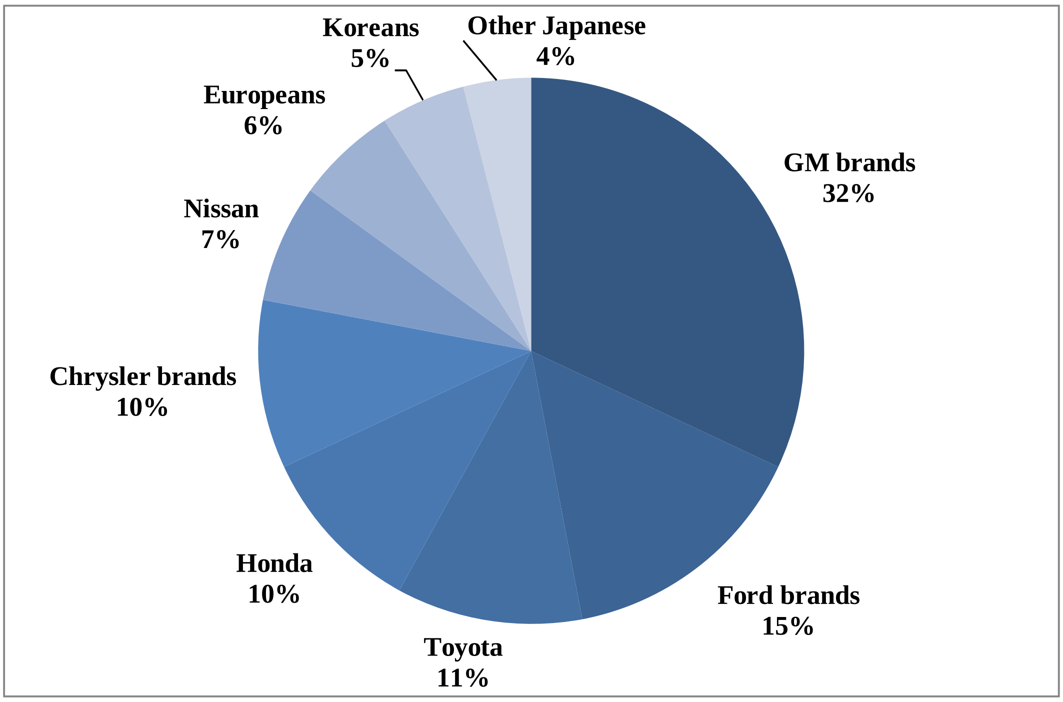
(OICA 2005)

Figure 5. Passenger vehicle production per company/group, 2006 (units).

As we can see, in 2005, the biggest single motor vehicle producer is still the United States with almost 12 million vehicles produced annually. Japan is close with almost 11 million. However, at this point in time Europe is the largest production region, with manufacturing in Germany, France, the UK, Spain, Italy, Poland, Sweden, Slovakia, Portugal, the Czech Republic, etc. The People's Republic of China is the fourth largest producer, but with a double-digit growth rate, something which will soon bring it to the top. India, Brazil and Mexico are nowhere near China in automotive significance.

At this point in time, GM is still the largest of automotive producer in the world with almost 9,000,000 passenger vehicles produced. Toyota, on second place, will finally win over GM in 2008 and become the new number one. The big established Western car companies are still unrivaled champions, with India's Tata coming in only on 21st place, and China's Chana on 23rd. However, over 15 of the 50 top companies are Chinese – this reflects the strong growth potential Chinese automakers.

USA



(Maxton & Wormald 2004:122

Figure 6. North American volume car market, market shares 2002.

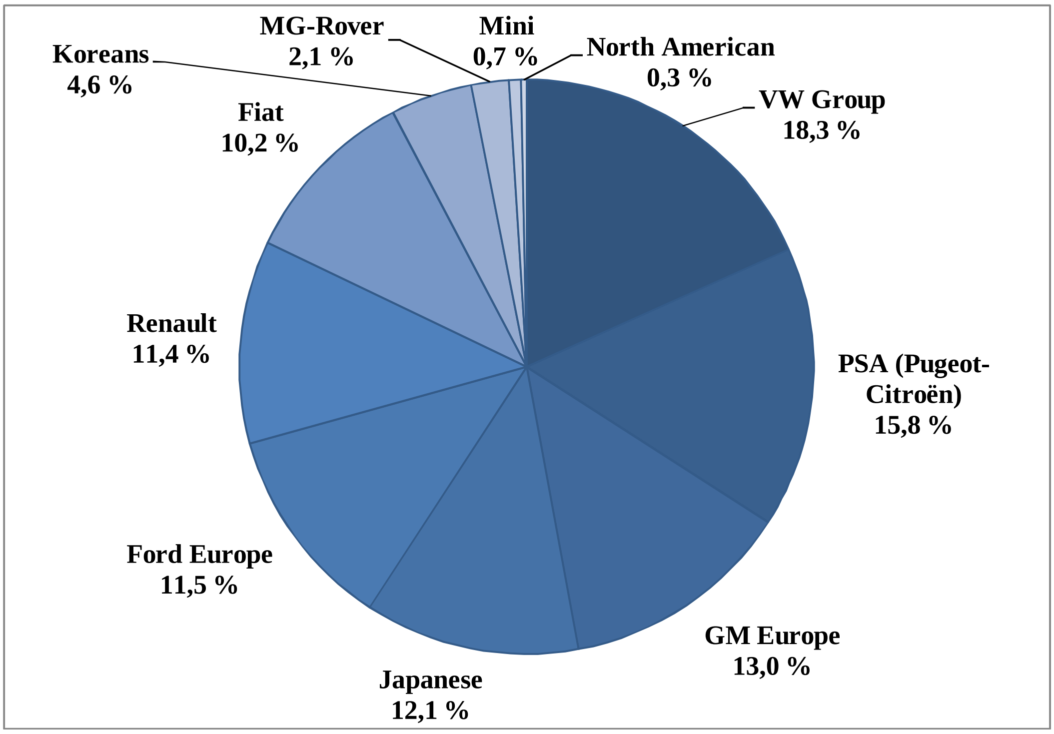
In Figure 6, we can see a breakdown of the North American volume car market – volume car in this case means common passenger car models (mostly sedans, but also hatchbacks, wagons, etc.). The brands of the American Big Three cover almost 60% of the market, but we can also see that Asian brands have established a significant level of presence. The European automakers are not strongly present in the volume car segment (mostly Volkswagen models) but would show a much stronger performance if we were to look specifically at the high end car segments (sports cars and luxury vehicles).

The US automotive industry is not a significant source of exports – mainly because of its large local industrial presence in other countries. GM and Ford have an extensive plant production in Europe, but work mainly by joint ventures in Asia. At 2005, the American automobile manufacturing industry represented about 5% of the US GDP (BERA 2005).

The American Big Three have had a long standing history of strong sedan brands, but despite this many sedan models were discontinued or dropped in status to fleet sales in the decade leading up to 2005(Autoblog 2006). The focus of GM, Ford and Chrysler (DaimlerChrysler 1998–2007) shifted away from the volume model (midsize and compact cars) to focus on light trucks and especially Sports Utility Vehicles (SUVs).

In the late 1990s, when SUV sales were at their highest, more than half of the Big Three's profits came from light trucks and SUVs. Their volume car models on the other hand, would often not break even, cost-wise. The compact cars were kept on only to bring customers to the brand, and later keep customers that climbed the income ladder tied in with the brand. According to the estimates of automotive industry researchers, the big three North American automaker needed to sell ten compact cars to make the same profit as one big vehicle. (CarAndDriver 2008). However, the sales of SUVs peaked in 1999 and have not returned to that level ever since (Maxton & Wormald 2004:15). The rising oil prices from 2003 forward led to a strangulation of the market in fuel hungry light trucks and SUVs.

Europe



(Maxton & Wormald 2004:123)

Figure 7. European volume car market, market shares 2002.

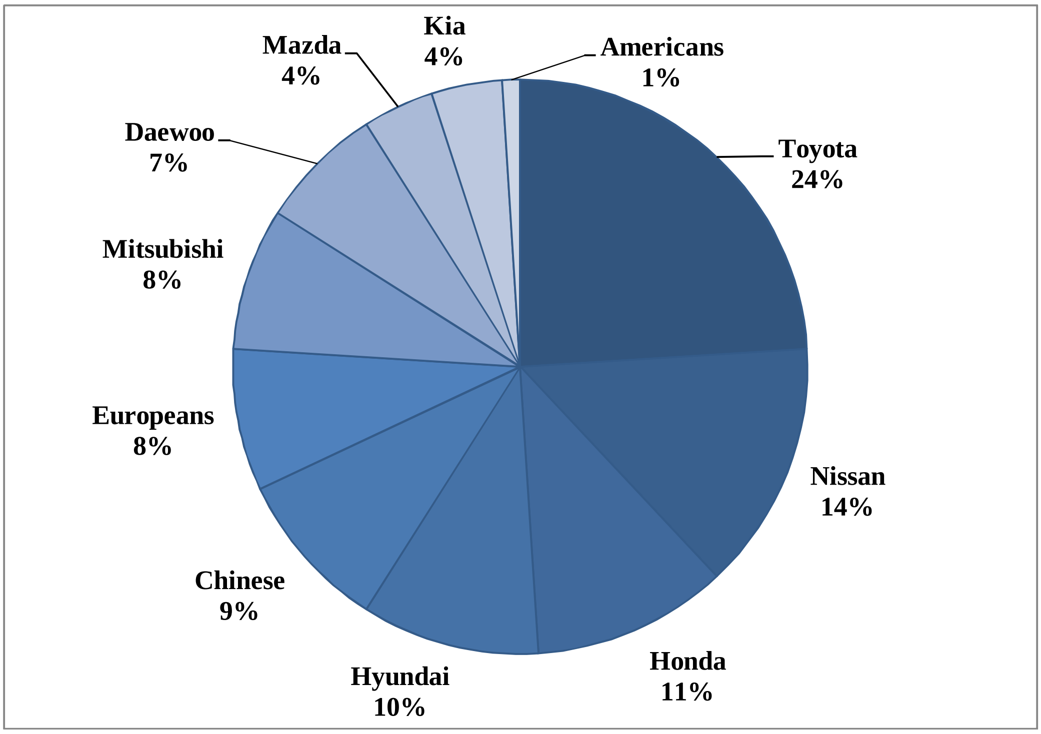
In Figure 7 (Maxton & Wormald 2004:123), we see the division of the European volume car market. Also this region is dominated by "local" brands: almost 60% of the volume car market is covered by European car companies. The dominance is divided among more companies, though. The 0,3% North American segment stands for imports from America – quite unusual since both Ford and GM have a strong transplant factory presence in Europe. Chrysler on the other hand has not managed to make a significant instep in the European market. Similarly, the Asian brands have not reached a very strong presence in Europe – the European Union's common (strict) external import rules have hindered the inflow of imported cars somewhat.

Before the automotive crisis of 2008–2009, the EU was still the world’s largest automotive manufacturing region, and the world’s largest automotive consumption market. The European automotive industry stands for nearly 9% of the EU manufacturing sector. The largest producer is Germany, with about 30% of the EU’s total production. France comes second with 19%, followed by Spain (17%), and the UK (10%).

According to the US International trade commission (2002:51), the large interest in light trucks seen in the US is not present in Europe – light trucks represented just 11% of new vehicle registrations in Europe 2001, as opposed to over 50% in North America. The reasons include higher fuel prices, population density, constricted urban areas and narrower streets. High fuel prices meant a boost to the fuel-efficient diesel technology – in 2001 43% of newly registered vehicles were diesel powered.

According to the US International trade commission (2002:53), the decade leading up to 2002 included a significant restructuring and consolidation of automakers in Europe (but also globally). The merger of Daimler-Benz and Chrysler (1998–2007), GM's acquisition of Saab, Ford's acquisition of Jaguar, Land Rover and Volvo's passenger car division and Volkswagen's acquisition of SEAT, Skoda, Bentley and Lamborghini – these are just a few examples of the lively acquisitions race. This development was facilitated by the European Commission's decision to open up the internal EU car market, making it easier to buy cars from other EU countries, to established dealerships anywhere in the EU and to broaden options for vehicle repair.

Asia



(Maxton & Wormald 2004:124)

Figure 8. Asian volume car market, marketshares 2002.

The Asian volume car market is unique in its level of domestic dominance – over 90% Asian brands (Maxton & Wormald 2004: 124). European cars account for only 8% and North American exports for as little as 1%. Admittedly, the situation looks more moderate if you consider stock interests – Ford has controlling interest in Mazda, GM has equity in Subaru and Suzuki, Renault has a controlling interest in Nissan, etc. Be this how it may, the Asian countries have managed to avoid both direct imports and transplants to a surprising degree.

Japan

According to the US International trade commission (2002:58) the Japanese have a longer history of automotive production than South Korea and China, but the Japanese national car market has of course long since matured. The automotive industry is extremely important to Japan – the combined motor vehicle industries account for over 13% of the countries manufacturing output and 10% of country's jobs. In 2001, Japan exported up to 44% of the vehicles produced (about 8 million passenger cars). The United States is the most important export market, receiving about 35% of this outflow. Their success is based on quality: US market quality studies put Japanese brands in the lead of 12 out of 14 categories of passenger cars and light trucks.

On the other hand, imports only account for 5% of vehicle sales in Japan, with German cars making up the majority of these imports (BERA 2005). According to the US International trade commission (2002:57), Japanese consumers purchase new, domestic vehicles instead of imports or used cars, something which creates a large supply of secondhand vehicles. Japanese used cars are popular throughout Asia.

The Asian financial crisis during the late 1990's dampened the demand and production of cars in Asia. According to BERA (2005) the problematic domestic market were beginning to lead to problems for some of the Japanese automakers, and before the 2008-2009 crisis their American and European competitors were allowed equity ownership in some Japanese companies in return for financial infusions, etc.

South Korea

Several of the Korean passenger car producers were also shaken by the Asian financial crisis towards the end of the 90s (US International trade commission 2002:60). A wave of consolidation begun – Hyundai acquired Kia in 1999, Daewoo took a controlling interest in Ssangyong in 1998, a few years before GM bought a large interest in Daewoo itself (42% in 2002). Samsung Automotive was acquired by Renault in 2000.

According to BERA (2005) South Korea exports more than a third of its vehicle production. This is probably an effect of the country's long-standing conscious efforts to become a net car exporter: foreign auto imports were prohibited up until 1987, and Japanese imports were not admitted until 1999. South Korea's greatest export market is the US (more than 30% of South Korean exports go there). Much in the same way as in Japan imports are negligible, accounting for about 0.7% of the passenger car market.

China

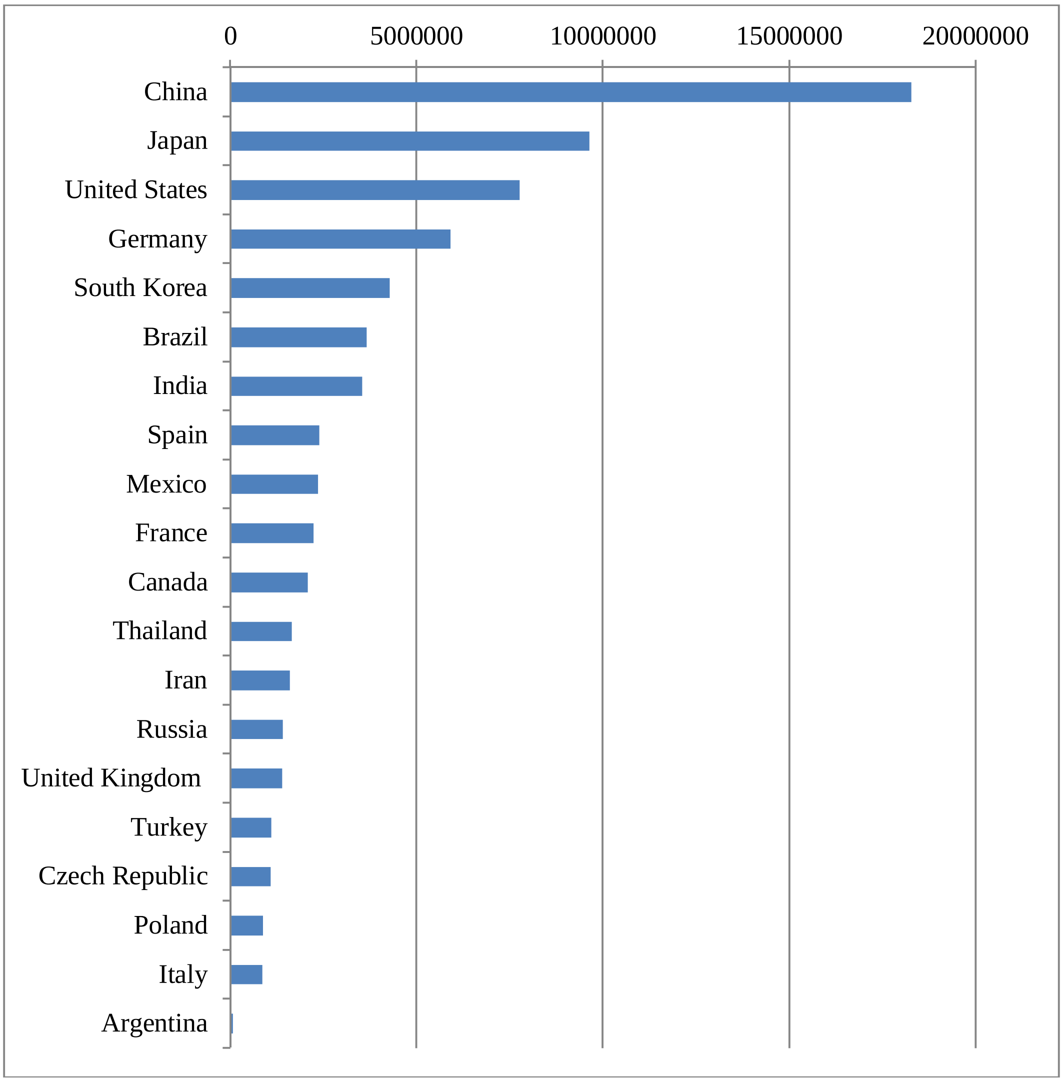
Already before the crisis, the Chinese auto makers were growing rapidly, and it was envisioned that the Chinese would soon surpass the Japanese as the as the main automobile producing country of the region. (BERA 2005.) In absolute terms, the number of produced cars in China grew larger than that of Japan in 2009 (OICA 2009).

The automobile industry in China is composed of over a 120 vehicle manufacturers, and the industry employs about 2 million people (an impressive number in absolute terms, but only about 0,3% of the entire work force). However, the official government policy is set to encourage the growth of the domestic automobile manufacturing industry. There are trade barriers in place for foreign competitors, and tariffs on foreign auto imports.

The FAW (First Auto Works of China) group is China's first large-scale auto manufacturer, and early on it tied agreements with for instance Volkswagen to produce their Jetta model and Audi sedans in China. The second and third largest automotive producers of China are Dong Feng Motor Corporation and Shanghai Motor Group, respectively.

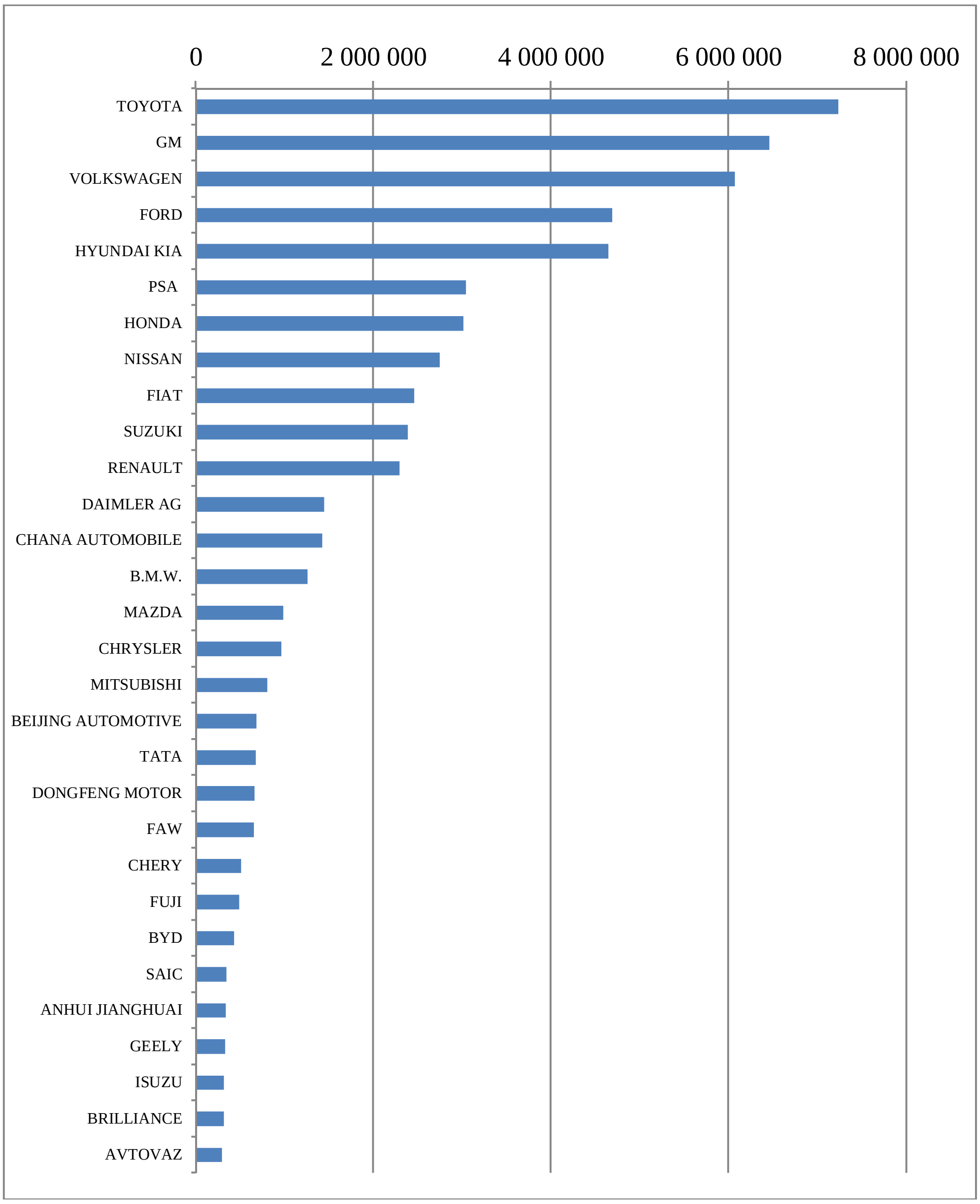
3.1.3 Situation during the 2008–2009 automotive crisis

The 2008–2009 automotive crisis might actually be a misnomer – in fact the automotive industry crisis was only a smaller part of the overall global economic downturn triggered by the 2008 sub-prime mortgage crisis in USA and the consecutive failure of several international banks. Nevertheless, 2008–2009 saw severely reduced profits and production for almost all automotive industry companies across the world and the partial bankruptcy of two of the American Big Three – Chrysler and GM. The consequences were many and far-reaching but the following section will briefly mention the most important happenings during the period.



(OICA 2010)

Figure 9. Motor vehicle production per country, 2005–2010 (units).



(OICA 2010)

Figure 10. Passenger vehicle production per company/group, 2009 (units).

As we can see in Figure 9, big changes in the structure of the world’s automotive production occurred during the few years before, during and after the automotive crisis of 2008–2009. China is now the world's leading automotive producer with 18 million vehicles produced annually – an increase of 220 % between 2006 and 2010. China passed Japan in 2009, Japan having in turn passed USA earlier because of the economic crisis (ChinaAutoWeb 2011). Asia is now the largest automotive producing region in the world.

The automotive industries of the industrialized countries – but especially that of the United States – fared badly during the automotive crisis. The United States' production fell 35% between 2006 and 2010, France's with 37% and Japan's with almost 11%. Germany's production on the other hand stayed relatively static during the crisis and even grew a bit. Similarly South Korea managed to defend its position and even grow with 15%. India is a large winner of the great restructuring with a 116% growth between 2006 and 2010.

There is a lot to be said about the ups and downs of the established automakers during 2006–2009 (Figures 5 and 10). The old Western car companies took a major hit. Those worst affected were the American Big Three: GM's production decreased by 28%, Ford's decreased by 25% and Chrysler's – the company affected most of the three – decreased by no less than 62%. Toyota, which rose to surpass GM in 2009, did this mainly by not losing as much: only a 10% decrease in production. Toyota fared better than its other Japanese colleagues though – Honda (–18%), Nissan (–15%), Mazda (–29%) and Mitsubishi (–39%) all fell even farther. Volkswagen (+7%) and Fiat (+6%) did mildly well, and the other European automakers did not fall drastically. The only real winner of the old top-ten crowd turned out to be Hyundai-Kia, with an increase of 21% (adding Hyundai's and Kia's results from 2006).

As we can also see, even that positive result is dwarfed by those achieved by the Chinese car companies. The biggest Chinese automaker Chana (Chang'an Automobile Co. Ltd.) is now ranked 13th in the world – a staggering increase of 173%. FAW (+104%), Chery (+66%) and SAIC (+95%) all do very well, but all these pale next to the success of BYD (Build Your Dream) with a 611% growth in production over four years.

USA

Bankruptcy and bailout

In September of 2008 the first signs of impending trouble showed, with the American Big Three asking for a 50 billion dollar loan (about 35,7 billion euro) from the government to help support the car companies. Nominally the loans would help companies develop greener, more fuel-efficient models in response to continuous escalation of gas prices, but other issues such as the health care expenses carried by the companies were also included in the plea. The United States Congress approved a 25 billion dollar loan (about 17,9 billion euro). (Minyanville 2008).

However, in December of 2008 the car companies asked for additional loans, bringing the total up to 34 billion dollars (24,3 billion euro). Chrysler and GM needed immediate funds just to keep running – as a compensation the companies submitted new revised plans for cost reductions (lowering the executive's pay, reducing the number of brands, refinancing company debt, etc.). Ford had earlier secured some credit in the private market and was not under direct threat of default. (PBS Newshour).

The government under President George W. Bush approved the bailout plan, which would give 17.4 billion dollars (about 12,4 billion euro) worth of loans to stave off the default of the two companies – 13,4 billion dollars immediately (GM 9.4 billion dollars and Chrysler 4 billion dollars) and 4 billion dollars in February of 2009. This mainly because of the importance of the automotive industry to the economy of the USA. (New York Times 2008b).

In February of 2009, General Motors and Chrysler declared that they would need even bigger loans still to avoid default in the future: a total of 21,6 billion dollars (about 15,4 billion euro), GM 16.6 billion dollars and Chrysler 5 billion dollars. In return GM would downsize 47000 jobs, close five plants, discontinue 12 car models and try to sell Swedish Saab. Chrysler would downsize 3000 jobs and discontinue three car models. (BBC News 2009i). The companies did not receive that amount but smaller sums were made available during April and May (Fox News 2009).

In April and June of 2009, Chrysler and GM respectively filed for Chapter 11 bankruptcy (BBC News 2009d; BBC News 2009b). Chapter 11 bankruptcy is also known as restructuring, when a corporation is allowed to renegotiate contracts, sell assets or daughter businesses, negotiate debts, etc. to see whether the corporation can survive in a reduced form.

At the point of bankruptcy General Motors was almost a wholly publically owned company, with the American government owning 60% and the Canadian government 12.5%, with the remainder being owned mainly by employees (BBC News 2009d). A large share of Chrysler was sold to Italian Fiat (PRNewswire 2009) and in June of 2011 Fiat bought an even larger stake in Chrysler bringing its ownership up to 52%. This made Chrysler a wholly owned subsidiary of Fiat (Bloomberg 2011). Both GM and Chrysler discontinued several brands and terminated agreements with many dealerships as a part of the bankruptcy agreements. Ford Motor Company was able to survive without entering bankruptcy partly due to a large line of credit obtained in 2007.

Background and reasons for the crisis

Several factors are said to have contributed to the automotive crisis situation of 2008–2009. First of all, the American Big Three were negatively affected by the continuously rising oil prices in the period leading up to 2008 (MSNBC 2008). The American focus on fuel hungry SUVs and pickup trucks, made them especially sensitive to changes in oil prices and the subsequent customer refocus on more energy-efficient cars. Secondly, car sales in the USA were commonly financed as a part of the home purchase loan, and when the American mortgage crisis struck, the availability of such credit declined drastically leading to falling sales on the American home market (SeattlePI 2007). These two factors were probably the most significant and immediate.

Thirdly, North American automakers were dealing with higher total costs of labor than the foreign transplants (foreign car companies that have built plants in the United States) because of the long-standing benefits, healthcare, and pensions packages negotiated with the United Auto Workers union (CSNNews 2008; National Post 2009). The transplants, having started production more recently in America, retain a younger workforce and have avoided many of these issues by default. The estimated labor cost differences range from 10–30 dollars per hour (LA Times 2008; New York Times 2008; Mclean's 2008), or about 350–500 dollars per vehicle (CBC News 2009).

Finally, the Big Three upkeep a wider selection of brands and a larger dealership network than its competitors. More brands mean a greater chance to capture the customer's fancy, but also entail higher costs in marketing and product development and can lead to a situation where the company's brands cannibalize each other's customer base. According to Deutsche Bank in 2008, reducing GM's brands from eight to three would save 5 billion dollars annually (about 3,6 billion euro) (New York Times 2008). As part of its bankruptcy, GM was left with only four brands: Chevrolet, Cadillac, GMC and Buick (New York Times 2009).

Argumentation for and against the bailouts

The automotive industry is normally a very important industry to a country's employment and GDP. According to the Center for Automotive Research (CAR) (2008), allowing the American Big Three to fail completely would mean a loss of up to 240 000 jobs at the car companies themselves, and a further 980 000 jobs from the automotive suppliers and dealers, plus as much as 1,7 million additional jobs closely impacted by the loss of the original 1,2 million. In terms of personal income, this would mean a loss of 398 billion dollars (about 284,3 billion euro) over three years. The ensuing loss of tax revenue and increase in welfare spending would amount to a total of 156 billion dollars (about 111,4 billion euro) over three years.

According to other opinions, foreign car companies such as Honda and Toyota could have stepped in to compensate for the loss by opening up new plants if the competitive climate changed, dampening the negative effects to employment. The government's bailout plans could be seen as an attempt to throw good money after bad – the opinion that the effects of poor management decisions (unpopular models, bad investments decisions, failure to compete efficiently, etc.) should not be corrected by government spending (CNBC.com 2008). As of early June 2009, the governments under presidents Bush and Obama had invested close to 80 billion dollars (about 57,1 billion euro) in support GM and Chrysler (Fox News 2009)

Asia

Japan

Toyota was affected negatively by the economic and automotive crisis of 2008–2009, with sales in North America and Europe falling by 34% compared to previous years (CTV News 2008) and experiencing its first annual losses since 1938. The net profit 2008 was negative 1,7 billion dollars (about 1,2 billion euro), as compared to a profit of positive 28 billion dollars (about 20 billion euro) in 2007. The loss resulted from falling sales in mainly the North American market, but also in Toyota’s promising ‘future’ markets, India and China. (New York Times 2008c).

In the American markets, the sales of big pickup trucks and S.U.V.’s fell strongly, and Toyota’s large investments in such production became difficult to carry during the economic downturn. Toyota responded by cutting production in its American truck plants. To further worsen the situation, the growing demand on more fuel efficient cars could not be met in the short run. Toyota was not able to produce enough of the Prius, Corolla and Yaris models fast enough to compensate their loss. (New York Times 2008a).

During 2009 and 2010, Toyota was further struck by another problem – the discovery that their vehicles could experience unintended acceleration. In some cases this was due to floor mats trapping the accelerator pedal and in other cases due to a mechanical sticking of the accelerator pedal. (Toyota USA Newsroom 2011). Toyota eventually issued a recall of 5.2 million vehicles over the floor mat problem, and 2.3 million vehicles over accelerator pedal problem. The problems occurred on many of Toyota's models, including the Corolla, Matrix, Camry, Avalon and several other. (BBC 2010).

Honda too experienced a drop in sales of 31,6 percent between 2007 and 2008 – from 8.1 billion dollars (about 5,8 billion euro) to 2.5 billion dollars (about 1,8 billion euro) (CBC News 2008). Nissan reduced their vehicle production by almost 80 000 vehicles, and temporarily laid off workers (ABC News). Suzuki cut production by about 30 000 vehicles (Bloomberg 2008c).

South Korea

The South Korean car manufacturer Hyundai-Kia was able to withstand the crisis relatively well. Their line-up of small and energy-efficient cars, such as the Kia Picanto, Cee’d and i30 sold well, even in the worsening American market. Furthermore, the Korean currency (the Won) stood low against the dollar and yen, further improving the export possibilities of Hyundai. (Bloomberg 2008a) During 2008, Hyndai managed to bypass Honda as the world’s fifth largest car producer (Autoblog.com 2008), and in 2009 it passed Ford Motor as the world's fourth largest car producer (sgCarMart.com 2009).

But the South Korean car companies could not entirely avoid certain negative effects of the global recession. Because of lower market demand, Hyundai Motor Company started reducing production at its plants in the U.S., China, India, Turkey and Slovakia from 2008 forward. Hyundai-Kia furthermore announced a freeze of wages for office workers and reduced factory operations to an average of four hours per day. (Bloomberg 2008a). SsangYong Motor, (owned by Chinese SAIC – Shanghai Automotive Industry Corporation) was hit strongly because of its heavy focus on SUVs (sales down by 63 percent). In 2008, SAIC fought the SsangYong workers' union into accepting its restructuring plan, threatening to withdraw the parent company's support (Korea Times 2008).

The South Korean Ministry of Knowledge Economy stated clearly that there would be no bailout programs from the government's side for South Korea's five automakers – Hyundai, Kia, Ssangyong, Samsung Renault and GM Daewoo (Korea Times 2008).

China

The effects of the global economic crisis on the automotive industry of China were noticeable, but nevertheless of little consequence – China's was one of the best performing automotive industries during the crisis.

In 2008, the Chinese market experienced a slow-down of the rate of growth of car sales to a single-digit number, for the first time in ten years. This lead to the Chinese central government implementing steps to stimulate the industry. One significant stimulus policy halved the vehicle purchase tax on cars with engines below 1,6 liters, targeting the companies that provide lower-price cars for large consumer groups (i.e. Chery and Geely), and led to companies focusing on larger models (e.g. Great Wall, China's largest independent producer of SUVs) diversifying into the smaller car segment. (Reuters 2009).

China's exports were probably affected most strongly – the majority of cars manufactured in China are sold within China, with only about 370 000 cars being exported in 2009 – this out of a production of 13,8 million vehicles (China Daily 2010; ChinaAutoWeb 2011) However, the 370 000 cars sold represented a drop of 46% compared with 2008 (China Daily 2010).

China took the opportunity to look for interesting investment opportunities when the prices of overseas automotive companies and suppliers trended downwards. Geely, China's biggest private automaker put in the winning bid for Swedish car company Volvo when it was sold off by Ford (BBC News 2010d). Furthermore Geely also bought certain parts of the bankrupt Australian gearbox maker Drivetrain Systems International – known as the world's second largest producer of automatic gearboxes (MoneyMorning 2009).

Similarly, Chinese BAIC (Beijing Automotive Industry Holding Co Ltd) joined Koenigsegg Group in a bid on GM's Saab division (MoneyMorning 2009). Sichuan Tengzhong Heavy Industrial Machinery Company Ltd. made a bid for GM's Hummer brand (New York Times 2009). Even though both of these deals later fell through, this marked a significant change in the dynamic between China and the Western automotive manufacturers.

India

The State Bank of India chose to lower interest rates on loans for new cars, in an effort to stimulate the consumption level in general and the important auto industry in particular (ET Bureau 2009). Indian car manufacturer Tata launched its ultra-cheap car Nano (100 000 rupees, 2000 dollars) to great interest of the public (not only in India) in the economically troubled times. The launch in 2009 (APF 2009), served to stave off Tata from the worst effects of the global crisis, giving them the possibility to return to positive profits during 2010 (Reuters 2010).

Europe

In Europe, the economic crisis had a strong negative impact on car sales, and the car industry was deemed in need of bailout, much in the same way as in North America. However, while there was an initial move to form a common EU bailout package, this was not realized; the individual car producing countries decided on their own plans to support their car industries.

Germany

Germany, the EU's largest car producer felt several negative effects of the automotive crisis. Daimler announced it would cut 3500 jobs at their North American plants and halt production at its largest German plant. BMW closed a plant in Germany, and Opel two. Volkswagen AG applied for loan guarantees through the German government's bank bailout program. (Speigel Online 2008).

In response to USA's bailout package to its own industry, the German Association of the Automobile Industry pleaded for state aid to the German auto manufacturers, citing competitive edge as the main reason. They also debated for a joint European Union package of 20–40 billion euro in low-interest loans to European auto manufacturers, especially earmarked for the development of environmentally friendly vehicles. (Speigel Online 2008).

However, the German government refused to issue a bailout plan for the German car companies just because of international pressure (The Telgraph 2008). However, The German government did set up an old-cars-scrapped program valued at 1,5 billion euro (about 2,1 billion dollars) where owners of 9-year-old or older vehicles who scrapped their cars would receive 2500 euro (about 3500 USD) when buying a new one. The target of 60 000 participants in the program was met already during 2009. (People's Daily online 2009).

France

France budgeted 7,8 billion euro to invest in the national car industry, setting a condition that any automaker receiving support must strive first and foremost to keep their production plants in France running (People's Daily online 2009). Peugeot Citroën received such a loan for 3,9 billion euro in February of 2009, and also announced cutting 2700 jobs worldwide in 2008 and 11 000 jobs during 2009. However, because of the conditions of the bailout loan, the production personnel in France was largely unaffected by these cutbacks.

Renault experienced a 78% fall in profits during 2008, but nevertheless managed to get a (barely) positive net result for the year (BBC News 2009h).

Italy

Italy’s Fiat felt the economic effects of the economic crisis through falling profits and sales (25% fall in sales of Fiat, Lancia and Alfa Romeo cars in 2008) (BBC News 2009c), but nevertheless announced in January of 2009 that it would be buying 35% of Chrysler. The deal was a sort of swap: in exchange for the 35% equity stake and access to Chrysler’s dealership network, Chrysler would gain the use of Fiat’s environmental and fuel efficiency technology.

Chrysler simultaneously received a 4 billion dollar emergency loan from the US government, and committed to producing nine Fiat-derived cars over a four year period – four of these models hybrids or electric vehicles. (Edmunds.com 2009) Fiat made this move because they have had a hard time creating substantial sales in the US, while Chrysler similarly has never had a strong presence in Europe. (BBC News 2009b).

The United Kingdom

The UK budgeted 3,8 billion dollars (about 2,7 billion euro) to industry support: half for straight guarantee loans to the auto industry, half for investment in the production of greener cars (People's Daily online 2009). One of the biggest hits to the British auto industry in terms of employments was Nissan UK's announcement that they would cut down 1200 jobs (out of 4900) at their factory in North East England as of 2009 (BBC News 2009e).

British Jaguar Land Rover, bought by Indian Tata Motors in early 2008 from the Ford Motor Corporation, negotiated with the British government for loans to keep Jaguar Land Rover running, but due to the hard conditions set for such loans, Tata chose to seek private sector loans instead (289 million dollars or about 206 million euro) (autoblog.com 2009). However, Jaguar Land Rover received a 550 billion dollar loan from the European Investment Bank in 2010 to develop more energy efficient car bodies and hybrid drive trains (EIB 2010). Tata managed to turn profit on both companies for the last part of 2009 (BBC News 2010b).

Sweden

In Sweden, the Swedish government supported Volvo and Saab with credit guarantees and rescue loans amounting to 3,5 billion dollars (about 2,5 billion euro) in 2008 (BBC News 2008). However, the since GM and Ford (the owners of Saab and Volvo respectively) were facing economical difficulties of their own, the two Swedish companies were put up for sale in 2010. Volvo was sold to Chinese Geely Automobile for a price of 1,8 billion dollars (about 1,3 billion euros) (BBC

News 2010d). Saab was bought by Dutch producer of luxury sports cars, Spyker, for 74 million dollars (about 53 million euro), and an additional 400 million euro loan (about 560 million dollars) from the European Investment Bank (BBC News 2010c).

Russia

Russia's automotive industry was hit especially hard by the economic downturn. The passenger car production numbers fell steeply from 1470 000 units in 2008 to 597 000 units in 2009 (Federal statistics agency). The government stepped in with a 5 billion dollar (about 3,58 billion euro) economic support plan: car company bailouts of 2 billion dollar and subsidies to buyers of Russian cars worth 3 billion dollars (Financial Times 2008). The government decided to support Russia's largest car company Autovaz (maker of Lada and Niva brands) with a 600 million dollar loan (about 430 million euro) (BBC News 2009g).

In further measures to strengthen the domestic production of cars, the tariffs on imported cars were increased to a 50% minimum (RIA Novosti 2009) and a governmentally financed old-cars-scrapped program implemented. (RBTH 2010). The increased tariffs lead to protests in some cities, especially Vladivostok (on the eastern sea border of Russia). Vladivostok has a long standing tradition of importing second-hand Japanese cars rather than using the Russian models – the quality difference is seen as substantial (RIA Novosti 2009) However, in general, the stimulus package was effective and Avtovaz' sales doubled in the 2010, returning the company to profit (BBC News 2010a).

Summary

In general, we can see that the status quo of the established car producing countries is being challenged once again – much in the same way that that happened when the European and Japanese firms challenged American's dominance in earlier years. These waves of change left the old leading companies diminished, but they were nevertheless able to sustain themselves on the continuous growth of the automotive markets. However, the automotive markets of the established car producing countries are long since mature. Any further expansion will unavoidably happen by cannibalizing the market shares of other companies. The economic crisis might well prove to be a catalyst to this change – a chance for the Chinese and Indian car companies to start growing beyond their home markets as worsening economic conditions bring consumers towards more low-price products.

3.2 The Automotive Assembly Process Explained

In this section we look at the automotive assembly process, to get a better idea of what impact redesigned products could have on assembly in the automotive industry. Furthermore, we will see more closely what sections of a vehicle are done by robotic assembly and what sections use human workers. Before this we briefly go through the recent history of robotic assembly, especially in the connection with car production. For further reading on the automotive assembly process, together with detailed examples of the assembly of actual components (doors, alternators) see for instance Whitney (2004).

A Short History of Robotic assembly in the automotive industry

The first industrial robot (Unimate) was created in 1954 and in 1961, General Motors purchased and installed its first Unimate-robots for die casting handling and spot welding. (Devol 1961.) In the 1980's, automotive companies invested strongly in robots to improve the profitability of their assembly lines (often in response to the Japanese Lean production methods). General Motors spent 40–45 billion dollars on automatization of their plants during 1980–1985 (Robotworx (2011a).

However, the robots could most often not replace human assembly: the high capital cost and lack of flexibility in the robots' work abilities meant that they were only profitable during extremely large production runs. In general, a production volume of 100 000 – 1000 000 units annually is considered necessary for robotic assembly to be profitable (Hamazawa 1999). Furthermore, the production system must be highly coordinated and flow perfectly (Brogårdh 2007). In 1988, robots at the Hamtrack Michigan plant even went out of control, smashing windows and spraying their vicinity with paint. (Finkelstein 2006).

Because of the early shortcomings the robotics industry only regained its status relatively recently. If used correctly, industrial robots perform their tasks with great consistency, in both accuracy and precision – the product quality improves significantly. They handle toxic substances, lift, carry and select products that are demanding ergonomically. They are also good at repetitive and detail-driven jobs that exhaust a human. (RobotWorx 2011b; Kucera 2011).

The automotive industry uses the robots mainly for welding, painting and assisting human workers with insertions and orientation of heavy components (Brogårdh 2007). Robotic welding is an especially well suited area of usage: there are thousands of spot welds on a car and the welding equipment is heavy. Robots are capable of carrying the equipment and placing it in the correctly with near perfect repeatability. Another area of usage is the paint job, where consistent application is crucial (Endregaard 2002). Painting robots can apply paint along the same patterns and at the same distance on every car in less time than even the most skilled human being. (Lippert 2010).

The Automotive Assembly process

In this section the modern automotive assembly process is presented step-by-step (MadeHow 2011). Figure 11 shows the 14 general steps through which a normal car model passes on its way to completion. The complete car is produced on two separate "branches": the chassis together with heavier components (engine, axes, brakes, suspension, etc.) are assembled separately, and the body is assembled and painted separately.

1. Procurement, logistics.

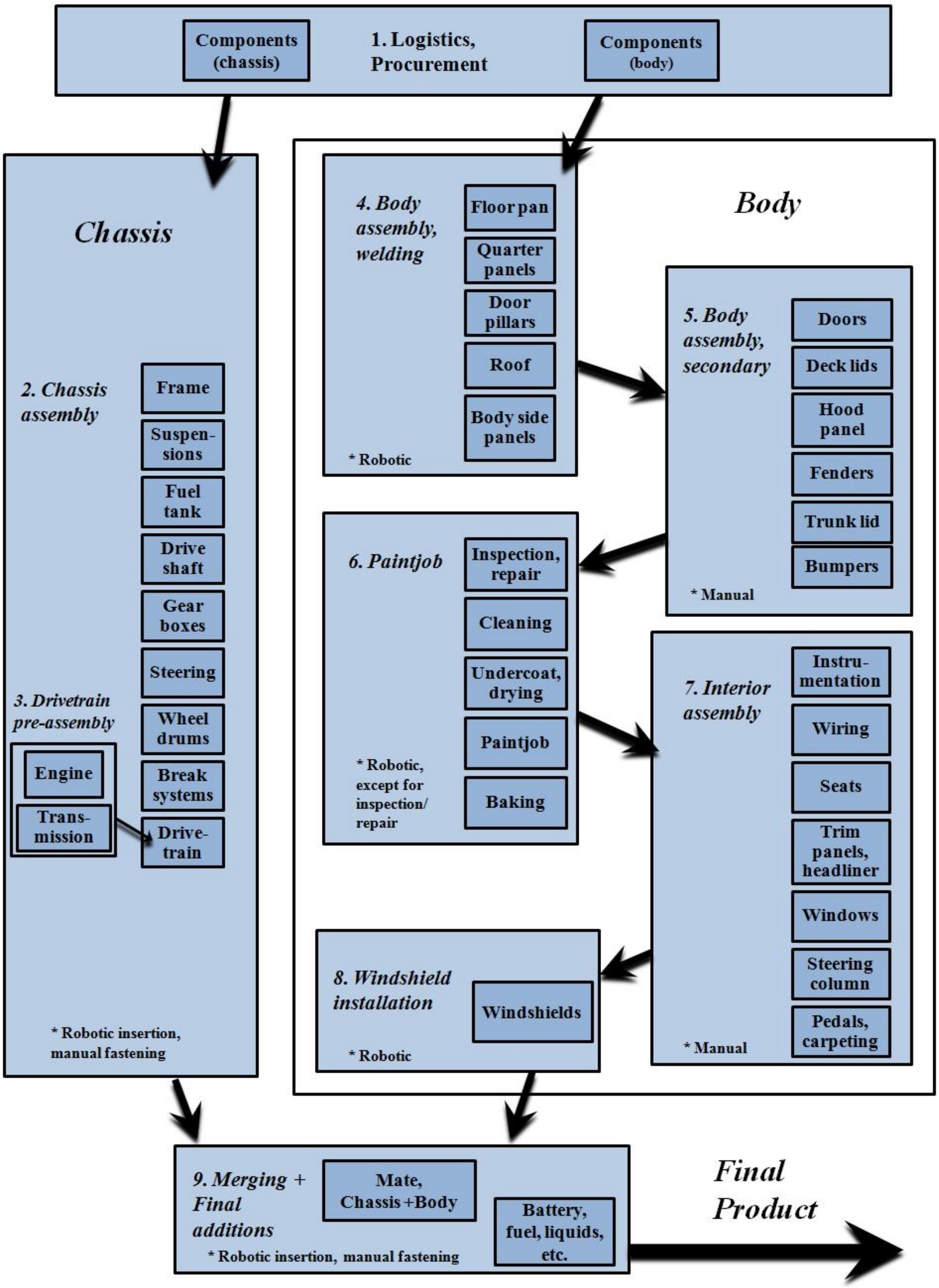
The first step consists of successfully sourcing and receiving the components necessary to produce a car. In the days of Henry Ford, the company strived to own the entire supply chain, from raw material to finished product, but today sourcing and supply chain management is extremely important in building the product (a product that uses more than 4000 outside suppliers). This is also a logistical challenge, since most automakers endeavor to use Just-in-Time manufacturing: the necessary parts should arrive exactly when needed in small batches..

2. Chassis assembly

The second step is the pre-assembly of the chassis. The car frame is clamped to the assembly line's conveyor belt. The car is built from the bottom up as far as possible: the heaviest and most bulky "base" components are installed, and lighter surrounding components are added in order. The frame moves between components assembly areas where suspension, fuel tanks, axles, drive shafts, gear boxes, steering and brakes are installed in sequence.

3. Drivetrain pre-assembly

Before the engine is mounted on the frame it is coupled with its transmission, and then lifted onto the frame by robotic arm. Robotic arms are generally responsible for lifting the heavier components into place, to ensure human ergonomics and safety. The human assemblers bolt the components onto the frame with pneumatic wrenches.



(Madehow 2011)

Figure 11. The automotive assembly process.

4. Body assembly, welding

The construction of the car body starts with the floor pan, the largest part of the body, onto which structures and panels are bolted or welded. The left and right quarter panels are the first major body sections to be attached to the floor pan. After this the front and rear door pillars, the roof and the body side panels are added to the shell in consecutive assembly stations. The shell of the car is generally assembled and welded by robots since they achieve a high degree of accuracy and a high weld speed. Furthermore they are easily able to pick up heavy panels such as the roof and hold them in place while welding at high tolerances.

5. Body assembly, secondary

In the next phase, the body moves from the welding area assembly area and the secondary body assemblies are installed. These include doors, deck lids, hood panel, fenders, trunk lid, and bumper reinforcements – all the components that are included in the so called "body-in-white" or the parts of the body that need to go through the paint shop. The fitting and attaching off these assemblies is mostly done by human labor with pneumatic tools, if yet assisted by robotic arms for insertion.

6. Paintjob

Once the body shell is finished, is taken away for painting. The body is visually inspected in a brightly lit white room. The body is wiped down with a highly reflective oil compound enabling the inspectors to see any defects in the sheet metal clearly. Any dents in the material will stand out compared to the unbroken surface. If any defects in the surface are found, they are repaired at this point. After inspection and repair, the body shell continues to a cleaning station where it is fully immersed in a cleaning compound that removes all the residual oil and dirt.

Once the shell is dry again (having passed a drying booth) it is dipped in a bath of an electrostatically charged undercoat paint or primer. Again the body is dried, and finally the main paint operation can start. The body is spray-painted by robots arms, which move over the body along pre-programmed paths, spraying it with the exact amount of paint for the exact amount of time. (Endregaard 2002.) The result is a smooth and glossy paint surface that is that result of intensive research and programming. Once the paint job is complete the body shell is transferred to a baking oven station where the paint is cured in high temperatures.

7. Interior assembly

After this the now painted body continues to the interior assembly area where workers insert all the interior trim and equipment that the finished car model will contain. This includes instrumentation panels and consoles together with the instruments necessary, wiring systems, dash panels, interior lights, seats, door and trim panels, headliners, radios, speakers, windows, steering column, brake and gas pedals, carpeting, etc. All of these fittings are necessarily done by human labor, since the assembly work is highly varied and complex.

8. Windshield installation

The final step before the body encounters the chassis is the attachment of windshields – robots with suction cups insert the windshields into place after having applied a urethane sealant around the edge of the glass. The body also goes through a water test to ensure that the seals, doors and windows are tight.

9. Merging + Final additions

At this stage the two conveyor belts meet, and the body shell is mated with the chassis. The body shell is lifted onto the car frame by robotic arm and assembly workers above and below the car bolt the body onto the frame. After this car is essentially ready, but it continues down the line to receive liquids, fuel, a battery, etc. Other steps such as final inspection and wheel balancing can be added to the list, but from an assembly point of view to car is now finished.

Assembly intensive work stages

In terms of DFA, all assembly operations (including body assembly, drive train, chassis) could technically be improved to lessen the time demand, but the real improvements would most probably be realized in the interior assembly. These work steps are labor intensive and must be achieved in complicated ergonomic positions (upside down, etc.). The assembly and overhaul sequences are especially similar in this area of the car – very little automatization is possible. In the next section we can see two redesign examples – an instrumentation panel and a seat – that show a great time savings potential in the interior assembly.

However, we must also consider the fact that greatest gains would not necessarily come from making the final assembly process (as seen above) more DFA, but rather by making the modules provided by the suppliers DFA. Final assembly is becoming more and more an issue of connecting modules produce elsewhere, as can we will see in Chapter 4.5. In terms of Figure 11, it is actually the first stage that might be the most important to DFA.

3.3 Why is DFA relevant to the auto industry?

Price competition from lower-wage countries

Relatively soon China and India will be ready to start exporting cars on a large scale. As we saw in Chapter 4.1, China is only exporting a small part of its multimillion unit production. The reason for this is probably twofold – a very large demand inside of China and very mature markets outside that demands a high degree of quality and equipment (see for instance Holweg & Pil 2004). To support the argument that China and India will actually turn to exports, let us look at Clayton Christensen's theories of technology trajectories and disruptive innovation, since these have direct relevance to the issue.

Christensen (1997) found that the established, leading companies specialized in a mature technology tend to over-develop their product over time. In an effort to offer something new, they strive to improve the performance of their product every year, add new features, etc. They do this according to their best sense of business – trying to please their customers and keep them loyal. In other words, they think about adding even more features and performance to better serve their high-end customers – a demanding group, but also a group that is willing to pay a premium to get the best.

Logically, it is best for a company to focus on high-end, because the profits are larger there, and the established companies have the skill set necessary to develop the already existing technology further and further (a process called sustaining innovation). This is not an easy achievement – a lot of time and money will go into this development, ultimately to please the customer.

Unfortunately, the low-end market segment will most probably not get their wishes fulfilled by the same company. An established company may well try to offer more basic products for a lower price, but their focus will not be on that segment. The low-end offers lower profit margins, and we must remember that R&D projects constantly compete for resources within the company. The prospect of developing a really cheap product (with low profit margins) as opposed to developing a high-end product (with high profit margins) makes most managers uncomfortable.

In the end this leaves a segment of consumers unsatisfied. Alternatively there may also be a segment of non-consumers "beneath" the unsatisfied consumers: people who cannot afford even the basic product. The savior of these consumers will most probably be a new company, a company that has a significantly different business model that can make "acceptable" profits even on the low end.

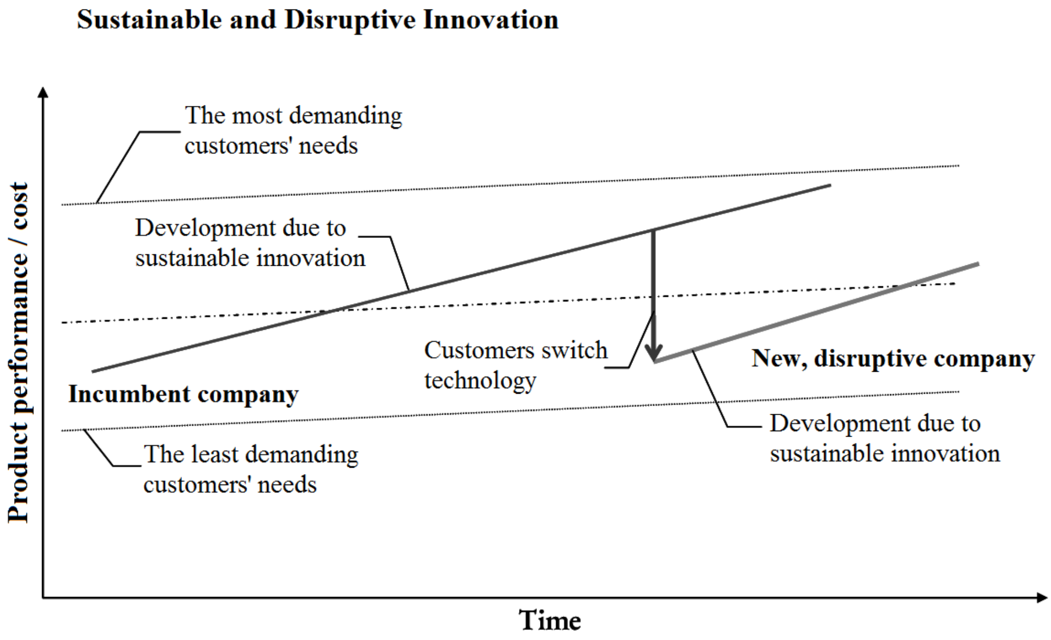
This new company will produce a product that is basic and cheap, but fulfills an unsatisfied need. Their new way of doing business is profitable even at the low-end, their supply chain is also able to function with lower profits, and they have a company culture built around serving a new kind of customer. The old established companies are often quite willing to cede this market, as it is of little interest to them. Better to focus on the higher end, and serve their core customers better. However, in the ceding the low-end segment they may already have started their own defeat.

The new, small and hungry company will eventually look "up-market" and see large profits to be made by only improving their product a little bit. Furthermore, if they do so, their new business model will ensure larger profits for them than for the established companies. The established companies may even voluntarily repeat their former strategy: cede the mid-market and retreat up-market.

This process may well continue, until the new companies are directly competing for the high-end of the market. At which point, the new company will probably be the larger, more successful company, with deeper pockets and a more effective product. Eventually the old, established companies will find themselves out of business.

In Figure 14 we can see concept of disruption explained. The two lines moving upwards at a shallow angle represents the technology performance demand of the high-end and low-end of the customer market. The two lines moving more steeply upwards are the technology performance supplied by the established companies and the "upstarts". Sooner or later, we see the upstarts moving up to the level of technology demanded even by the high-end of the customer market. By that time, they are the new “big” companies and the cycle begins anew, with other upstarts challenging them for dominance, with yet new business models and practices.

This process is called low-end disruption by Christensen, and has happened in numerous industries already. On-line bookstores, discount stores, low-price airlines, there are many examples. There may be established companies that can fight the disruption, but this takes large efforts and a high degree of awareness of customer signals.



(Christensen 1997)

Figure 12. Technology trajectories.

If we want, we can draw parallels between the low-end disruption theories and the situation of the automotive industry today. As we saw in Chapter 3.1, the new car companies in especially in China and India are growing exponentially. They are mainly satisfying the needs of non-consumers – offering cars that are bought by Chinese and Indian customers who could not previously afford cars (previous owners of bicycles, scooters and motorcycles, for instance). But they are also offering a good alternative to unsatisfied consumers of the established companies, who would happily settle for a simpler product if only it were cheaper. The Tata Nano is a brilliant example of this principle. Extremely cheap and basic, but exactly what is needed in urban India.

This principle may well be the reason (coupled with political factors of course) why Chinese car companies are so successful in the Chinese domestic market. The Western companies (the old established companies) have been trying to gain a foothold in China and have succeeded moderately. However, to them, designing extremely cheap cars with low profit margins and with limited functions probably feels unnatural – they would rather focus on the high-end market with large profits, something which could be seen from the SUV craze of the late 1990s. The compact car models were treated quite coolly, as they could not offer the same margins as the SUV and light truck models. The Chinese manufacturers on the other hand are in their own element.

We can see the Western companies trying to emulate this by creating divisions and joint ventures in China. Christensen agrees that this may be a possible solution for the established companies – creating spinoff companies or buying small disruptive competitors. However, these new companies must then be allowed to cannibalize the old companies to a certain degree as they grow, and cannot be too closely regulated by the mother company or old business practices will dominate. Not very many companies can do this successfully.

According to Maxton and Wormald (2004:10), the problem with China as a market for the established car companies, is that the Chinese government has made it perfectly clear that it expects China's demand for cars to supplied in full by Chinese companies. An automotive industry policy document was issued by the State planning committee in 1994 that lays out when, how and how many Chinese firms will dominate what sectors of the Chinese automotive market. It specifically states that the automotive industry will be an independent one, and free from foreign control. A further draft policy document from 2003 states that by 2010 one half of the Chinese car market should be in the hands of 100% Chinese owned firms using their own models and technology. Few foreign car companies seem to have taken these statements seriously.

The importance of assembly labor cost

According to the American automotive industry union UAW (United Auto Workers) labor costs only represent a marginal part of the vehicle's price. The UAW Research Department (2010) calculated a labor cost of 2400 dollars per car, on the basis of hours-per-vehicle data from the 2007 Harbour Report (a widely used analytical benchmark report presented annually by Harbour Consulting) and labor costs as reported in the companies' financial statements. This price includes direct, indirect and salaried labor for engines, stamping and assembly at the automakers' plants. The 2400 dollars represent only 8.4 percent of the typical 28000 dollar price of a new vehicle in 2006.

According to the Macleans (2008) it takes on average 30 hours to produce a Chrysler automobile. Using this piece of information together with another – GM's projected average labour costs for 2008 is 69 dollars per hour – and assuming that the American Big Three have a relatively similar wage structure, we can calculate that it takes 2070 dollars worth of labor to produce an average vehicle. This is not far away from the estimates produced by the UAW.

However, these calculations are a truth with modification – they are looking only at the cost of final assembly. We must not forget that the cars are a part of a supply-chain. According to Maxton & Wormald (2004:144) over 75% of the vehicles total value was bought from suppliers in 1995. Looking at the entire supply-chain, there are significant savings to be had – if the assembly cost of every module could be halved, the total cost of a car would certainly fall.

The precise cost structure of a car and its components is naturally a closely guarded company secret – the data is not available freely. However, there has been some research into the issue; Monteiro (2001) presented a study in 2001 that compares the production cost structures of three Portuguese automotive industry suppliers, providing stamped steel parts for the automotive industry. The figures are presented in Table 7. They show a higher significance of labor costs – about 19% of the production costs are related to labor. This is understandable, considering that a larger amount of value is added to the final product by the suppliers than the automobile producing company (Wormald & Maxton 2004).

Table 7. Production cost structures of three Portuguese automotive industry suppliers.

Material Cost	50 %
Main Machine Cost	12 %
Overhead Labor Cost	10 %
Labor Cost	9 %
Tooling Cost	7 %
Energy Cost	6 %
Maintenance Cost	5 %
Buildning Cost	1 %

(Monteiro 2001)

Of course, 10–20% of the cars' and components' total cost may not sound very much. However, Boothroyd et al. (2002) stress that cost savings come not only from reduction of assembly labor, but from the elimination of unnecessary components, the usage of fewer materials and a simpler product structure in which less material is used. And as we can see in Table 7, material costs make up 50% of the production costs. With a significant reduction of both assembly time and material costs, tangible cost-benefits should be realized by a successful DFA redesign.

A large untapped cost-reduction potential

In the following, we will see two DFA case studies that seem very relevant to the automotive industry.

1. *Instrumentation panel case study*

Boothroyd Dewhurst Inc. (1999a) presents the redesign of an instrument panel from a current truck model, using the DFMA method – a straight example of the improvements possible in the automotive industry's current products. The point of the work is stated to be a demonstration of redesign potential.

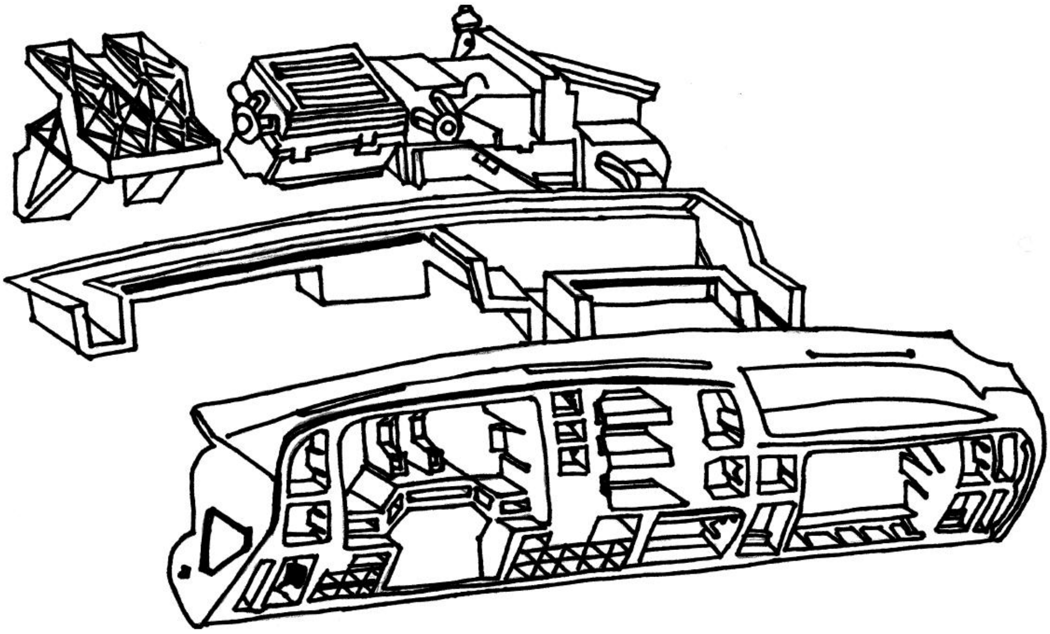
The instrument panel is always a tricky component of a car: because of its size and shape complexity it is fairly hard to insert. The article defines four assembly problems that are encountered especially frequently when considering instrument panels: 1) the panels are not secured on insertion and need to be held down during assembly, 2) the panels' components are not easy to align for insertion, 3) the panels' components are assembled with obstructed access or restricted view of the of the insertion point and 4) the panels contain components which resist insertion or require some manipulation for insertion. Because of these problems, the instrument panels are work-intensive to assemble, but more importantly, add an important source of assembly defects and quality problems.

The analysis of the panel showed that there was indeed room for improvement. The old design consists of 314 parts in 28 subassemblies, which have to be combined in a total of 482 assembly tasks. The total estimated time for these tasks is 3780 seconds or 63 minutes. The analysis of the old panel design shows that only about five minutes were spent on tasks that are absolutely necessary (installing wire harnesses, instruments, etc.). A full 17 minutes goes towards assembling separate fasteners, 24 minutes to assemble components that the author considers candidates for elimination, and 16 minutes to perform tasks such as welding, staking, gluing, etc. These three main assembly task categories all contain room for improvement.

After the initial analysis, a newer and leaner product design was proposed, together with time and cost estimates for its production – the improved design can be seen in Figure 12. The results are impressive – the overall assembly time may drop as low as 12 minutes. The material costs of the two designs are estimated to $38,69 (old) and $39,06 (new).

The basic idea of the new design is to a) integrate the existing panel components into larger units, b) provide structural integrity by the shape of the injection molded parts, rather than by separate supports and c) increase the recyclability of the instrument panel by removing the need to disassemble it for non-plastic components when recycling.

The new design could (probably) be completed in 121 assembly steps. For instance – the number of fasteners in the redesigned product would only be 23, as compared to 123 in the old. The "candidate components for elimination" category is reduced from 173 to 39, of which the remaining are mainly separately molded parts in the four air deflector assemblies, assemblies which could probably be further improved.



(Boothroyd-Dewhurst Inc 1999a)

Figure 13. Redesigned truck instrumentation panel.

2. *Car seat case study*

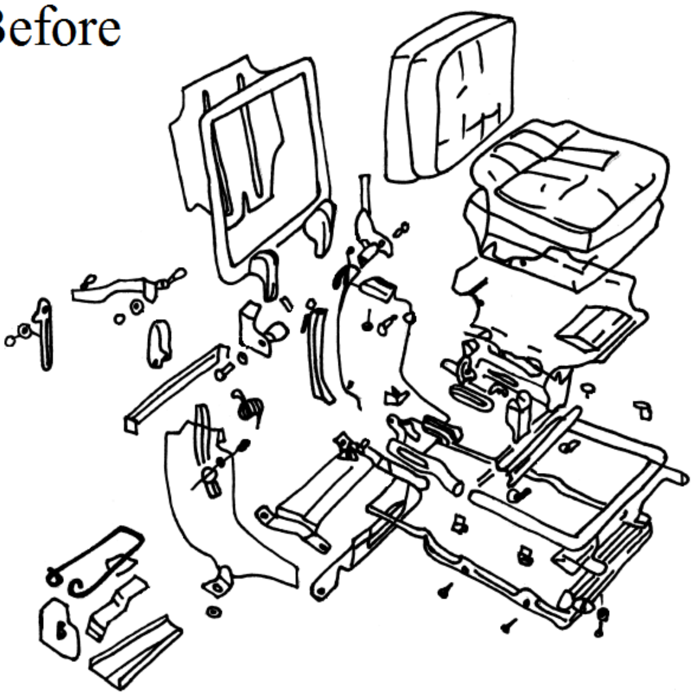
Another relevant case study is Boothroyd-Dewhurst Inc.'s (1999b) redesign of a pickup car seat together with the Magna Seating group. The car seat initially consists of 105 separate parts made from four different material types and uses several different manufacturing techniques (welding, riveting, screwing, snapping, etc.). Wire welding of small components that are difficult to handle is common – this is an especially work intensive technique. In general the work steps consist of

MIG welding the basic framework, assembling the tubular framework and attaching the final cushioning. The total assembly time is 24 minutes .

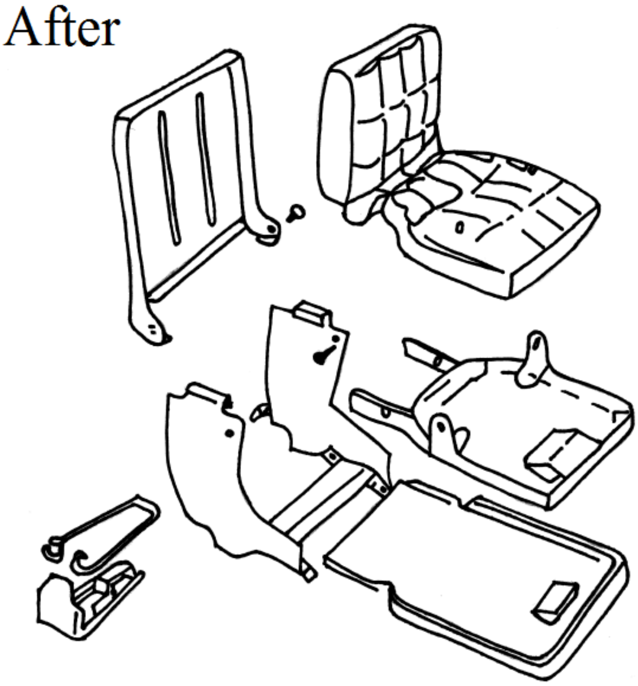
The two redesigns were made – one where only small modifications to the basic structure was allowed, and one where major changes could be made to the seats' outlook as long as their functions were preserved. The first "conservative" redesign eliminated a lot of the welding steps and several multilayer parts were made integral. As a result, the parts count could be reduced from 105 to 19, and assembly time reduced from 24 minutes to 4.3 minutes.

The second round of redesign – where any change could be accepted as long as the functionality of the system remained – eliminated most of the welding, kept only the essential screws and rivets, removed all tubular parts and integrated their functions with the seat cushions and back support stampings, removed all separate brackets and weld nuts, etc. Such a seat would in effect only consist of nine components, and assembly time would only be in the neighborhood of 1,5 minutes. It is doubtful whether such a seat would be approved by the industry as a whole, but the first "conservative" redesign nevertheless shows the potential that DFA redesign has to improve existing products. In Figure 13 we can see the old and second new designs.

Before



After



(Boothroyd-Dewhurst Inc 1999a)

Figure 14. Redesigned car seat.

The future of the automotive industry

Eventually, the Chinese companies will start to export more aggressively. Eventually, the quality of these upstarts will become so good that they will be accepted in the Western world, and at that time, a wave of export cars (currently a trickle) will surge to North America and Europe (see Holweg, Tran, Davies & Schramm 2011; Holweg, Davies & Podpolny 2009). We have seen this happen back in the day when Japan and South Korea were still considered low-cost, low-quality countries.

China and India are experts at exporting – acoording to Qureshi & Wan (2008) the trade to GDP ratio in China was 70% in 2005 and India's was 44%. Nothing says that cars are a different product. Furthermore, the average annual wage in China 2007 was about 25000 Yuan (about 3900 dollars or 2800 euro) (Yang et al. 2010). The wages are rising fast, granted – in 2002 the same figure was 1329 dollars for China (and 285 dollars for India)(Qureshi & Wan (2008) – but compared to the average annual 30 000+ dollars of the Western world, there is still a significant difference.

But what can the established car companies do to fight for their position? And fight they must if they want to keep their position as car company giants – otherwise they will become niche players, focusing only on certain market segments, constantly under attack by the new companies (see the example of Harley-Davidson in Christensen 1997). They can choose to fight back with better techniques, like in the example of South Korea in Section 3.1.: despite the low wages and positive exchange rate of South Korea in the 1980s, Korea could not compete with the superior quality of Japanese cars in the American market. Only much later, when South Korea had adopted lean production techniques, could they rival the Japanese companies.

Design for Assembly could become one of the weapons of the established companies. Production machinery and robotics can only push down production costs so far and does not solve all problems of assembly, as we saw previously. Furthermore, it is relatively easy for the new companies to buy the same machines. Radically different design on the other hand is harder to incorporate in a production environment that supports old techniques. (Thoma and O'Sullivan 2011). Expertise in assembly design could become the new (old) defense of the established car companies.

4 THE CONNECTION BETWEEN ASSEMBLY AND REPAIR

In this section we look closer at the link between assembly and repair. Our focus in this study is mainly on Design for Assembly, but the objective would be to infer the presence of DFA in the car models we study by looking at repair times. For this to make any sense, we must assume that a product that has been designed for assembly will have faster repair times. This would probably not be a 1:1 relationship – certain types of assembly improvements are bound to have positive effects on repair time, while other will affect the results negatively. However, a certain degree of positive correlation seems possible, especially when looking closer at the connection between assembly and repair, or more precisely, the connection between assembly and disassembly.

4.1 Design for Assembly guidelines

In Table 8 we see some of the design guidelines for DFA, collected from literature and compiled into a general list. 38 guidelines are given here, but there are certainly more if we start looking at product specific literature. The guidelines can be grouped into four different categories we might call *minimize, standardize, handling* and *assembly*. The *minimize* and *standardize* guidelines are about making the product simpler, easier, less complex. A smaller number of components, materials and fasteners used, and these should all be assembled in a standardized way with a normal toolset.

The *handling* guidelines are about ease of use in the industrial workplace. Components that are tangled, sharp, slippery, small, flexible and delicate are hard for assembly workers to grip and control, especially considering they might be wearing gloves and holding tools at the same time. The *assembly* guidelines are called so because they are meant to facilitate the process of putting product together – visibility, easy orientation, modularity, access, wide tolerances, etc. Ideally the number of movements and insertions should be kept at a minimum, the product should be stacked from the bottom up and two-handed grips and insertions should be avoided. Keeping these guidelines in mind might well produce a much more efficient product to assemble, even without quantitative calculations or computer programs.

Table 8. Design for Assembly guidelines.

Minimize

1. Eliminate product features of no value to the customer
2. Reduce the number of components to a minimum
3. Reduce the number of materials used
4. Reduce the number of fasteners used (safely)
5. Minimize the types of fasteners used
6. Maximize functions performed by individual components

Standardize

7. Use standardised components
8. Standardize materials used in the product
9. Specify material that is easy to obtain
10. Use a standardized, normal toolset
11. Use standardized fasteners
12. Fastener ranking: Snap fit (best) – Plastic bending – Riveting – Screw fastening (worst)

Handling

13. Avoid parts that stick together
14. Avoid parts that are slippery
15. Avoid parts that are very small
16. Avoid parts that are very delicate
17. Avoid flexible parts (difficult to control)
18. Reduce the weight of components for easier handling by human workers
19. Avoid parts that are hazardous to the handler (sharp, splinters, etc)
20. Provide features to prevent jamming or nesting of parts when stored

Assembly

21. Ensure clearance for hands, tools, probes, etc.
22. Place fasteners away from obstructions.
23. Consider access and visibility for each production step
24. Make sure disassembly is equally practical as assembly
25. Modularize multiple parts into single subassemblies.
26. Design a base component to reduce the need for jigs and fixtures
27. Design a stacked product that can be assembled from above
28. Avoid orientation after insertion
29. Design components to maximize operations possible without repositioning
30. Eliminate high precision fits
31. Design to reduce resistance to insertion of components
32. Design shapes, protrusions that will disallow incorrect assembly
33. Design Parts to be self-locating and self-aligning
34. Make components symmetrical
35. If symmetrical components are not possible, exaggerate asymmetry to facilitate orienting
36. Avoid sharp edges and angles
37. Avoid designing parts that need holding down during assembly
38. Avoid secondary operations – plating, painting, heat treatment, etc.

(Andreasen 1988; Edwards 2002; Rampersad 1996; Joneja 2009; Boothroyd et al. 2002; Bralla 1999)

4.2 Design for Maintainability guidelines

While there are almost no references to such a concept as Design for Repair, there are several that are concerned with Design for Maintainability (see for instance Lele 1997; Takata, Kirnura, van Houten, Westkamper, Shpitalni, Ceglarek & Lee 2004). The terms maintainability and serviceability seem to be used almost synonymously (Blanchard & Fabrycky 1998) but both methodologies are concerned with allowing for easy maintenance by incorporating certain functions already on the design stage (Tan, Matzen, McAloone & Evans 2010). The objectives are to identify and prioritize maintenance requirements, increase the available run time of the product and decrease maintenance time, increase customer satisfaction and decrease lifecycle costs. (RIAC 2011; Moss 1985). Dhillon (1999:1) defines maintainability as *"…the measures taken during development, design, and installation of a manufactured product that reduce required maintenance, man-hours, tools, logistic cost, skill levels, and facilities,…"*.

The Design for Maintenance methodology is certainly less well-known than Design for Assembly or Design for Manufacturing, and has not been a part of the Design-for family very long. Interestingly enough, NASA is one of the forerunners in this field: NASA has published several editions of its publication Man-Systems-Integration Standards, where Design for Maintainability is given much attention. The MSI Standards are comprehensive set of guidelines that define the requirements for space facilities and other equipment used by man in space. Under such conditions, when replacement equipment is not readily available and breakdowns can cause life-threatening situations, it is important that all machinery is easy to repair by human hand. The MSI Standards define minimum standards of physical access, visual access, removal, replacement, modularity, fault detection, test points etc. (NASA 1995)

Also General Motor’s is said to be using a "*Serviceability Task Evaluation Matrix*" (STEM), a design tool that evaluates estimated repair and maintenance time, parts cost, diagnosis time, tool requirements and part availability, etc. (Lynch 1995). Tjiparuro & Thompson (2004) classify the five most important Design for Maintenance objectives: simplicity, part features, operating environment, part identification and assembly/disassembly principles.

Table 9. Design for Maintainability guidelines.

Standardize

1. Maintenance equipment and tools shall be kept to a minimum
2. Design all adjustments controls in same direction (i.e. clockwise, right, up)
3. Use standard fasteners and components
4. Reduce number of components in final assembly
5. Conformance to national, international, and industry standards and codes
6. Maintenance requiring special skills shall be minimized

Handling

7. Avoid sharp edges, corners and protrusions that can cause injury
8. Component size, shape shoud ensure self-alignment during insertion
9. Adjustment controls should be self-guiding and self-stopping
10. Provide guide pins for alignment of modules
11. Provide handles for components weighing over 5 kg or unwieldy components
12. Mount heavy units as low as possible
13. Installed components should require no or minimal adjustment
14. Quick-disconnect connectors should be used

Replacement

16. Provide a path to remove replaceable units w/o removing other units.
17. Make it possible to remove replaceable units w/o interrupting functions
18. Make it possible to test units w/o interrupting functions
19. Provide test points or self-diagnostics on circuit boards

Access

20. Route cables for easy access and replacement
21. Provide clearance around connectors for viewing and access
22. Components most critical to system operation shall be most accessible
23. Access ranking: no cover (best), transparent window, quick-opening metal cover (worst).

Identification

24. Code cables and wires for easy identification
25. Parts references displayed next to each part

(Kuo et al. 2001; Ivory, Thwaites & Vaughan 2001; NASA Man-Systems Integration Standards 1995; RIAC desk reference 2011; FreeQuality 2011)

A summary of relevant guidelines is presented in Table 9. These guidelines can be roughly divided into five categories – *standardization, handling, replacement, access* and *identification*. The *standardization* guidelines define that maintenance should be performed with a minimum of special skills, special tools, special fasteners etc. This ensures that maintenance can be performed on a daily basis, easily. The *handling* guidelines ensure that components are as easy to handle as possible, by using lightweight modules, self aligning components, etc. The *replacement* guidelines ensure that it is easy to test and remove components even while running the machine, and the *access* guidelines define easy access to critical components. Finally the *identification* guidelines state the need for clear references to color coding for easy troubleshooting.

Now, these guidelines are in fact not very similar or perhaps even compatible with those of Design for Assembly – and the argument of this work is that we should be able to see evidence of Design for Assembly in the repair data we will be analyzing. However, at this stage we must jump forward to Section 5.4, where we can see the definitions of the repair procedures given in the repair guide finally chosen as the source of data. First of all, the most commonly used procedure in the guide is:

"Remove and Install (R&I): Remove a part or assembly, set it aside and reinstall it later. The time shown includes the alignment that can be done by shifting the part or assembly." (Collision Estimating Guide Imported 1991: P3.)

The term Remove and Replace (R&R) can be used almost synonymously, since in that case, the part is removed and replaced with a new replacement part. In both cases, there is no damage to the part being removed and installed. We can also look at the following quote from the guide:

"[the times] are for replacement with new undamaged parts from the vehicle manufacturer on a new undamaged vehicle… The actual time taken by individual repair facilities to replace collision damaged parts can be expected to vary due to severity of collision, vehicle condition, equipment used, etc." (Collision Estimating Guide Imported 1991: P3).

Given these definitions it is clear that Design for Maintainability is not the correct discipline to be looking at – the repair guide is not talking about maintenance, but rather about disassembly and reassembly (limited to a particular component and the components blocking it from access). From this point of view it makes more sense to look at another design methodology altogether: Design for Disassembly.

4.3 Design for Disassembly

Design for Disassembly is a design methodology that assists the disassembly of products, often in connection with recycling, and also often seen as a part of Design for Remanufacturing and Life Cycle Costing techniques. However, on its most basic level, it is simply a way of designing a product that can be taken apart more easily – as an effect of more easy disassembly, recycling simply becomes more viable option. (Gungor & Gupta 1999.) DFD stresses the selection and use of correct materials, the design of components and product architecture, and the selection and use of fasteners (for literature on disassembly planning see for instance Mascle 1998; Yokata & Brought 1996; Zussman, Krivet, & Seliger 1994; O'Shea, Kaebernick & Grewel 2000).

Design for Disassembly is also often mentioned in connection with Design for Assembly, since Disassembly is a relatively new offshoot of the Design-for family (circa early 1990s) and borrows some principles from the older DFA (Westkamper, Feldmann, Reinhart & Seliger 1999; Feldmann, Trautner, & Meedt 1999 and Yu & Li 2006). The 2000 European Union directive on vehicle end-of-life handling and the 2004 European Union Waste Electrical and Electronic Equipment (WEEE) directive are often cited as significant boosts to its popularity – the directives places the responsibility of disposing products with their manufacturer (Sundin 2004; Chung and Wee 2011, Kumar and Putnam 2008 etc.).

The European Parliament end-of-life vehicles (ELV) directive 2000/53/EC defines the minimum reuse and recovery rates for end-of-life vehicles (Ferrão & Amaral 2006):

- Until 01/01/2006: reuse and recovery of 85% on a mass basis (recycling 80%) for vehicles produced after 1980.
- Until 01/01/2006: reuse and recovery of 75% on a mass basis (recycling 70%) for vehicles produced before 1980.
- Until 01/01/2015: reuse and recovery of 95% on a mass basis (recycling 85%).

This has brought several issues to attention: the blending of materials, which can make components impossible to recycle; the extensive use of non-openable fastening methods such as gluing; the popular use of special tools in assembly which makes disassembly problematic; etc. According to Sundin (2004), metal recycling is a complex issue since contaminants destroy the possibilities of reuse. The addition of copper, tin, zinc, lead, or aluminum makes steel and iron less recyclable, while the addition of iron, steel, chromium, zinc, lead, copper or magnesium makes aluminum less recyclable, etc (Bellmann & Khare 1999). In general, unplated and low alloy metals are the best for future reuse.

Remanufacturing

A concept that is often closely connected with disassembly is remanufacturing – the practice of disassembling, cleaning, refurbishing, replacing parts (as necessary) and reassembling the product so that it will function as well as a new product (Hazen, Overstreet, Jones-Farmer & Field 2012). The remanufactured product is sold as an equivalent of a new product, if yet often at lower prices (45–65% of comparable new products) because of their lower perceived quality (Lund & Hauser 2010). However, a remanufactured product can be taken into use with a reasonably high degree of confidence that it will last another full cycle of usage. (Bras & Hammond 1996; Guide & Li 2010). Thorn & Rogerson (2002) define remanufacturing as "*the process of disassembling, cleaning, inspecting, repairing, replacing, and reassembling the components of a part or product to like-new condition*"

In Table 10 we can see some compiled DFD guidelines. The DFD guidelines can be roughly divided into five groups – *minimize, standardize, handling, disassembly* and *recyclability*. The *minimize, standardize* and *handling* categories match the DFA guidelines very well. The last two – *disassembly* and *recycling* – on the other hand are of course specific to DFD, especially the recycling aspect. Those guidelines consider mainly the re-usage of the materials after the product has been disassembled. As such they are more an aspect of Design for Environment, but nevertheless often mentioned in connection with DFD.

In Table 11 se see a matrix matching the DFA and DFD guidelines against each other. Several of the DFA and the DFD rules match relatively well – 16 rules resemble each other to a large degree, and very few seem to directly contradict each other. The environmental aspects of DFD and the clearly assembly-connected aspects of DFA make up for the largest differences. Looking aside from these, Design for Disassembly and Design for Assembly have a lot in common. On the other hand we must always remember that intent and the background thought is what really matters. Even though the most basic guidelines – minimizing the use of components, materials, fastener types, etc. cannot be interpreted very differently no matter what your intent, other guidelines such as easy insertion and self aligning shape of components (assembly) promises nothing in terms of easy disassembly.

Table 10. Design for Disassembly guidelines.

Minimize

1. Minimise the number of components used
2. Minimise the number of component types used
3. Minimise the number of material types used
4. Minimise the number of fasteners used, safely
5. Minimise the types of fastener used

Standardize

6. Standardize components used
7. Use standardised, normal tools
8. Standardise the types of fasteners used

Handling

9. Use lightweight materials and components easily handled by workers
10. Avoid toxic or harmful materials and chemicals

Disassembly

11. Separate working components into modular sub-assemblies
12. Consider the use of destructive fasteners
13. Improve access to components and fasteners
14. Try to make the plane of access to components the same for all
15. Avoid permanent fixing (adhesives, co-molding)
16. Mount electrical components with sockets, do not solder
17. Use fixings which snap, clip or slot into place

Recyclability

18. Design connectors to withstand repeated assembly and disassembly: recyclability
19. Prefer metals over plastics, more easily recyclable
20. Avoid using laminates, amalgams – bad for recycling
21. Avoid painting parts, contamination prevents recycling
22. Apply markings (e.g. etching, moulding) for easy sorting

(Güngör 2006; Guy & Ciarimboli 2005; Shedroff 2010; Active Disassenbly Research 2005; Information Inspiration 2011)

Table 11. DFA-DFD guideline similarities.

		Min Components 1	Min component types 2	Min material types 3	Min fasteners 4	Min fastener types 5	Standard comp. 6	Standard tools 7	Standard fastener types 8	Light materials 9	No toxic, harmful 10	Modularity 11	Destructive fasteners 12	Access, fasteners 13	Access plane 14	No glues, co-molding 15	Sockets, no solder 16	Snap, clip, slot fix 17	Repeat assembly and dis- 18	Metals over plastics 19	No laminates, amalgams 20	No painting 21	Apply markings 22
Eliminate features	1																						
Min components	2	X																					
Min materials	3			X																			
Min fasteners	4				X																		
Min fastener types	5					X																	
Max functions/comp	6																						
Standard comp.	7						X																
Standard materials	8																						
Easy-get material	9																						
Standard toolset	10							X															
Standard fasteners	11								X														
Fastner ranking	12																	X					
No stick	13																						
No slippery	14																						
No very small	15																						
No very delicate	16																						
No flexible	17																						
Light components	18									X													
Not hazardous	19										X												
No jam/nest	20																						
Clearance	21													X									
Free fasteners	22													X									
Access + visibility	23																						
Disassembly	24																		X				
Modular	25											X											
Base component	26																						
Stacked assembly	27														X								
Min orientation	28																						
Max one-side	29																						
No precision fits	30																						
Easy insertion	31																						
Impossible incorrect	32																						
Self-locating/aligning	33																						
Symmetrical	34																						
Assymetrical	35																						
No sharp edges	36																						
No holding down	37																						
No secondary	38																						X

Interestingly enough we see that both the Design for Assembly and Design for Disassembly guidelines recommend the usage of snap fits. We can immediately see the benefit in terms of assembly – a component that snaps on can be inserted in seconds, while a component that is screwed on might take minutes to fasten correctly. However, when talking about disassembly the benefits are less intuitive. A snap fit can be relatively easily opened, but might easily break if opened forcefully or without knowledge of its exact location and shape. Penev (1996) distinguishes two types of disassembly – nondestructive (true disassembly) and destructive (dismantling). While snap fits should be used cautiously if attempting true disassembly, they are perfectly all right thinking of dismantling a product – dismantling is most often the precursor of recycling, and the most important thing is that components and materials are separated. On the other hand, the alternative fastener types (such as screws or rivets) might well perform even worse for true disassembly: rivets cannot be opened without some destruction, and aged screws tend to jam, break, and "go bald" (the groove on the screw's head breaks) if handled with force. Comparatively speaking snap fits are very easy to open.

4.4 Connecting DFA and DFD – Evidence from academic research

Some scientific research makes a connection between Design for Assembly and Design for Disassembly. Gupta & McLean (1996), Penev & Ron (1996), Boothroyd & Alting (1992) have all reviewed the Design for Assembly methods and compared them to those of the newer Design for Disassembly. Feldmann & Slama (2001); Westkamper, Feldmann, Reinhart & Seliger (1999); Feldmann, Trautner, & Meedt (1999) and Yu & Li (2006) study integrated methods of planning design for assembly and disassembly. Aguinaga, Borro & Matey (2007) create an automated disassembly planner that integrates with assembly and maintenance simulation tools to provide disassembly analysis information during product design.

The collection term Design for Assembly and Disassembly is mentioned by Nof & Chen (1992) and Velásquez & Nof (2009). Hammond & Bras (1996) use the Boothroyd-Dewhurst assemblability index method as a model for the cretion of a remanufacturability index. They point out the many similarities between the two methodologies – tools, techniques and fixtures. Jovane, Alting, Armillotta, Eversheim, Feldmann, Seliger & Roth (1993); Brennan, Gupta & Taleb (1994) and Bras & Emblemsvag (1995) look at the role assembly plays in remanufacturing.

According to Penev (1996:34) the application of DFA is the first step in achieving a successful disassembly. He goes on, however, to stress that DFA is only a first step – to achieve truly suitable products for disassembly further redesign efforts have been made. Seliger, Karl & Weber (1997) and Barkan & Hinckley (1993) state similar findings.

In Harjula, Rapoza, Knight & Boothroyd (1996) we see one of the few existing empirical studies about the link between DFA and DFD. In their first example a normal household coffee maker is redesigned using quantitative DFA redesign software, but a disassembly sequence (with recyclability cost calculations) is also generated at the same time. The original product consists of 84 parts (only 9 theoretically needed) and has an assembly time of 660 seconds (11 minutes). After the redesign, however, the parts count is down to 58 and the assembly time is 473 seconds (about 7,9 minutes). The number of materials used has been reduced to 8 from 12. The disassembly time has also been drastically reduced from 333 seconds (about 5,6 minutes) to 130 seconds (about 2,2 minutes).

The study goes on to check the relationship between assembly and disassembly on a few larger products: a washing machine, a refrigerator and a TV set. On average, the DFA redesigns (again using the same software and method) have resulted in disassembly time reductions of 48%. The authors conclude that a typical DFA redesign will have an almost equally positive effect on the disassembly of a product. For an even better result, however, the disassembly considerations should be included already in the design phase, alongside the DFA analysis.

At the moment it is hard to find a consensus in academic writings on the issue of whether efficient Design for Assembly is reflected in efficient Design for Disassembly – the study by Harjula et al. is almost unique. However, given that the Design for Disassembly is a research area of growing interest, it seems probable that we shall soon see more research trying to quantify the relationship, and that these works can be used to strengthen the validity of this particular work.

4.5 Connecting DFA and DFD – Interview results

To investigate the general opinion of the automotive industry concerning the link between fast assembly and fast disassembly, several interviews were conducted with automotive professionals and academic specialists.

The interviews were conducted either by phone or mail, and included a total of eight professionals with experience of seven major automotive companies. The interviewees are automotive researchers, managers, and engineers:

- BMW – Former Senior Researcher
- Ford Motor Co. – Materials & Manufacturing Research Manager
- Honda R&D Americas, Inc. – Advanced Materials Researcher
- Hyundai Motors – Senior Researcher
- General Motors Brazil – Vehicle Architect + Senior Product Engineer
- Valmet Automotive – Simultaneous Engineering Manager
- Volvo Car Corporation – Former Director Executive Business Support

The questions posed to these persons were divided into a short-set and a long-set, depending on their time and availability. The short-set simply asked:

1. Does your company normally consider Design for Assembly at the design stage?
2. If you answered yes, why does your company use this methodology?
3. Does your company normally consider Design for Disassembly at the design stage?
4. If you answered yes, why does your company use this methodology? For remanufacturing, repair or recycling?
5. Do you think that a successful Design for Assembly -redesign would improve or worsen the ability of some later company to disassemble the car?

The long-set added the following three questions

6. Do your suppliers know about DFA and DFD, considering that more and more significant modules are being designed and manufactured by them?
7. Are there any companies in the world that are especially well-known for their easy-to -assemble cars? What about easy-to-disassemble?
8. In your own opinion – were cars easier or harder to assemble ten years back? Twenty years? Has anything changed?

The answers of the interviewees can be summarized as follows:

Is DFA used, and why?

In general – it seems that DFA and DFM are still being used. Especially the American companies continue to upkeep the methodology and even publish a few articles on their redesign projects. However, in the non-American companies, DFD seems to be getting a stronger interest than DFA.

A few of the answers seem to indicate that DFA methods were used more actively 10 to 20 years ago, and have seen less development lately. However, the companies that are using DFA and DFM say that these design methodologies have a considerable impact when it comes to saving money – program costs, timing and manufacturing ease (ergonomics).

In the companies that do not expressly use DFA, the ease of assembly is still taken into consideration during the design phase, but not in a formalized way, but rather by using the designer's experience and seeing what works. The companies that are not expressly focusing on DFA at this moment do not seem to be eager to implement it as a methodology either.

Is DFD used, and for what purpose?

DFM is a growing area of research for the automotive industry, all interviewees agree on this. The companies that are actively focusing on DFD at present time have seen their recycling rates (the amount of materials in a car that can be recycled) grow constantly since implementing their DFD programs. But, the ELV (End of Life Vehicle) directives (present or future) of different countries do seem to have been the main reason for these companies' efforts.

The general consensus of the industry seems to be that recyclability is not something that the general public will pay for. The car companies that are focusing on DFD admit that the customer plays quite a small part in that particular methodology choice – the customers will not be swayed by a car that is easy to recycle. Design for Disassembly is seen as a way to realize the governmental demands for vehicle recyclability. And specifically recyclability – disassembly and reuse of components (remanufacturing) is not the aim. Naturally, the OEM's do not have recycling businesses of their own, and will therefore focus mainly on their customer's needs and wants, in order to increase their market share and profits.

Ease of repair is equally not considered much in the industry: easy-to-repair is not a marketing point – rather an admission of failure in public eyes. The customers are still mainly interested in:

- Styling (Design Studio)
- Robustness (Engineering)
- Comfort (Engineering / Design Studio)
- Fuel economy (Engineering)
- Price (Everyone – Engineering/Design Studio/Marketing/Finance, etc.)

Does DFA have a (positive) effect on DFD?

The interviewees disagree on the effect of DFA on DFD – about half feel that DFA have a positive effect on DFD, and half feel that there is no link to be seen between the two. The people that do see a link say that there might be certain similarities between the DFA and DFD, but probably not that large – the intent should be to design with both in mind simultaneously to improve on both. However, as a disassembly sequence is often the reverse of the assembly sequence, and DFA expressly gives such guidelines as "reduce the number of parts and integrate" and "simplify the structure" etc., disassembly times should be affected somewhat positively.

The interviewees that do not feel that DFA and DFD correlate in any way (or even see one as detrimental to the other) especially point to fasteners and integrated materials as key problem areas that separate the two methods.

An interior door trim panel can either be attached to the door proper with 5–6 screws (with cover caps to hide them) or with internal push pins (snap fits). The screws and caps can be attached in about 30 seconds, while the clip-on solution only takes about 10 seconds to attach. The clip-on is certainly DFA, but bad for DFD, especially if you want to get the part out undamaged.

Integrated materials are the second problem – since fewer components doing more work is a key aim of DFA, more complex single components are often the end result. The weather-strips of the doors are a good example – they contain soft rubber for effective water seal, hard rubber to provide structure, steel to provide stiffness, and other soft rubber types to produce a nice appearance and feel. If the aim is to separate materials completely (as is often the goal of DFD for recycling), this successful DFA redesign produces problems later on. In general, DFA redesigns that result in components or materials being joined by thermal or chemical processes become hard to disassemble. Unfortunately the automotive industry is clearly heading in a direction where more mixed materials are used.

Several of the interviewees will point out that the best results are achieved if both DFA and DFD are taken into account at the same time (an integrated approach); if the components that need removal or can be reused are identified at the beginning of the design process, a solution with better access to these components can be achieved.

Are the suppliers using DFA

In general it seems that a lot of the responsibility of design is moving to the supplier. Some of the closer suppliers are working with the OEM:s on DFD projects, but the question remains how much DFA is still in the picture. In America the possibility is better, but in other countries, the low enthusiasm of the automakers for DFA is probably reflected by their suppliers.

The future is looking a bit bleak for DFA at the moment. The trend is towards increased separation of tasks in the supply chain – between OEM and supplier, and even between OEM and assembler (initial design by the OEM, nuts-and-bolts engineering and assembly by another, specialized company). This sort of separation (geographical, company-cultural) may form another obstacle for the concurrent-engineering -minded DFA process.

The possibility to achieve Design for Assembly is somewhat limited by the big suppliers – a radically new design is made hard by the usage of more standardized components, shared between several car manufacturers. On the other hand, a higher degree of standardization (as a side effect of using the components of large suppliers) might also have its positive effects on DFA and DFD. Twenty years ago, the cars were much more unique in terms of components than they are today.

What companies are especially well-known for their easy-to -assemble cars?

There is assumed to be a link between Design for Assembly and lean design, as spearheaded by the Japanese car makers over the last decades. Logically then, the Japanese car makers should be best at making easy-to-assemble designs. Toyota is mentioned as the most probable candidate. But these opinions are not based on any particular measurements, just overall gut-feeling.

Other issues – Modularity

However, across the board, it is felt that the future (and now) of the automotive industry design lies in modularity. The OEM:s will design an end product that consists of modules that trusted suppliers will design and engineer much more independently. This so-called black-box design will allow cost cutting for the OEM:s, but it is also seen that assembly and repair will benefit significantly from such methods. Assembly will simply be a matter of joining modules through standardized interfaces, and repair will aim at replacing the entire module rather than a single part. Whether disassembly is affected positively depends on the build of the module – it will certainly be easier to get the module out of the vehicle, but if a certain part in the module needs to be changed, that can be significantly harder if DFD is not taken into account by the supplier. Robust and durable modules will, however, be an excellent source of material for remanufacturers.

Academic interviews

In further interviews with members of the MIT International Vehicle Program and authors on Design for Assembly, the question of whether fast assembly and fast disassembly have common factors is debated. Two IMVP researchers consider that there is a certainly degree of overlap between the two methodologies – on the surface, as much as 70%–80% seems common to both easy assembly and easy disassembly. A well-known expert in DFA techniques replies that it is not obvious that the assembly, disassembly and repair will follow the same pattern – the dislocation lines in the structure where assembly and disassembly are intended will probably not be similar following the different design regimes.

Conclusion – open

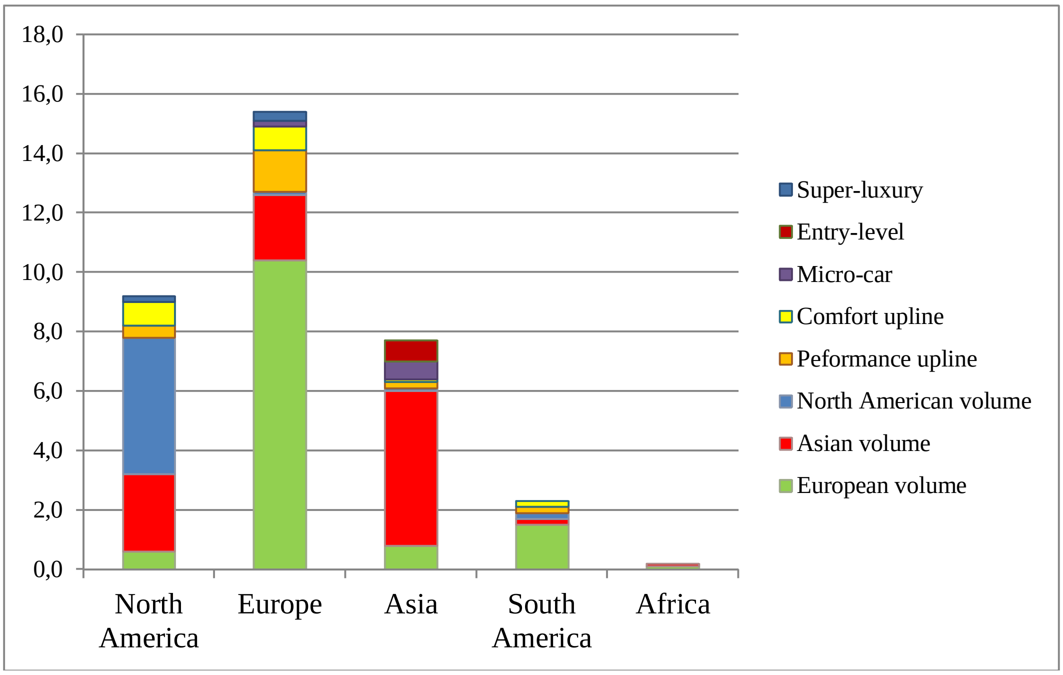
To summarize – the question of how DFA affects DFD is certainly debatable and about half of the researchers and industry experts seem to believe that there is a positive link between easy assembly and easy disassembly. The other half are doubtful.

However, if we consider repair time data to be a combination of the time it takes to disassemble and reassemble an assembly on a car, even a weak positive link should make it possible to assume that models with lower repair times display elements of DFA. If looking at a large enough sample, general trends in ease of assembly should be reflected in lower repair times, as long as the disassembly fraction of the repair time is not inversely proportionate to the assembly fraction. We will go forward on this assumption, and meanwhile continue to try and find more a more conclusive answer to the question.

5 METHODS AND DATA COLLECTION

General preferences

Choosing the setting for an investigation of car models is not easy, but we can make several choices based on simple availability. First of all – the region to study. It is a fact that the Asian and European car markets have long been dominated by local brands. According to Maxton & Wormald (2004:16) trade barriers, policy choice and customer preferences have kept the markets safe from outside interference until relatively recently. The authors mention customers' brand loyalty is a strong motivator, coupled with the fact that different markets demand different cars. The Asian markets for instance traditionally preferred smaller and more fuel-efficient cars for use in congested cities where gasoline is expensive. Powerful, American v-engine sedans would simply not have been well-received there.



(Maxton & Wormald 2004)

Figure 15. World market for cars (2002).

In Figure 15 we see a breakdown of the world market for cars in 2002. Since then, Asia has become the largest car producing region in the world, but we can assume that the relative class proportions have not changed radically during the last ten years. The market is divided into several segments – super luxury, entry-level, micro-car, comfort upline, performance upline and the three volume segments (missing is also the super performance segment, which is too small to register). The volume segments are mainly made up from sedan models, but also contain hatchbacks, wagons, etc.

The North American market

North America, despite its low European brand content, is actually the market with the greatest amount of equality between cars from the three production regions. Europe and Asia are dominated by their own production, and American brands have not managed to gain significant instep in these markets – except by buying subsidiaries and forming joint ventures.

The North American car market has remained remarkably open to outside investment. This fact is demonstrated by the Japanese "trade-invasion" of the 70s and 80s, when the products and car models produced by Lean production methods washed over the USA. Even today foreign car companies have an extensive production in North America and the North American market remains an attractive export market to many of the car producing countries (as we saw in Section 3.1).

Therefore it seems logical to choose the USA market for this particular comparison – the largest amount of different car models are sold there at any given time. Of course the USA market is dominated by the American brands, but the Asian competitors have a presence that is almost equally large. Also the European brands are present – to a smaller degree – but certainly this is their largest presence outside of Europe. There is also a lot of easily available data on this market, which certainly helps matters greatly.

The sedan body type

Secondly, we should choose the type of car to compare. In this case, the sedan seems the best choice – it is by far the most widely used and produced body type in the world (gasoline powered sedans, naturally, since that is by far the most common power source for the world's cars). The sedan is also the most consistent and internally comparable type of car that we have. Wagon type models, vans, minivans, off-roaders, coupes, sports cars: all of these classes show a much larger variation in terms of size, style, equipment, and other design solutions. Furthermore the sedan model is a body type that has been consistent for a long time. The sedans of today have better performance and a higher basic equipment level, but are still easily recognizable when compared with something that existed 20–30 years ago.

Time interval

Finally, the time interval – what time period should we look at, and how often should we look in order to produce a valid comparison of car design between companies, regions and its development over time? This must necessarily be a function of availability: what data can we get, how far it spans, etc. – this we will look at more closely in the next section. However, we can already say now that it is hardly necessary to compare each and every year with the previous.

According to Holweg and Pil (2004) the cycle of redesign is currently about five years. During this time a model is sold constantly with only smaller cosmetic modifications, but at the end of the cycle the model is either substantially upgraded or dropped from the company's lineup. This cycle is shortening, of course – in 1970 the average product lifecycle was seven and a half years. But since it is what it is at the moment, we can assume that a five-year interval will be enough for a good investigation: no new models are completely missed during their lifespan, and we should be able to see an almost completely new and refreshed set of vehicles during each measurement interval.

5.1 Selecting Sources of Data

There are several sources that hold that kind of repair data we are looking for. The best thing would of course be to select several of these sources and combine the data to form a very reliable composite database. However, the possibility to do so depends on the compatibility of the different sources. In general, the data that we will look at will come from either

a) the type of repair guide intended as a help for the workshop mechanic or from

b) the insurance claims estimate guides intended as a help to the insurance estimator presenting a quote on how expensive it will be to repair a car.

There are several commercial options available, unfortunately none free-to-use. The following is a short list of the most common sources of repair time data (databases mentioned often on the Internet, either as close competitors or complements to each other). The list is by no means exhaustive, but these are certainly the most well-known alternatives.

Alldata

Alldata is a leading North American provider of auto repair software. They provide diagnostic, repair and collision information, together with business management tools for the automotive service industry. Alldata was founded in 1986 (California) and functions offered are (in the simplest versions): manufacturer technical service bulletins and recalls, wiring diagrams, maintenance tables, parts and labor information, part removal procedures for disassembly, diagnostic and repair procedures, etc. (Alldata 2011.)

This database is often considered the most widely spanning source of automobile repair data. The company offers versions that contain both Asian, European and North American cars, all presented to an astonishing degree of detail. The only problem is price – at €1500 and more per license it is clear that Alldata is intended for serious professional use at a workshop. More affordable alternatives are available.

Autodata

Autodata is a leading European supplier of technical information for automotive repair shops and other automotive professionals. Established in 1975 (U.K.), Autodata provides their data through both electronic and printed media. Functions offered are (in the simplest versions): Technical data, vehicle identification, service adjustments, lubricants and capacities, tightening torques, repair times, wheel alignment, service illustrations, service schedules, diagnostic trouble codes, wiring diagrams, etc. (Autodata 2011.)

Autodata provides a similar database to Alldata, and at a more affordable rate (about €500). However – the problem is that it focuses on the European market, omitting some of the American brands that have not made it Europe. Plymouth, Oldsmobile, etc. – none of these are covered in the guide. Renault, Citroen and Seat are all present on the other hand. It's a question of choice – which market do we focus on? But since the North American market is very wide and international, coupled with the fact that it is easier to find historical car data from this area, we choose to look at that particular market, and in effect have to ignore the Autodata software as a source.

Chilton Automotive Data

Chilton is a producer of automotive repair guides and reference sources for service shops and enthusiasts. It was founded in 1904 (Philadelphia) as The Chilton Publishing Company with a focus on periodicals for automotive repair. The company has kept to its roots – while the company upkeeps online databases too, the focus is traditionally on printed media and disc editions. (Chilton 2011.)

Chilton provides a number of different types of manuals – most commonly repair time manuals and service manuals, but also more specific volumes such as the "Timing Belts, 1985–2005" "Brake Specifications and Service 1990–2000" etc. The repair time manuals – which are of the greatest interest to us – cover European and Asian brands as well as North American.

Chilton's manuals are a comparatively speaking affordable source of repair time data (at about €150 for a set of labor time manuals or a disk issue). However on closer investigation, the Chilton manuals are not altogether very specific when it comes to components and sub assemblies – most of the procedures described in Chilton are focused on repair, but not linked to actual removal and installation of components – for instance balancing tires, bleeding brakes, etc. Furthermore, the repair times given are quite bluntly estimated, relatively speaking.

Mitchell International

Mitchell International (headquartered in San Diego) is one of North America's largest providers of collision repair information for use in insurance estimation. Mitchell has long been known (founded 1946 by Glenn Mitchell) for their collision estimating guides published in paper format – their manuals are widely used by collision repair shops and insurance companies. The company continues to issue these paper guides annually, but they also upkeep an online database that presents the same data. (Mitchell 2011).

Mitchell's guides are an excellent source of repair data in that it is precise (down to tenths of an hour), cheap (about €120 for 3 months of access to their online database) and wide – the manuals and the database cover both import and domestic North American models from the late 1980s forward (much longer back than that, if you only look at domestic North American models).

Motor Information Systems

Motor Information Systems is another large North American supplier of automotive data, headquartered in Montana. Founded in 1903, they focus on offering parts and labor data for repair estimating, service manuals and shop management software for business owners. In addition to their paper manuals and disc issues, Motor Information Systems has entered into an agreement with Alldata, providing access to a Motor/Alldata repair information database online. (Motor Information Systems 2011.)

The Motor Information Systems guides are very similar to the Mitchell's guides, but they are unfortunately not sold outside of North America. The Alldata information database would be available for international use, but unfortunately at the same price as the original Alldata service, €1500.

Tolerance data

Tolerance A/S from Denmark is a European supplier of data solutions and technical vehicle data. They provide automotive repair data, testing equipment software, circuit diagram data, trouble shooting for electrical systems, etc. While they do sell software and databases on disc for use in individual service shops, they focus on their online services and selling access to the different databases they offer. (Tolerance Data 2011.)

Tolerance data provides perhaps the cheapest source of automotive data of the different alternatives (access to the online portal at about €40 per year). Unfortunately, only European market cars are covered, leaving out the Oldsmobiles, Plymouths, etc. while covering the specifically European models such as those by Citroen, Renault, Seat etc.

Vivid Automotive Data and Media

Vivid Automotive Data and Media is a European software company focused on providing technical data for the automotive industry (headquartered in the Netherlands). The company is young compared to many of the other – they launched their first version of their main product Vivid Workshop data in 1996. The software is available on disc and online, covering technical drawings, engine management systems, wiring diagrams and repair times. (Vivid).

Vivid 's data is also of European origin, and omits several of the American models. The cost is somewhat high at about €600 per software issue.

Final Choice – Mitchell

In the end, after having reviewed the different choices, the Mitchell repair guides stood out as the winner. The reasoning behind this is mainly practical. Autodata, Tolerance data and Vivid Workshop data are not good choices given that we want to look at the American market specifically. Alldata is simply too expensive for a purely academic comparison – there are several sources that are much more affordable for our needs. Motor Information Systems will not sell their manuals outside of the United States. That leaves us with Mitchell International's guides and the Chilton guides.

Having purchased and looked at both, it is clear that the Mitchell collision estimating guides are more suitable for the needs of this research – more specific repair time estimates, a higher degree of time variance between models (something which implies intimate knowledge of the models) and a very large amount of specific components and sub assemblies presented together with the time it will take to remove and install a new component.

Using both of the guides together would have been possible: making a composite or average estimate of the repair times from both, to gain a stronger and more unbiased picture of the real world situation. However, the practical situation is that the different guides uses very different metrics (Chilton focusing on repair and tuning procedures, Mitchell focusing on the exchange of individual components) – it is hard combine the two. Only about 20 subassembly exchange procedures would have loosely matched both sets of guides, as opposed to 53 (44) suitable candidates available to us in the Mitchell guides only, as we will see in the later sections.

Parts count and fastener types

In the beginning of the data collection phase, the plan was still to also investigate other metrics of DFA in addition to repair times. It seemed possible, for instance, to study parts counts and fastener types from the same repair manuals already acquired. However, this proved to be impossible because of the inconsistent parts listings given in several of the repair manuals. For some models the manuals may list parts down to the nut-and-bolt level, while for others only the sub-assembly level is outlined. Even if the listings for one year were comparable (and this is rarely the case) the differences in detail level between years are significant enough to make the study of parts count and fastener types meaningless on the basis of this data.

5.2 Car Model Selection

To select the largest possible amount of viable, comparable cars for the selected years, we must begin by establishing what cars were in production during that year specifically and furthermore find a suitable method of classifying these cars so they truly are internally comparable.

The second point is especially important. Naturally all cars will differ from competing models in some way – otherwise the model would be nothing but an imitation or a copy. This will of course also impact on our measurement results – we can never be truly sure whether the differences in repair time come from large differences in the models' true build and structure, or whether they just come from simple small differences in the models' shape and styling. However, by only comparing cars that compete with each other in the same class segment, and that have a very similar profile in terms of physical size, drive, transmission, engine size and type, body size, etc. we can minimize the distorting effect of radically different builds. We can ensure that the differences between cars in the same class will be mainly cosmetic on the outside and mainly component-level on the inside.

Finding such comparable class segments is not easy. Choosing to restrict ourselves to sedans only is of course a first step. But there are many different ways of classifying the cars – according to price, according to size, according to motor size, etc. A composite indicator of all these would of course be best, to ensure that we are not comparing cars that are clearly different in some aspect but not in others.

Finding a classification

The first step in finding such a composite indicator would be to look at the car rental companies, since they are already using systems of car classifications on which the customers make their rental choices. A few of the rental car companies have even created a joint classification system, represented by the Association of Car Rental Industry System Standards (or ACRISS for short). The system standard is a joint project of Avis, Budget, Europcar and Hertz started in 1989, and the stated purpose is to create standards of rental cars to "*avoid misleading information when making a car rental booking online or via electronic means*". The classifications are performed by an independent automotive evaluator. (ACRISS 2011a)

The ACRISS members use a four character vehicle code to describe a vehicle, with each character representing a characteristic of the car. The first character stands for the vehicle category – based on size, cost, engine size and luxury factor, while the second character defines the car's chassis type (van, SUV, wagon, etc.) The third and fourth characters stand for transmission and drive (manual/automatic, 2WD, 4WD, etc.) and fuel type (gasoline, hybrid, etc.) respectively. So for instance we can have a code such as CCMN, which stands for Compact Car – 2/4 Door – Manual Transmission – Gasoline, Non air-conditioned. Several car models fit this description – the Ford Focus and Opel Astra are given as examples. (ACRISS 2011b)

There is just one problem. These ACRISS classifications are not available freely – they are the intellectual property of the rental companies subscribing to the system standard. An individual rental car franchise operator does not have access to the oldest classifications – the codes of the models from the beginning of the 90s. Their databases only cover the more current models. The ACRISS secretariat will divulge the classifications of a few car models if asked, but do not hand out complete listings to the outside individual.

This means that some other type of classification system must be used. Fortunately there are several such sources of a more public nature: the new-car reviews of automobile magazines. Each year several periodicals publish issues where the coming year's car models are presented – new models are of course covered, but also already existing models and any possible modifications are presented – to provide a source of information and comparison data to the new car buyer. Are this year's models better than the old "trustworthy" models that we already know? The magazines review for us.

Selecting the car magazines

There are several car magazines that publish such a yearly model review at the moment. However, there are not equally many that have been doing so consistently since the late 1980s. This seems to be a natural barrier in the data – before the late 80s the car magazines are either unavailable or focus entirely on local car brands. An interesting fact in itself, but nevertheless an almost insurmountable hinder to research that goes farther back in time.

Keeping this criterion in mind, five sources are found relatively easily: The Consumer Reports' new car buying guide, Edmund's new cars, Road & Track Magazine's new car buyers guide, Car and Driver Magazine's buyers guide and Motor Trend Magazine's new cars. The last three of these are magazines, which publish the new car reviews in addition to their monthly general issues. The first two are organizations that specifically focus on offering consumer advice. All five have been around for several decades.

Rather than choose a single one of these to dictate the car's classification it seems prudent to gather data from all five. This is especially true because of the fact that all of them do not cover the exactly same cars, especially not during the earlier years. Furthermore, with several sets of price estimates and classification suggestions it seems we can get a more complete picture of what type of car we are dealing with at the moment.

Consumer reports

Consumer Reports is an American magazine published by the American Consumers Union. Issued since 1936, the guides contain reviews and comparisons of consumer products based on tests performed by the Consumers Union test labs. The guides do not contain advertisements and the staff performs their tests on products bought retail to avoid the chance of positive bias towards a generous contributor. The annual Consumer Reports new car issue is released every April, and is considered a strong influence on the American car buyer's purchase decision. (Answers.com 2011e.)

The Consumer Reports books are a good source of car data – even the 90s issues have a complete listing of the models on sale for those years. The 1990 and 1995 guides divides the four door sedan models into "small cars", "compact cars", "medium-sized cars" and "large cars". In the 2000, 2005 and 2010 guides, the previous groups are remodeled into smaller, more specific listings: the four door sedan models are now "small cars", "large sedans", "family sedans", "luxury sedans" and "upscale cars". For all years, these guides offer detailed information on car specifications, characteristics, reliability and safety, prices, etc.

Edmund's

Edmunds car guides is a provider of car information, reviews, prices of new and used vehicles, tips on purchases and car ownership, etc. Edmunds was started in 1966 as a publisher of printed booklets with automotive specifications meant to help car shoppers make their purchases. Their titles included Edmunds New Cars & Trucks Buyer's Guide, Edmunds Used Cars & Trucks Buyer's Guide and Edmunds Strategies for Smart Car Buyers. Presently Edmund's no longer publish printed works – they have completely migrated all their services and data to the web (www.edmunds.com). (Answers.com 2011d.)

Edmund's new car guides are an equally good source of automobile specifications as the Consumer Reports guides, and are even more specific in terms of equipment listings. One problem is that the earliest guide used in this work (1990) only covers the American models, and thus only supplies a third of the data needed. This deficiency is corrected already by 1995, however. Also, the guides do not start classifying models by any kind of system (except the alphabetic) before 2005 when the four door sedan models are divided according to price: "sedan under $15,000", "sedan under $25,000", "sedan under $35,000", "sedan under $45,000" and "sedan over $45,000".

It should be mentioned, also, that the Edmund's guide from 1990 proved hard to find and because of this the 1991 issue is used instead. This means slight changes in prices of certain models, but not necessary any other problems. With the help of the other Magazine guides it is easy to determine what models were on the list in 1991 and not yet in 1990, choosing the correct models from the Edmund's guide accordingly. Similarly, as of 2006, Edmund's no longer publishes the new car guides in paper format – the website www.edmunds.com offers the same information in electronic format. Therefore the data from 2010 is taken from this website.

Road & Track

Road & Track is an American car magazine, founded in 1947 in New York, making it one of the longest running car magazine in America. (Answers.com 2011c) Road and Track Magazine annually publishes a special Car Buyers Guide issue – this issue, unlike the normal monthly numbers, deals exclusively with the comparison of the car models on sale that particular year. These guides are an excellently regular data source, something which can also be seen from the data listings that will be presented later on in the text – the vehicle data and reviews are highly consistent over 20 years.

The 1990 guide was unavailable, so the 1991 the guide is used instead. Around this time the four door sedans were divided into three different groups: "economy cars", "family cars" and "luxury cars". After this, the magazine drops the classifications and presents the cars in alphabetic order only. However, the 2005 and 2010 issues do for each model list a number of comparable models, which more or less match the model in terms of price and performance.

Motor Trend magazine

Motor Trend is an American automobile magazine, operating since 1949 out of Los Angeles despite a varied chain of ownerships. Its new car issues are released every September and October: the September issue presents the upcoming car models for the next calendar year, while the October issue focuses on off-roaders, sport-utility vehicles and minivans. (Answers 2011b)

The Motor Trend magazine's New Cars issue strives to present the years models in a brief and compact way – this means that there is not much room for vehicle specifications and similar, but the guides are completely sufficient and provide a better-than-average overview because of their brevity.

The 1990 issue is not a complete car buyers guide – it is only a new car presentation, where about 10 to 15 models are presented that are new or improved for that particular year. For the other four years and listings are more complete. The complete buyers’ guide for 2001 and 2002 is used instead of the 2000 issue. This is also the only issue where any kind of classification was attempted – a similar price driven classification as the Edmund's guides. The class range is "$16,000 &

under", "$16,000 to $20,000", "$20,000 to $30,000", "$30,000 to $4000", "$40,000 to $50,000" and "$50,000 & up". Otherwise only alphabetical order.

Car and Driver magazine

Car and Driver magazine (originally founded as Sports Cars Illustrated in 1955) has worked under its current brand name since 1961(Answers 2011a). Car and Driver magazine's new car issues are the hardest to use in terms of data collection. The 1990, 1995, 2000 and 2005 issues all follow the same structure – the model changes since a last year are verbally and briefly presented, mostly in terms of outlook changes and problem fixes, with a few select models presented and reviewed in greater detail. These select models are extremely well documented, however. Unfortunately this inconsistency means that we get a spotty image of the complete model lineup will offer.

The 2010 issue breaks off from this trend, however, and present short reviews and specification lists for each model individually. The outlook is similar to that of the Road and Track issues. As an additional bonus a two page list of all sedan models is presented, with the most important data (price, fuel consumption etc.) compared. Here a similar prize classification is also used, with a class range of "under $18,000", "$18,000–$25,000", "$25,000–$40,000" and "over $40,000".

A custom classification system

As we can see the whole concept of classification is quite complex. None of the guides offer a single system of classification that is valid for the 20 year span that we are currently looking at. This is of course natural and understandable; the car models on offer vary with each year. Also, the current automotive industry trend has been one of diversification: while it might have been natural to talk about "economy cars", "family cars" and "luxury cars" during the late 80s and early 90s, we have later started seeing a plethora of difficult-to-classify car types such as the crossovers, the SUV:s, the hybrids, etc. Therefore those guides using a verbal classification system (Consumer Reports, for instance), have also been forced to expand their classification.

The more simple system of assigning classes according to price has probably seemed the stable choice, and therefore we also see it used more often. However, we encounter problems even there. First of all inflation – the price classes do not stay constant over 20 years. The very popular Ford Taurus model cost on average about $22,000 in 1990, but 20 years later the average price was closer to $28,000. Some of these changes depend on model refits and upgrades, but in practice inflation is a factor.

Secondly, none of the guides we have been investigating agreed on the same price scale; their classes are not exactly the same, if yet similar. While this is also understandable – each magazine wants to show individuality and not copy their competitors – it is a problem to consistency. Finally the third problem: the magazines do not agree completely on the price span off the model. This minimum-maximum price span that depends on optional equipment, engine, service agreements and probably the retailers profit margin, is different for each magazine, probably on the basis of different retailers' price quotes.

In conclusion, there is no readily available single classification offered by these guides that will suffice for the comparison of models over 20 years. The verbal classifications depend mainly on popular opinion, and have furthermore evolved over the last decades. The price classifications cannot be used because of inflation and disagreement over what price a model really is. It is clear therefore that we must create our own hybrid classification depending on the natural groups we see during data collection (based on price, engine type, luxury factor, etc.), supported of course by the classifications of the guides we have studied.

5.3 Car Model Selection

The classification finally used in the comparison is a verbal hybrid classification based on price, drive type, engine type, and of course body type. The reasons for choosing this specific classification are varied, but mainly based on observational evidence from the data collection phase.

Class 1: Low-Price – Front Wheel Drive – Inline (straight) engine – Sedans

Class 2: Mid-Price – Front Wheel Drive – Inline (straight) engine – Sedans

Class 3: Mid-High-Price – Front Wheel Drive – V-engine – Sedans

Class 4: High-Price – Rear Wheel Drive – V-engine – Sedans

First of all, it seemed natural to omit any kind of hard numeric price boundaries between classes, inflation would render these meaningless. The next logical step would be to formulate three simple classes based on the relative price concepts: low-price, mid-price and high-price. These three are generalizations of the more specific terms economy, family and luxury – general enough that specific customer opinions or value decisions do not play a large part.

However, during the process of data collection, certain obstacles were encountered. The mid-price class is large and varied – especially obvious is the break between the cheaper in-line (all cylinders in a line) engine models, and the more expensive v-engine models. The inliners are more a continuation of the low price car lineup, only with more equipment and larger in size to satisfy the more discernible (family) customer. The v-engine models on the other hand, with their stronger motors and higher prices definitely seem to cater to yet another class of customer. This problem is especially tangible in North America, where the v-engine type is more common than in Europe and Asia.

The price differences can be in the region of several thousands of dollars. But this is an unreliable metric since expensive inliners and cheap v-engines do exist. It would not, however, seem entirely prudent to compare both groups internally. The engine type does have an impact on several assemblies in terms of repair time. The V-engine motors are larger, their removal generally takes longer, and the assemblies connected to them also seem to take longer to remove than those of the in-line models.

And, in addition, there is a clear distinction between the two groups when talking about transmissions. The V-engine models distinctly favor the automatic gearbox, while the in-line engines are almost always equipped with a manual gearbox. This will become obvious later on when the car model selection is presented.

Since the mid-price group has such a large span – containing models that could not in good conscience be said to give exactly the same value proposition (a customer opinion thing, but nevertheless) at both ends of the spectrum – it seems natural to divide it into two.

The fourth class (the high-price, rear wheel drive, v-engine sedans) differs from the others in that it features rear wheel drive models. Naturally it would be preferable to only study cars that are completely similar in terms of drive, layout, etc. but the reality is simply that the high price front-wheel-drive models are few in between, almost nonexistent. When using more powerful engines, it is common knowledge that a vehicle's handling is negatively affected if both drive and steering are combined in the front of the car. Thus the more powerful and expensive models favor rear wheel drive.

Because of this we must try to work around this problem by making a clear division of classes, only comparing the same type of cars within a class, and trying to choose such assemblies to study that do not depend too heavily upon the drive or engine type (more about this in the next chapter).

At this point in time a small quirk of car development should be mentioned. During the last few years the designers of high-priced cars have moved on from rear wheel drive to all wheel drive (AWD). Like four-wheel drive (mainly used in connection with terrain vehicles and trucks), this type of system provides motive force on all four wheels, but is mainly used to provide a more smooth ride and better traction. As of 2010, the majority of luxury vehicles have switched to all-wheel drive, and because of this we are forced to accept AWD as the defining feature of fourth class, for 2010 only.

Guidelines to selecting the cars

For a more general reasoning behind why certain cars were chosen and others not, let's look at the criteria that were used to make selections.

1. *Follow the classes as strictly as possible*. Only allow V-engine, automatic transmission, front drive vehicles of a certain price range into the third class, for instance. There is a certain amount of leeway in this selection, however. The V-engines include V6s, V8s, and even V12s (number of cylinders) – most of the third class models only have a V6, and most of the fourth class models a V8, but exceptions occur. The style of the engine is the most important thing in terms of repair time. The transmission type should also match – automatic for the V-engines – but towards the later years a few new items such as the continuously variable transmission (CVT) had to be allowed.

Furthermore the cutoff points between what is considered low price and mid-price or mid-high price and high price are quite hard to define clearly. In most cases the guidance of the car guides proved sufficient, and a decision could be made on the basis of the recommendations. In other cases the decision was harder – but most often the complicated cases disqualified themselves because of their uniqueness. See the discussion on omitted models below.

2. *Choose the Base model whenever possible*. The base model, the model with the least amount of optional packages and accessories is likely to be the model that is most comparable to other models. Less components to be detached before the "important" assemblies can be removed. In certain very rare cases, an optional model can be chosen if this means a better fit with one of the categories – an engine upgrade for instance.

3. *No hybrids*. Towards the end of the timescale, electric-gasoline hybrid cars begin to make their presence known. These can not in any way be compared to

the early 90s models or even the 2010 normal models. Therefore they must be omitted from the comparison completely.

4. *No Subarus*. Subaru Motor Company has consistently been using the flat boxer style engine type for several decades. Since a lot of the internal classification depends on engine type such a unique solution cannot be used in the comparison.

5. *No ultra-luxury cars*. In this comparison we have chosen a relatively moderate definition of "luxury" or high-priced cars. The highest price encountered in the cars chosen for analysis is $169,000, for a Mercedes-Benz S430. This is admittedly a high price, but the majority of the models go for between $35,000 and $80,000. On the other hand, if we start admitting Rolls-Royce, Maybach and Bentley into the comparison we multiply prices by several factors. Most of these brands are not covered in the guides or in the Mitchell manuals and those that do are certainly in a class of their own. In terms of repair times and equipment levels, these cars are not similar to those at the lower end of the high-price range. And since the majority of the class lies at the lower end of the scale it is easier to simply omit the "ultra-luxury" cars.

6. *Same transmission type*. The models chosen for each class should have the same type of transmission, since this is an important difference between car builds. This type of differentiation comes almost naturally since each of the four chosen classes has a "normal" transmission type - class one manual, class two automatic, etc. But there are a few odd models that have to be left out because of this.

In Table 12 we can see a small list of the sedans that were omitted from the 2010 listing because of various invalidating reasons. From some of these examples it is clear that the car producing regions and companies do not always work in sync with each other and use the same drive/engine/transmission combinations on their models – especially the European designers often make cars that are quite unique in their equipment combination. This is of course irritating to the researcher, but from the larger (consumer's choice) perspective quite a good thing.

In appendices 11 and 12, we can see the cars that were finally chosen for the analysis. In appendix 11 the model specifications are presented – the model, the more specific model line, the drive layout, the length, width and height of the car, the weight, the engine type, the brake horsepower of the model, the engine's displacement (cylinder displacement) and transmission type. Concepts and abbreviations are explained in the beginning of the appendix.

In appendix 12, the various prices and classifications of the models from the different guides are presented. The classifications are a little bit truncated, but the full class names are presented in the beginning of the appendix. The models are divided by year, class and region.

Table 12. Incompatible models omitted from the 2010 comparison.

Model	**Omitted from**	**Reason**
Subaru	All	Boxer Engine
Volvo S60	Class 2	Expensive inline-4 model, more suited for the 3rd (mid-high) price class
Dodge Charger	Class 3	Cheap RWD model, more suited for the 2nd (mid) price class
Mercury Grand Marquis	Class 3	Cheap RWD model, more suited for the 2nd (mid) price class
Chrysler 300	Class 3	Cheap RWD model, more suited for the 2nd (mid) price class
Saab 9–3	Class 3	AWD only, but too cheap for the 4th (high) price class
Saab 9–5	Class 3	AWD only, but too cheap for the 4th (high) price class
Volkswagen CC	Class 3	AWD only, but too cheap for the 4th (high) price class
Saab 9–3	Class 4	AWD only, but too cheap for the 4th (high) price class
Mercedes-Benz CLS	Class 4	RWD only, but too expensive for the 3rd (mid-high) price class
Lincoln Town Car	Class 4	RWD only, but too expensive for the 3rd (mid-high) price class
Hyundai Genesis	Class 4	RWD only, but too expensive for the 3rd (mid-high) price class
Jaguar XF	Class 4	RWD only, but too expensive for the 3rd (mid-high) price class
Cadillac DTS	Class 4	FWD only, but too expensive for the 3rd (mid-high) price class
Lexus HS	Class 4	Expensive inline-4 model
Aston Martin Rapide	Class 4	"Ultraluxury"
Bentley	Class 4	"Ultraluxury"
Maserati	Class 4	"Ultraluxury"
Maybach	Class 4	"Ultraluxury"
Rolls Royce	Class 4	"Ultraluxury"
Mercedes-Benz S-class	Class 4	"Ultraluxury"

5.4 Sub-Assembly Selection

Selecting the sub assemblies is more a question of availability than a deliberate choice. The Mitchell guides' pages for each car model generally divide the parts and repair time registry into several general sections – these sections are presented in Table 13.

The aim is of course to find items and assemblies from as many of these sections as possible while at the same time striving to select only such items and assemblies that are general enough to be found on each of the car models we've chosen for the comparison.

This forces us to make several omissions already from the beginning. Since all cars in the comparison will not have options such as an electric sunroof or an air conditioning device, no such assemblies can be chosen. Furthermore we must try not to choose items and assemblies that will differ between the different classes. A good example would be the drive axle: the first three classes selected consist of front wheel drive cars, but the fourth class of rear wheel or all wheel drive cars. Thus we cannot in all conscience look at the repair time of either front or back drive axles – the two are not comparable, and whichever we would choose to observe, some class of car would not have the other one.

Table 13. Mitchell collision estimation guides', sections.

1	A/C / Heater / Ventilation	16	ront door	31	Rear gate
2	ABS/Brakes	17	ront drive axle	32	Rear lamps
3	Airbag system	18	ront fender	33	Rear seat
4	Air cleaner	19	ront lamps	34	Rear suspension
5	Center console	20	ront seat	35	Rocker/pillars/floor
6	Cooling	21	ront suspension	36	Roof
7	Cowl & Dash	22	uel tank	37	Seat belts
8	Cruise control system	23	Grille	38	Steering gear
9	Electrical	24	Hood	39	Steering linkage
10	Emission system	25	nstrument panel	40	Steering pump
11	Engine/Trans	26	Quarter glass	41	Steering wheel/column
12	Engine/Trans Mounts	27	Quarter panel	42	Sunroof
13	Exhaust	28	Rear bumper	43	Trans oil cooler
14	Frame	29	Rear door	44	Wheel
15	Front bumper	30	Rear drive axle	45	Windshield

As an additional problem to solve, we also have the fact that the Mitchell guides do not display exactly the same assemblies, items and procedures for each year and for every car model. While the sections displayed in Table 13 are generally present in all five year-sets of the manuals, especially the older manuals may sometimes vary a bit in section content and section division. Certain assemblies are presented in some of the manuals but not at all in the others. The larger assembly procedures (discussed in the next section) are also more consistently displayed in the manuals from 2000 and forward.

The conclusion of all these variances is that subassembly selection is a problematic and boundary restricted task. The only way to achieve a goodly selection of assemblies is to begin by choosing as large a possible amount of items to follow and gradually whittle down the list of assemblies when problems occur. If an assembly is consistently presented and accounted for in several of the manuals but not in all, we should omit this assembly from the list. If an assembly is consistently presented and accounted for in even the most of the car models, but not in all, we may still have to omit the assembly. This process can only be done manually by going through the steps of data collection and finding out what is left to compare. Needless to say the remaining assemblies will all be extremely general in nature, and more or less present on any car everywhere.

Mitchell manual outlook

As already mentioned, the Mitchell collision estimating guides are mainly for the use of insurance estimators and repair shops, to estimate how much a certain repair will eventually cost in total, before the actual repair is made. For each part and assembly presented in the manuals an estimated part's price and an estimated repair time is given. The part's price is a guideline to how much the spare part will cost, bought new from a licensed dealer. The estimated repair time, which we will mainly be looking at in this investigation, is a guideline to how long it will take to remove and replace said part at the repair shop.

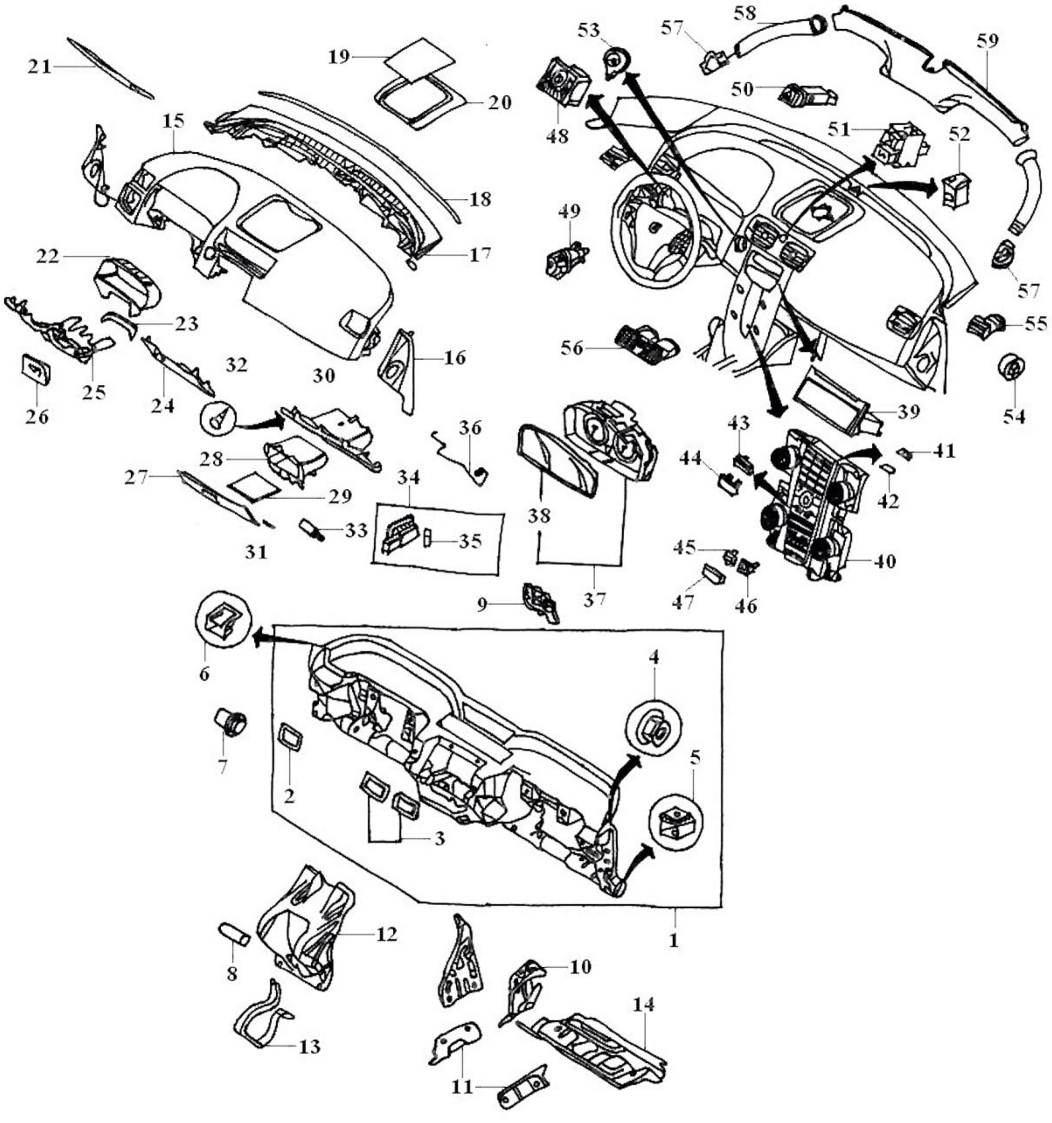
The repair times shown in the guides are given in hours and tenths of hours, thus 0,1 hours represent six minutes. As is also explained in the guides

"*[the times] are for replacement with new undamaged parts from the vehicle manufacturer on a new undamaged vehicle… The actual time taken by individual repair facilities to replace collision damaged parts can be expected to vary due to severity of collision, vehicle condition, equipment used, etc.*" (Collision Estimating Guide Imported 2005: P3).

While this definition may in fact produce certain unrealistic estimates when talking about the repair of a severely damaged vehicle (bodywork skewed to jam bolts, parts deformed to hinder removal) it is strangely enough an almost ideal setting for assembly analysis. New undamaged parts on a new undamaged vehicle – a similar setting to that of the assembly line.

The manuals' listing for one type of car model is most often about 15–20 pages long, divided into sections which we saw earlier in Table 13. Also most often, each section begins with a sort of summary of the larger procedures connected with the section. These larger procedures outline how long it will take to replace or overhaul an entire section of the car' machinery for body. For instance the front bumper section or subsection starts with estimates of how long it will take to 1) refinish bumper cover, 2) refinish upper filler 3) remove and install bumper assembly and 4) overhaul bumper assembly (includes remove and install). Under the larger procedures there is a parts sketch – in Figure 16 we see a rendition of the type Mitchell's guides uses in its guides, the dashboard of a European car model from 2005.

Most of the repair times given in the manuals will be for one of the three following procedures: *R&I (Remove and Install), O/H (Overhaul)* or *Refinish*. The most commonly used is the *Remove and Install* procedure, but sometimes the *Overhaul* time estimate is given side-by-side since there is a certain difference to the two procedures. The *Refinish* procedure is mainly used when talking about sheet metal parts. The definitions of each of these procedures are presented below.



(Mitchell International 2005)

Figure 16. Instrumentation panel, Mitchell guide.

Under the parts sketch each part is listed with number, VIN code, replacement time and estimated parts cost:

Part name	VIN	Time (H)	Cost $
Panel Assy, Intrument	30722602–7	6,5	302,17

Procedure definitions

The definitions of the terms are stated in the collision estimating guides:

“*Remove and Install (R&I): Remove a part or assembly, set it aside and reinstall it later. The time shown includes the alignment that can be done by shifting the part or assembly*.” (Collision Estimating Guide Imported 1991: P3).

The term Remove and Replace (R&R) can be used almost synonymously, since in that case, the part is removed and replaced with a new replacement part. In both cases, there is no damage to the part being removed and installed.

“*Overhaul (O/H): Remove an assembly, disassemble, clean and visually inspect it, replace needed parts, reassemble and reinstall on the vehicle making any necessary adjustments*.” This is a more time consuming process than Remove & Install, and certainly one where DFA should be apparent.

And finally Refinish – the process where a certain panel is removed, prepared, repainted and re-installed on the vehicle. This is a procedure where the principles of DFA are not as clearly visible – most of the time goes not to removal and installation, but rather to the paint job – and as such should be considered an inferior indicator to the other two. However, for comparable vehicles, there is a certain amount of information to be gleaned even here.

In general, the ranking of the three indicators is such that Overhaul can be considered a better indicator of DFA than Remove and Install, which in turn is a better indicator better than Refinish. This because more time is actually used to disassemble parts and assemble them, and the basic design come into play – an assembly designed to the principles of DFA should make this process faster.

Final assembly selection

Selecting as many subassemblies and items as possible, taking care to select only those that are most general and present on the largest amount of cars, we arrive at the list of 53 possible assemblies. However, after the gradual whittling down of the list to arrive at something that is commonly shared by all the selected car models, we arrive at a final selection of 44 subassemblies and items. These selections are presented in Table 14.

Table 14. Final assembly selection.

1 A/C/Heater/Ventilation; Motor, Blower
2 Air Cleaner; Housing, Air Cleaner
3 Back Window; Glass, Back Window
4 Center Console; Console Assy, Center
5 Cooling; Fan, Cooling
6 Cooling; Radiator Assy
7 Electrical, Alternator
8 Engine/Trans; Pan Assy, Engine Oil
9 Engine/Trans; Pulley, Crankshaft, R&I
10 Engine/Trans; R&I Engine/Trans Assy
11 Exhaust; Manifold, Exhaust
12 Front Bumper; Cover, Front
13 Front Door; Panel Assy (Interior), Door Trim
14 Front Door; Panel, Door Repair
15 Front Door; Shell Assy, Door
16 Front Fender; Fender (Left)
17 Front Inner Structure; Apron Assy
18 Front Inner Structure; Crossmember, Front Suspension
19 Front Inner Structure; Support Assy, Radiator
20 Front Lamps; Lamp Assy, Combination
21 Front Seat; Cushion, Seat Bottom
22 Front Steering Linkage/Gear; Gear Assy, Steering
23 Front Suspension; Arm, Lower Control
24 Front Suspension; Bar, Stabilizer
25 Front Suspension; Hub Assy
26 Front Suspension; R&I Suspension (One Side)
27 Fuel Tank; Pump assy, Fuel
28 Fuel Tank; Tank, Fuel
29 Grille; Grille Assy
30 Hood; Cable, Hood Release
31 Hood; Panel, Hood
32 Instrument panel; Panel, Main Instrument
33 Quarter Panel/Side body; Panel, Outer Quarter
34 Rear Body; Panel Assy, Rear Body
35 Rear Bumper; Cover, Rear
36 Rear Lamps; Lamp Assy, Combination
37 Rocker/Pillars/Floor; Pillar Assy, Hinge
38 Roof; Headliner (w/o Sunroof)
39 Roof; Panel, Roof (w/o Sunroof)
40 Seat Belts; Belt Assy, Seat
41 Steering Wheel/Column; Column Assy, Steering
42 Windshield; Glass, Windshield
43 Windshield; Tank Assy, Washer
44 Wiper System; Motor Wiper

The assemblies omitted include highly common components such as steering pump, rear shock absorbers, muffler (exhaust), brake caliper, steering wheel assembly, etc. All are found on a majority of cars but are unfortunately not presented in the manuals for certain models or simply presented as a part of different assemblies.

If we look at the list of assemblies selected in Table 14 we can see that it is quite a diverse collection with parts and assemblies from all the sections of the car. Motor parts, suspension, cooling, lamps, sheet metal, interior, electrical equipment – as close as we can come to an overall representation of the car's parts in total, working within the boundaries and limitations of the data source and car selection. Most of these parts should in addition be relatively insensitive to the class of the car.

Now, it should of course be said that several of the subassemblies are quite simple in their design and as such can probably not benefit much from redesign with assembly in mind. The stabilizing bar in the front suspension is an example of such a simple component. However, this is not necessarily the point of the whole exercise. We must consider that to remove even this simple component other components must be shifted, and for the larger collection of simple components there are still opportunities to implement DFA. Looking at the sum total of the time it takes to remove and install the whole number of individual components we should get an idea about the Design-for-Assembly level of car.

5.5 Data collection and limitations of the data

The data collected is naturally too large to present in this text – and is of course also the intellectual property of Mitchell International – but for the sake of the company level analysis of repair times, a summary table of the individual models' results will be presented in connection with the data analysis (Tables 16–20).

Having selected the sources of data, the car models and the relevant assemblies, the actual data collection is easy but time consuming. 316 models, with 44 subassemblies each, plus several subassemblies that were later thrown out makes for close to 14,000 observations. Unfortunately, in terms of statistical analysis the data is not ideal, despite this large number of observations.

The problem is the concept of the width versus depth. We must remember that despite the large number of actual observations we are only looking at a small amount of actual car models – 316 in total. Furthermore, this amount is divided by five since we are looking at five different years – only about 60 models per year. If we look at the other modes of division, we have about 80 cars per class or about 100 cars per production region. And if we finally combine these criteria, we're only looking at about 15 models for each class per year, and so on.

Now, each of these models is being studied carefully, by observing the 44 different subassemblies. These should (when combined) act as a relatively good indicator of the vehicle's overall level of efficient design in terms of disassembly and assembly. In other words, the individual vehicle data is strong. But because of the small numbers of vehicles we are dealing with, the statistical analysis of the larger variables (such as yearly development, regional differences, etc.) will be relatively weak.

This should be kept in mind throughout the analysis, and the results should be viewed critically in turn. However, since reality rarely provides perfect sets of data, it is not necessarily wise to ignore the results that even an imperfect set of data can show us. We should simply proceed with caution, and not take the results out of their proper context.

6 METHODS AND DATA ANALYSIS

In this chapter we will first analyze at the data statistically and later review it on a more individual basis. The statistical analysis will focus on investigating the distribution of three variables – year (five groups: 1990, 1995, 2000, 2005, 2010), class (four groups, see previous chapter) and production region (Asia, USA, Europe). The individual analysis will look at the models' successes on the corporation level – GM will be compared with Toyota and Volkswagen, etc. By doing this we can hope to find an answer to the research questions stated at the beginning:

What are the trends in automotive assembly time, looking at the last 20 years?

What companies consistently produce the cars with lowest (and highest) assembly times?

The program used to statistically analyze the data is SPSS's PASW statistics 18.

6.1 Statistical analysis

There are several ways of conducting a statistical analysis on this type of data. However, the most common method when wishing to analyze the difference between several groups of scores is the ANOVA (ANalysis Of VAriance) method.

The easiest way to simplify the data into something that can comfortably analyzed by the ANOVA analysis method – and still produce numbers that have a real world meaning – is to summarize all the time measurements of a car model into one grand total. Now, this sum does not have a real world equivalent in practice – it is just the added value of time it takes to repair 44 more or less randomly selected assemblies on a car – but it can nevertheless be seen as a proxy for the time it would take to overhaul a car.

These figures, together with the columns indicating year, class, and production region are presented in Tables 16–20. The figures have been structured in such a way as to show the repair times ascending for each year and class: those cars with the lowest total repair times are at the top of each class and year

The ANOVA assumptions

According to Gamst, Meyers & Guarino (2008: 49–84) there are three main assumptions that must be fulfilled to perform a successful ANOVA analysis on a set of data: "(*a*) *the error components associated with the scores of the dependent* *variable are independent of one another, (b) these errors are normally distributed, and (c) the variances across levels or groups of the independent variable are equal*".

Independence of errors

The first assumption is often the most overlooked of the three; it depends more on choosing the right kind of data and experimental setup than on anything else. It is also relatively hard to use statistical analysis to examine whether one's data is truly error independent.

According to Stevens (2002) ignoring or dismissing the error independence can have the outcome of inflating the targeted alpha level "*Just a small amount of dependence among the observations causes the actual alpha to be several times greater than that level of significance*." The only way to really avoid violating error independence is to make sure that the data analyzed from comes from truly randomly selected sample cases.

The car repair data gathered for this investigation is sure to suffer from violations of this assumption. Considering that a) many of the car models are built on production platforms intended to produce other closely related models, b) that especially the American car producers share components and designs between many of their brands and badges and c) that the same car model can return in the analysis during several different years with only minor modifications – it is simply not possible to assume perfect independence. However, there is no way around this problem, and as such it will have to be recognized and taken into consideration but not be allowed to hinder further analysis. We must simply acknowledge that the results of the analysis are correspondingly weakened, and that any measure of statistical significance should only be accepted if it is safely large – no border cases accepted.

Normality of errors

The error components of the analyzed variables should also be normally distributed for the ANOVA analysis to be valid. This to make sure that no hidden influence has been forgotten in the analysis: if a statistically significant variable has been left out of the equation its regular influence will skew the distribution away from its normal, natural distribution. The most common reasons for irregular distributions are, however, more prosaic – the sample size is too small or there are outliers with extreme or unusual values skewing the results.

Because of the central limit theorem (*with a sufficiently large sample size (n) the resulting sample mean will approximate a normal distribution*) we can feel reasonably content with the normality of errors in this analysis. All of the factor groups should have at least 50 observations in each and that should be enough for one-way ANOVA (where only one independent factor is used to explain the dependent factor). If we find the opportunity to use a two- or three-way ANOVA, on the other hand, (with two or three independent factors explaining one dependent factor) we may run into problems with too small a sample size. This because using more independent factors further divides the groups into smaller groups (if we choose a two-way ANOVA analysis with the independent factors Year and Region, we have not only one 1990 group, but 1990-Asia, 1990-USA and 1990-Europe) and each of these groups should have a normal distribution to satisfy the ANOVA assumptions.

If we observe difficult outliers, we will decide whether they will have to be removed later on.

Homogeneity of Variance

The third ANOVA assumption dictates that the variances between groups should be homogeneous (homoscedastic). There are three main reasons why such an assumption would be broken. Firstly, the classifying independent variable may have an inherently natural difference of variance (a gender variable, for instance, can easily have different variances for the two different groups). Secondly, outside manipulation of an experiment can bias the variables in one direction. And finally, large differences in sample size can affect the homogeneity of variance negatively.

In our case, the data used is not naturally ideal. There may well be natural differences between groups – especially when we look at production regions this may become an issue. There should be no experimental bias in the data set, but factors such as the source of data (only one, North American repair time database used) could leave a mark. Even the third issue – unequal sample size – will play a role in especially the regional analysis (the European set of cars is much smaller than the rest). However, we will have to see what the numbers say during the analysis – it is possible that the assumptions will be fulfilled without any problems.

6.2.1 Exploring the data

Variable 'Year'

As we see from appendix 1, the 316 individual cases (or car models studied) are fairly equally distributed over the five years: the largest amount of models from 2000 (69), the smallest amount from 1990 and 2010 (59). If we look at the descriptives for the year variable, we see that the means of the yearly distributions seem to be steadily growing – from 139.920 hours in the year 1990, to 165.722 hours in 2010 (an increase of about 18%). However, this is something we cannot classify as a trend before we have tested statistical significance of these differences.

Moving on to the tests of normality, we see that the results are not looking promising if we intend to perform an ANOVA analysis. Since the number of cases (N) is quite small, the Shapiro-Wilk test should give a more reliable result, but both the Kolmogorov-Smirnov and Shapiro-Wilk tests indicate that the yearly distribution of cases cannot be said to be normally distributed, certainly not at a 5% significance level (the null hypothesis of both tests is a normal distribution). The reason for this is obvious – we see clear evidence of both skewness and kurtosis in the descriptives.

1990	Shapiro-Wilk stat.: 0,877 – DF: 59 – Sig.: 0,000
1995	Shapiro-Wilk stat.: 0,776 – DF: 67 – Sig.: 0,000
2000	Shapiro-Wilk stat.: 0,877 – DF: 69 – Sig.: 0,000
2005	Shapiro-Wilk stat.: 0,911 – DF: 62 – Sig.: 0,000
2010	Shapiro-Wilk stat.: 0,924 – DF: 59 – Sig.: 0,001

This is especially clear, if we look at the collected histograms of the per year distribution in appendix 2. Most of the histograms show peaks at the far left of the figure and a long sparsely populated tale towards the right. In many ways this is only logical. We could see already during the data collection phase that the three low-to-mid price classes contained many cars with similar time statistics. But the fourth, high price class clearly contains fewer cars and more cars of unusual build, something which results in a skewed distribution. What we are seeing in the histograms is probably evidence of this – normal "bulk" production cars forming a coherent peak at the left, the more unusual higher price cars forming their own set of peaks at the right.

The box and whisker diagram of the year distribution confirms this idea; the outliers that we can see towards the top of the chart are exclusively made up of class 4 cars, the high-priced cars.

Returning to appendix 1, we take a look at the tests of homogeneity of variance. At a 5% level of significance, we can clearly accept the null hypothesis that the variances across the groups (years) are equal, irrelevant whether we look at mean, median or adjusted ditto. The third assumption for ANOVA analysis is thus fulfilled but not the second.

Levene stat. (based on mean): 1,379 – DF1: 4 – DF2: 311 – Sig.; 0,241
Levene stat. (based on median): 1,160 – DF1: 4 – DF2: 311 – Sig.; 0,328

Variable 'Class'

The variable Class is not of equally great interest to us as the variables year and region. It is interesting mainly as a confirmation of the division of models along the lines that seemed natural at the start of the data gathering phase – but it is perhaps not of academic interest: it would only seem natural that car models of higher cost involve more assembly work than those of low cost. But nevertheless, this is something that can be easily checked from the data at the same time.

The case processing summary in appendix 1 tells us that the high-priced rear wheel drive sedans class is the smallest (N=60) and the low price front-wheel-drive class is that largest (N=96). From the descriptive we can again find evidence of a growing trend: the low price class has the lowest mean repair time (136,8 hours) and the high price class the highest mean repair time (181,948 hours) – a difference of about 33%.

The tests of normality look better for this variable, but unfortunately not good enough. The low and high price classes are cleared for ANOVA analysis (we can perhaps accept the null hypothesis of normal distribution at a 5% level of significance), but not the midprice classes.

Class 1: Low-Price – Front Wheel Drive – Inline (straight) engine – Sedans
Shapiro-Wilk stat.: 0,977 – DF: 96 Sig.: 0,087
Class 2: Mid-Price – Front Wheel Drive – Inline (straight) engine – Sedans
Shapiro-Wilk stat.: 0,960 – DF: 64 Sig.: 0,038
Class 3: Mid-High-Price – Front Wheel Drive – V-engine – Sedans
Shapiro-Wilk stat.: 0,910 – DF: 96 Sig.: 0,000
Class 4: High-Price – Rear Wheel Drive – V-engine – Sedans
Shapiro-Wilk stat.: 0,979 – DF: 60 Sig.: 0,375

We can see evidence of why in appendix 2, the histograms: the midprice in-line class has two peaks, and the midprice v-motor class is strongly skewed to the left.

There is no easy explanation as to why this is so – probably this indicates that the class division is not entirely natural. If the two classes could be combined, the resulting chart might more closely approximate a normal distribution.

From the box and whisker diagram, we can clearly see that the fourth class, the high price class, is distinctly different from the other three with a greater variance and range. The highest outliers also come from this class.

Returning to appendix 1 and the test of homogeneity of variance we see another obstacle to the ANOVA analysis here – at a 5% level of significance we must reject the null hypothesis of equal variance between the groups. Thus two of the ANOVA assumptions are not fulfilled.

Levene stat. (based on mean): 16,592 – DF1: 3 – DF2: 312 – Sig.; 0,000
Levene stat. (based on median): 15,546 – DF1: 3 – DF2: 312 – Sig.; 0,000

Variable 'Region'

When looking at the variable region, (appendix 1) we see that the Europe-group only has 50 valid cases, as opposed to the Asia and USA groups with over 100 each. This reflects the situation of the chosen review area – the American car fleet is made up mainly by American and Asian car companies. European low-cost sedans are a rare sight in America – when buying a European car the choice often falls on a sports car or a luxury sedan.

The descriptives show us that the Asian and American groups are close to each other in terms of average repair time (Asia 147,961 hours; USA 142,219 hours). The European cars have a markedly higher mean (179,038). The same thing is true of the groups' variance (Asia 280,690 – USA 175,842 – Europe 927,081). As a result of this, the test of homogeneity of variance gets a negative result: the group's variances cannot be said to be equal. The American markets bias towards choosing more expensive European cars might be one of the reasons of this difference – as we saw in the previous paragraphs the higher cost cars seem to display higher repair time values.

Levene stat. (based on mean): 42,883 – DF1: 2 – DF2: 313 – Sig.; 0,000
Levene stat. (based on median): 40,942 – DF1: 2 – DF2: 313 – Sig.; 0,000

In terms of normal distribution, only the Europe subgroup can be said to show signs of normality. If we look at the histograms in appendix 2 week we can say that the USA subgroup shows a leptokurtic distribution, with a far too high peak to match a bell shaped curve. Looking at the box and whisker plot we again see that the Europe subgroup stands out completely in terms of mean and variance.

Asia	Shapiro-Wilk stat.: 0,972 – DF: 137 – Sig.: 0,007
USA	Shapiro-Wilk stat.: 0,970 – DF: 129 – Sig.: 0,006
Europe	Shapiro-Wilk stat.: 0,962 – DF: 50 – Sig.: 0,112

6.1.2 Adapting the data to ANOVA analysis

Since none of the three variables seem suited for an ANOVA analysis at the moment, an attempt should be made to adapt the data by means of mathematical transformations or by deleting disturbing outliers. Technically we could also attempt to make use of a nonparametric test to see whether there are significant differences between the groups. The Kruskal-Wallis nonparametric test is often used as a possible replacement of the ANOVA in the cases where the normality assumption is violated in the variable. However, it should be noted that also the Kruskal-Wallis test assumes equal variances between groups. This means that only the Year-variable is eligible for such analysis.

Since the nonparametric tests produce results that are less intuitively understandable and with less of a real-world equivalent than the normal ANOVA analysis, it would seem prudent to investigate whether the data can be made to fulfill the ANOVA assumptions. One way of achieving this would be to try out some of the “power family” of transformations, where each observation is replaced with x**p, where p is an integer or half integer:

- –2 (reciprocal square)
- –1 (reciprocal)
- –0.5 (reciprocal square root)
- 0 (log transformation)
- 0.5 (square root)
- 1 (leaving the data untransformed)
- 2 (square)

(Prophetweb 2009).

Since the histograms do not show any specific indication of what transformations would be necessary to transform the values into a normal distribution, the easiest option is to apply all of these transformations and see under which transformation the values are most improved. In appendix 3 we can see the results of the Shapiro-

Wilk test of normality and the Levene test of homogeneity of variance for each of the six transformations (and the original results for comparison).

For the year variable, looking at the tests of normality, we can see that the reciprocal transformations produce the best results, especially the reciprocal quadratic transformation. Only under this transformation, all the year groups display normal distribution.

The tests of homogeneity of variance did of course produce acceptable results already on the basis of the original values, but the transformations improved these test results too. The reciprocal transformations and especially the reciprocal quadratic transformation produce extremely statistically significant results, with significance levels in excess of 0.90. This means that under a regime of reciprocal quadratic transformation the recorded repair time values can be used in ANOVA analysis.

However, looking at the other variables Class and Region we can see that neither of these can be improved enough by applying transformations that they are made eligible for such analysis. The tests of normality for the Class variable always stumble on the mid-price V-motor sedans -class, which never rises above a 0,002 significance level – it is simply not distributed in a way that can be made to approximate the normal distribution. The tests of homogeneity of variance never approach the point where the null hypothesis of homogenous variance can be accepted.

In the case of the Region -variable, several of the transformations produce results that improve the variable’s normal distribution: the natural logarithmic transformation, the reciprocal transformation and the reciprocal square root transformation all produce results that indicate normal distribution. However, the tests of homogeneity of variance never produce acceptable results, and thus we cannot perform ANOVA analysis on this variable either.

6.1.3 ANOVA analysis of Reciprocal Quadratic -transformed time measurements

Since it is possible to perform ANOVA analysis on at least one of the variables (the year variable) without resorting to cutting any of the measurements, but instead only applying a transformation (the reciprocal quadratic transformation) we should do so. That analysis in question would be a one-way ANOVA analysis with the year variable as independent factor and the reciprocal quadratic transformed time variable as dependent factor.

The results of this analysis can be seen in appendix 4. At a significance of 0,000, the ANOVA analysis shows that the groups' means are not equal. We reject the null hypothesis of equal means between groups at a significant level of 5% and even at a significance level of 1%.

ANOVA F(4, 311) = 17,096, Sig.: 0,000

The Welch and Brown-Forsythe tests produce a more robust method of checking the equality of means between groups: if the homogeneity of variance assumption is broken or somewhat broken (as indicated by the Levene test) the Welch and Brown-Forsythe tests will display alternative versions of the F-statistic so that one may still be able to use the results. In this case however, since both assumptions of normal distribution and equality of variances between groups are fulfilled, we can focus on the normal ANOVA statistic.

Having established that there is indeed a statistically significant difference in means between the different year groups, we can employ a post hoc test to see what groups are naturally formed out of the original factors. If all the means of the groups are clearly different from each other five separate groups will be formed, but if some groups are closer to each other, one can consider that they should in fact form a single group.

The Tukey HSD (Honestly Significant Difference) post hoc test is a powerful and widely used test to further regroup the original groups. However, the Tukey test assumes equal group size (as well as equal group variances), and when this is not the case another test might be a better option. The Gabriel test explicitly allows for unequal group sizes and so does Hochberg's GT2-test, which can be used when the group sizes are very different. (MicrobiologyBytes 2007).

At the end of appendix 4, we can see the grouping results according to Gabriel. The test recognizes three different natural groups; the only point of uncertainty is the year 2005 – whether it should belong together with 2010 or with 2000.

Either way, we can see that the early years (1990, 1995 and 2000) appear to form a natural group with similar means and thus no clear change or trend in between. The same can be said for 2000 and 2005, and possibly for 2005 and 2010. This would seem to indicate that the rate at which significant change in the design of cars occurs used to be somewhat slower than 5–7 years that was suggested in Holweg & Pil (2004) – perhaps closer to 10 years. Possibly one could also infer that the rate of change is speeding up, but there are simply too few measurement years here to be able to say anything.

We can notice, however, that the rising trend in repair times that we observed earlier is indeed statistically significant. The numbers produced by the reciprocal quadratic transformation are hard to describe in terms of real-world applications but by proving that there are statistically significant differences between groups of transformed values, we can also say the same about the original values.

Further analysis

It is of course unfortunate that we were not able to use either ANOVA analysis or a nonparametric test to analyze the two other variables class and region – at least not on the basis of the original time measurements. Especially the Region variable would be interesting to investigate, to see whether anything conclusive can be said about regional expertise in Design for Assembly. Therefore it is a logical next step to look closer at the original data to see whether there are cases or groups that could be eliminated to improve the quality of the analysis material, since outliers or poorly motivated groups might worsen the chances of fulfilling the assumptions necessary to run tests.

If we again look at the histograms and box whisker plots in appendix 2, we can see that most the irregularities are to be found on the higher end of the scale (longer repair times). Most of the histograms show evidence of positive skew – the main body of the measurements are at the left side of the histogram with a long tapering tail towards the right. During the data gathering phase, it became clear that the fourth class of the car models (high-price models) often displayed significantly higher repair times than the cheaper models. If we look at the box and whisker plot for the class -variable we notice that the fourth looks nothing like the other three: a higher mean, and a much greater variance than the other.

This would suggest that we are looking at a subgroup that does not form a natural part of the greater data series. If we were to cut the fourth class entirely – omitting all the measurements of the high price, rear wheel drive sedans – what would we see change? The class does however provide 60 measurements, almost 20% of the total number of measurements. That is a disturbingly large amount of measurements to drop from an already small amount observations. However in the interest of seeing all the data can reveal, we will try also this method. We remove the fourth subgroup of the variable class and are left with 256 observations.

6.1.4 Exploring the smaller data

Variable 'Year'

As we see from appendix 5, the 256 cases are also now fairly equally distributed over the five years: the largest amount of models from 1995 and 2000 (57), the smallest amount from 2010 (42). If we look at the descriptives we see that the mean values of repair times are still growing – from 136.090 in the year 1990, to 155.695 in 2010 (an increase of about 14%) – but that the means are lower with the fourth class omitted.

In this variable the improvement of the data for future ANOVA analysis is obvious: the Shapiro-Wilk test of normality shows all subgroups conforming to the normal distribution (we accept the null hypothesis of normal distribution at a 5% level of significance, for all five years). Also the test of homogeneity of variances shows a reassuring degree of equality. On the basis of this we can say that the omission of fourth class has at least improved this variable for analysis – no transformations are necessary to run a normal ANOVA analysis on the year variable.

1990 Shapiro-Wilk stat.: 0,967 – DF: 51 – Sig.: 0,167
1995 Shapiro-Wilk stat.: 0,973 – DF: 57 – Sig.: 0,229
2000 Shapiro-Wilk stat.: 0,983 – DF: 57 – Sig.: 0,581
2005 Shapiro-Wilk stat.: 0,982 – DF: 49 – Sig.: 0,649
2010 Shapiro-Wilk stat.: 0,992 – DF: 42 – Sig.: 0,988

Levene statistic (based on mean): 1,598 – DF1: 4 – DF2: 251 – Sig.; 0,175
Levene statistic (based on median): 1,586 – DF1: 4 – DF2: 251 – Sig.; 0,179

Looking at the revised histograms in appendix 6 can see that they more closely approximate the normal distribution in almost all cases; certainly a lower degree of skew. The box and whisker diagram depicts the same thing: most of the previous extreme outliers are now gone and the quartile ranges have become a more unified in length.

Variable 'Class'

The case processing summary in appendix 5 tells us that the mid-priced inline engine sedans class is now the smallest (N=64). The growing trend is of course still unaffected: the low price class has the lowest mean repair time (136,799) and the mid-high v-engine price class the highest mean repair time (148,733).

Now, removing one class will of course not have any kind of effect on the normality distributions of the other three classes. So the first two classes are still more or less normally distributed, but the third class – mid-price v-motor engines – is not. The histogram of this class shows why: the distribution looks more like a ski slope than a bell curve, with its peak at the extreme left of the chart and a long tapering tail towards the right. Again we can only assume that the reason for this is an unnatural division of the mid-price cars into two classes.

Class 1: Low-Price – Front Wheel Drive – Inline (straight) engine – Sedans
Shapiro-Wilk stat.: 0,977 – DF: 96 – Sig.: 0,087
Class 2: Mid-Price – Front Wheel Drive – Inline (straight) engine – Sedans
Shapiro-Wilk stat.: 0,960 – DF: 64 – Sig.: 0,038
Class 3: Mid-High-Price – Front Wheel Drive – V-engine – Sedans
Shapiro-Wilk stat.: 0,910 – DF: 96 – Sig.: 0,000

On the other hand, the tests for homogeneity of variance do show a positive improvement. With the removal of the fourth class, the remaining three classes are now sufficiently equal in variance that they satisfy the requirements for an ANOVA analysis or at least a non-parametric test of the same type. Equal variances, thus, but not normal distribution.

Levene statistic (based on mean): 2,875 – DF1: 2 – DF2: 253 – Sig.; 0,058
Levene statistic (based on median): 2,650 – DF1: 2 – DF2: 253 – Sig.; 0,073

Variable 'Region'

The descriptives for this variable show that the region most affected by omitting the fourth class is clearly Europe, which now only has 22 valid cases, as opposed to the Asia and USA -groups still with over 100 each. However, the regions are now much more similar in terms of means (Asia 144,641 – USA 139,924 – Europe 152,191). Interestingly enough, the largest variance now resides in the Asia group (Asia 215,419 – USA 126,488 – Europe 133,922).

At least for this variable we see an improvement in the right direction. The removal of the fourth class has resulted in a much more normal distribution of the three regional subgroups. In the tests of normality we can now accept the null hypothesis for all three (at a 5% level of significance).

Asia	Shapiro-Wilk stat.: 0,981 – DF: 119 – Sig.: 0,101
USA	Shapiro-Wilk stat.: 0,982 – DF: 115 – Sig.: 0,131
Europe	Shapiro-Wilk stat.: 0,969 – DF: 22 – Sig.: 0,684

The histograms show us a similar picture – the blockiness of the European distribution despite its high rating in the test of normality is a result of the small number of observations from this region. In the fourth class we previously removed, the European cars were predominant and this regional group suffers in effect. However, in terms of variance Europe is no longer the most extreme. The box and whisker plot shows us that Asia has now taken over the position as most widely spread subgroup.

The tests of homogeneity of variance for this variable also show an improvement, if yet quite weak. There is now a small degree of equality in variance but not enough to satisfy the assumptions of the ANOVA analysis (at a 5% level of significance). Further modification or transformation is necessary to strengthen the equality of variance in this variable.

Levene statistic (based on mean): 5,604 – DF1: 2 – DF2: 253 – Sig.; 0,004
Levene statistic (based on median): 5,341 – DF1: 2 – DF2: 253 – Sig.; 0,005

6.1.5 Adapting the smaller data to analysis

In the previous paragraphs we could see that the omission of the fourth class did indeed improve the suitability of the data for ANOVA analysis. However, it is not yet good enough in its entirety that we can run a two or three way ANOVA analysis on it – only one variable fulfills all of the necessary assumptions. Therefore it still seems prudent to try to work with the data more to see whether even stronger suitability can be achieved.

Performing the same battery of power transformations data as we did on the original data on this smaller set, we can check the tests of normality (Shapiro-Wilk) and the (Levene) tests of homogeneity of variance to see whether the situation has improved. A summary of the results are presented in appendix 7.

The Year variable does not really need improvement as it is already acceptable in its original form, but we can observe that it shows its strongest results on the tests of normality under the square root transformation. In terms of homogeneity of variance, we see that almost all transformations produce acceptable results (except for the quadratic transformation) but the strongest results are had under the reciprocal quadratic transformation.

The Class variable on the other hand is a more complicated case. The third class, the mid-price v-motor models, can simply not be made more normal in its distribution by application of any of these power transformations. Under some of the transformations, the results of the other two classes are improved, however. The homogeneity of variance is acceptable at the 5% level of significance in the original form only.

Finally we have the Region -variable. According to the tests of normality this group is normally distributed under most of the transformations including the original. However, the tests of homogeneity of variance indicate that this variable does not really show equality of variance between groups, not under any transformation. This is at least true if we strictly adhere to the 5% level of significance -rule; a few of the reciprocal transformations do show results that gets close to this level. It may be possible to perform an ANOVA analysis on this variable if we look more closely at the robust tests of equality of means, Brown-Forsythe and Welch.

Further editing of the data

As we could see, the transformations resulted in certain improvements in some cases: the regional variable should now be passable for ANOVA analysis, as is. The class variable does still not fulfill the assumptions of such analysis, however. So is there any way we could continue to improve on the data and fulfill the assumptions?

Yes and no. The class variable showed clear indications of being an artificial variable. Especially it seems the division between classes two and three – midprice in-line motor models and midprice v-motor models – is ill-fitting and that the two classes could arguably be combined to form a more naturally distributed subgroup. Doing so would of course not affect the results of the other two independent variables year and region – but it might improve the class variable.

However, there would be some negative effects from all this too. In real world terms we would be combining two classes of cars that simply do not mix well – not unless we do a serious re-evaluation of all models in the two old classes. The cheapest in-line midprice cars are probably not wise to compare with the most expensive v-engine models, not unless we are seriously prepared to bend the criteria on which we made the selection. We would then have to reconfigure the classes more seriously and discard the cheapest and most expensive cars off each original class to form a believable new entity.

Secondly, we would knowingly be ignoring the fact that there is a systematic difference in the recorded time measurements between the two classes. Some of the sub-assemblies are strongly affected by the motor type. Exhaust manifold, alternator, the removal and placement engine itself, the type of transmission (which is now chosen on the basis of motor/class) – while these differences are taken into consideration by the current class division they would simply be hidden in the new class. A small difference but nevertheless a systematic error.

Besides the option of combining the midprice classes, one could also see whether manual deletion of certain outliers would help improve normality of class variable. This was even tested: having printed up a list of the lowest and highest outliers to be found in the class variable and deleting 10–15 possible candidates, the data was explored again. Unfortunately, this simple method did not produce any positive results in the terms of normal distribution. The homogeneity of variance did of course improved somewhat, but this was not expressly necessary.

To go further into the issue and start deleting specific observations that hinder the data from displaying a normal distribution not be a scientifically trustworthy option. Transformation of the data is approved since it does not specifically change the internal relations between observations, but the manipulation of data by conscious deletion of observations simply because they do not fit one's expectations is unethical research methodology.

Nevertheless, we could probably improve the statistical validity of the data by recombining the two mid-price classes, leaving us with only the low-price cars and the mid-price cars. Furthermore, when looking at the region variable, it is obvious that the European group stands out quite strongly as a candidate to be dropped from the analysis. The European group is only a fraction in size of the Asian and North American groups, and is thereby making the comparison less reliable just by being present.

These are both valid choices – they would leave us with a smaller data set (about 200 models) but would produce a more statistically significant comparison. But narrowing the scope of the comparison so much would feel irritating – better to see what the (admittedly less dependable) results of the wider and more international data set can tell us first. Cutting the data further can an option for later.

6.1.6 2nd ANOVA analysis of the Year variable

In appendix 8 can we see the ANOVA analysis for the smaller set of data, with the fourth class omitted. We perform this analysis on the untransformed data set – in appendix 7 we went through the normal power transformations and while the original data did not display the absolutely highest significance numbers on the tests of normality and homogeneity of variance, it did get completely acceptable results on both. And since the untransformed figures still have a connection to real life applications, it is best to use them.

Since both assumptions are fulfilled, the normal test statistic will work. Also on this smaller set of data the result is a conclusive rejection of the null hypothesis: the year groups have different means on a statistically significant level. This is not surprising as the ANOVA analysis on the larger but transformed dataset showed that same result. The only difference can be seen in the post-hoc tests – the different groupings now seem more conclusive. The first three years (1990, 1995, 2000) are similar enough in their means that they form one unit, while the later two years (2005 and 2010) form two separate groups. Repair times are conclusively going up with time and even more so in later years.

ANOVA F(4, 251) = 20,584, Sig.: 0,000

6.1.7 Kruskal-Wallis analysis of the Class variable

Despite the class variable not being valid for ANOVA analysis – failing to fulfill the assumption of normal distribution – the removal of the fourth class did nevertheless improve the homogeneity of variance to the point that a non-parametric test can be performed on it instead. As mentioned earlier, the Kruskal-Wallis test performs as a nonparametric alternative to the one-way ANOVA analysis.

According to a handbook of statistics (McDonald 2009) the The Kruskal-Wallis test performs its analysis on ranked data: the measurement observations are converted to ranks in the total data set. The smallest value gets a rank of 1, the second a rank of 2, etc.: this conversion is what makes the test less powerful than the ANOVA analysis, since some data is lost and is not taken into account by the test.

Also, the test produces results that are less intuitively understandable than its parametric counterpart. The test is not for identical means or medians – instead it tests for equality of the central tendency of the populations.: "*The null hypothesis is that the samples come from populations such that the probability that a random observation from one group is greater than a random observation from another group is 0.5*.". Another way to put it would be:

H0: the samples come from identical populations.

H1: The samples come from different populations sharing the same shape but with different central tendencies (Statisticssolutions 2011)

In Appendix 9 we can see the output of the Kruskal-Wallis test. The test is able to reject the null hypothesis of identical populations at a 5% level of statistical significance. This would indicate that the classes are separate from each other even from a statistical point of view – not a surprising conclusion, naturally. We can suspect that the positive link between repair times and rising cost and class is valid despite the limited conclusions that can be drawn from the Kruskal-Wallis test: the more expensive cars are more time-consuming to repair. Not surprising.

H: 37,989 – DF: 2 – Sig.: 0.000

6.1.8 ANOVA analysis of the Region variable

Earlier on we also saw that the region variable came relatively close to fulfilling the ANOVA assumptions. The different subgroups did not display a high enough level of homogeneity of variance to completely warrant success. However, using the robust tests of equality of means, Brown-Forsythe and Welch, we might be able to say something about the variable nevertheless. Furthermore there are several post-hoc tests that function despite differing variances between groups, i.e. Tamhane, Dunnett T3, Games-Howell, Dunnett C.

In appendix 10 we can see the output from this analysis. The ANOVA gives a rejection of the null hypothesis, which would indicate that the means of the different regions at different on a statistically significant level and the robust tests of normality support the test’s conclusion. The Brown-Forsythe and Welch tests both indicate that we can safely reject the null hypothesis that the groups’ means are the same.

ANOVA	F(4, 253) = 9,667, Sig.: 0,000
Welch	F(2, 60,770) = 11,809, Sig.: 0,000
Brown-Forsythe	F(2, 108,742) = 10,604, Sig.: 0,000

All four post-hoc tests show similar results: the mean difference is significant at the 5% significance level between all three regions. That is to say, each individual region has its own statistically significant mean. The United States has the lowest mean repair time (139,924 hours) followed in turn by Asia (144,641 hours) and Europe (152, 191 hours). The differences are not large however, especially not between USA and Asia.

6.2 Company-level Analysis

Having looked at the regional level of success in producing cars with low repair times, it will now be interesting to look more closely at the company level. What companies and corporations have produced the largest amount of good or bad cars in terms of repair (and assembly/disassembly) over the last 20 years?

First of all we will group together the car models according to corporation. Several of the companies in this analysis are simply branches of a larger corporation – this is of course especially true of the North American producers (GM, Ford and Chrysler each own several brands), but also some of the Japanese automakers have split off their luxury car divisions into a separate company (Toyota's Lexus, Honda's Acura, and Nissan's Infinity). The reason to look at the corporation rather than the brand is simply to make the comparison smaller and easier to overlook.

It should of course be mentioned that changes always occur in the ownership of companies: presently Hyundai and Kia are in fact merged (since 1998) but since they start out separate it doesn't seem right to group them. As we saw earlier on, there are several similar examples: Renault owns a large share of Nissan, Ford has an interest in Mazda, Volkswagen owns shares in Suzuki, etc. In the comparison we more or less choose to ignore this, looking only at the more historical groupings of the automakers.

In Table 15 we see the corporations and their different brands. Later on, in Table 21 we can see if how many cars each corporation has had the comparison.

Table 15. Corporate brands.

GM	Buick Cadillac Chevrolet GEO Oldsmobile Pontiac Saturn GMC
Ford	Ford Lincoln Mercury
Chrysler	Chrysler Dodge Plymouth Jeep Eagle
Toyota	Toyota Lexus
Honda	Honda Acura
Nissan	Nissan Infiniti
	Hyundai
	Mazda
	Mitsubishi
	Suzuki
	Kia
	Audi
	BMW
	Mercedes
	Volvo
	Jaguar
	Saab
	Peugeot
	Volkswagen

Now to look closer at the performances of individual car models. In Tables 16–20 we can see a summary list of all the car models in the comparison and how they performed on repair times. All the times in the list are total sums of a model's individual subassembly repair times – the grand total of 44 measurements from various subassemblies. These totals have no real world equivalent – they are simply aggregates – but they can be seen as an indicator of the time it would take to take a car apart and assemble it again. And as we have discussed earlier on, this could also be seen as an indicator of how fast a model is to assemble.

The list is divided by year, class and region, and each sub-section is sorted by value: the lowest repair times are at the top of each sub-section, and the highest at the bottom. The smallest and largest numbers of each subsection are highlighted for easier comparison: this way we can see directly what to car models were the fastest and slowest to repair for each year-class.

Table 16. Car model comparison, year 1990.

Class 1: Low–Price – Front Wheel Drive – Inline (straight) engine – Sedans					
ASIA		USA		EUROPE	
Hyundai Excel	116,2	Eagle Summit	114,8	Volkswagen Jetta GL L4	139,0
Suzuki Swift	117,5	Pontiac LeMans	115,9	Volkswagen Fox	147,7
Mitsubishi Mirage	121,4	Geo Prizm	122,1		
Daihatsu Charade	122,2	Pontiac Sunbird	134,6		
Honda Civic	130,1	Mercury Topaz	136,4		
Toyota Corolla	138,4	Chevrolet Cavalier	138,5		
Nissan Sentra	139,4	Ford Tempo	139,6		
Mazda Protegé	146,0				
Class 2: Mid–Price – Front Wheel Drive – Inline (straight) engine – Sedans					
ASIA		USA		EUROPE	
Nissan Stanza	123,3	Chrysler LeBaron Sedan	122,1	Peugeot 405	139,6
Mazda 626	129,8	Plymouth Acclaim	122,4	Volkswagen Passat GL	148,7
Hyundai Sonata	130,5	Dodge Spirit	130,5	Audi 80	150,8
Mitsubishi Galant	133,3	Ford Taurus	130,7		
Honda Accord	140,9	Pontiac Grand Am	131,7		
Toyota Camry	142,8	Oldsmobile Cutlass Calais	133,2		
Acura Integra	149,9	Chevrolet Corsica	135,9		
		Chevrolet Lumina	138,4		
Class 3: Mid–High–Price – Front Wheel Drive – V–engine – Sedans					
ASIA		USA		EUROPE	
Nissan Maxima	135,4	Dodge Dynasty	135,4	N/A	
		Mercury Sable	135,6		
		Pontiac 6000	137,9		
		Eagle Premier	139,8		
		Dodge Monaco	140,4		
		Pontiac Grand Prix	141,6		
		Buick Skylark	141,7		
		Oldsmobile Cutlass Ciera	142,2		
		Buick Century	142,4		
		Pontiac Bonneville	142,5		
		Oldsmobile Cutlass Supreme	144,5		
		Oldsmobile 88 Royale	144,9		
		Buick Regal	150,7		
		Buick LeSabre	150,9		
		Chrysler New Yorker Salon	160,4		
Class 3: Mid–High–Price – Front Wheel Drive – V–engine – Sedans					
ASIA		USA		EUROPE	
Mazda 929	127,5	Cadillac Brougham	149,5	Volvo 760	141,9
Infiniti Q45	171,5	Lincoln Town Car	157,0	BMW 750i	183,2
Lexus LS400	179,2			Mercedes–Benz 420	204,9

Table 17. Car model comparison, year 1995.

Class 1: Low–Price – Front Wheel Drive – Inline (straight) engine – Sedans

ASIA		USA		EUROPE	
Suzuki Swift	118,3	Saturn SL	114,2	Volkswagen Jetta III	133,5
Honda Civic	125,8	Dodge Neon	119,1		
Hyundai Elantra	126,5	Geo Metro	120,8		
Hyundai Accent	127,8	Chevrolet Cavallier	126,8		
Mitsubishi Mirage	129,5	Eagle Sumit	129,9		
Nissan Sentra	131,0	Geo Prizm	137,0		
Kia Sephia	133,2	Ford Escort	140,0		
Toyota Tercel	133,5				
Toyota Corolla	138,3				
Mercury Tracer	140,0				
Acura Integra	143,2				
Mazda Protegé	143,8				

Class 2: Mid–Price – Front Wheel Drive – Inline (straight) engine – Sedans

ASIA		USA		EUROPE	
Mitsubishi Galant	129,2	Pontiac Sunfire	126,9	Volvo 850	131,9
Hyundai Sonata	135,4	Oldsmobile Achieva	134,3		
Nissan Altima	138,2	Pontiac Grand Am	137,3		
Mazda 626	151,4	Ford Contour	139,2		
Infiniti G20	155,6	Mercury Mystique	139,4		

Class 3: Mid–High–Price – Front Wheel Drive – V–engine – Sedans

ASIA		USA		EUROPE	
Nissan Maxima	144,0	Mercury Sable	133,8	Saab 9000	138,0
Honda Accord	145,2	Ford Taurus	136,9	Volkswagen Passat	150,1
Mitsubishi Diamante	148,5	Chrysler Concorde	137,1	Audi A6	158,0
Lexus ES300	157,8	Eagle Vision	137,4	Audi 90	163,1
Toyota Camry	158,7	Pontiac Grand Prix	137,5		
Acura Legend	162,9	Oldsmobile Cutlass Supreme	138,4		
Toyota Avalon	164,6	Chevrolet Lumina	139,3		
		Dodge Intrepid	139,6		
		Oldsmobile Aurora	140,6		
		Buick Century	141,9		
		Oldsmobile Cutlass Ciera	142,6		
		Pontiac Bonneville	143,9		
		Buick LeSabre	145,0		
		Oldsmobile Eighty Eight	145,3		
		Buick Regal	147,7		

Class 4: High–Price – Rear Wheel Drive – V–engine – Sedans

ASIA		USA		EUROPE	
Mazda 929	162,6	Cadillac Fleetwood	140,5	BMW 530 i	173,5
Infiniti J30	164,7	Lincoln Town Car	155,1	BMW 740	192,3
Infiniti Q45	172,5			Jaguar XJ12	214,3
Lexus LS400	181,9			Mercedes–Benz E420	257,6

Table 18. Car model comparison, year 2000.

Class 1: Low–Price – Front Wheel Drive – Inline (straight) engine – Sedans

ASIA		USA		EUROPE	
Kia Sephia	124,0	Dodge Neon	118,0	Volkswagen Jetta	146,2
Mitsubishi Mirage	125,1	Saturn SL2	119,3		
Hyundai Accent	125,2	Pontiac Sunfire	123,6		
Honda Civic	131,0	Chevrolet Cavalier	127,5		
Hyundai Sonata	132,8	Chevrolet Prizm	138,6		
Daewoo Leganza	133,9	Ford Escort	144,7		
Suzuki Esteem	134,5	Ford Focus	145,6		
Daewoo Nubira	135,7				
Hyundai Elantra	136,5				
Acura Integra	138,1				
Daewoo Lanos	138,9				
Mazda Protegé	139,0				
Nissan Sentra	139,4				
Toyota Echo	139,7				
Nissan Altima	141,9				
Toyota Corolla LE	145,2				
Honda Accord	158,4				

Class 2: Mid–Price – Front Wheel Drive – Inline (straight) engine – Sedans

ASIA		USA		EUROPE	
Acura Integra	139,0	Dodge Stratus	127,7	Volkswagen Passat	171,9
Toyota Camry	144,1	Chrysler Cirrus	128,9		
Infiniti G20	148,0	Pontiac Grand Am	129,0		
Mazda 626	159,3	Oldsmobile Alero	132,8		

Class 3: Mid–High–Price – Front Wheel Drive – V–engine – Sedans

ASIA		USA		EUROPE	
Mitsubishi Galant	136,4	Buick LeSabre	134,3	Audi A4	166,7
Acura 3.2 TL	140,4	Buick Century	134,5		
Mazda Millennia	145,7	Buick Regal	134,5		
Mitsubishi Diamante	146,8	Pontiac Bonneville	137,1		
Nissan Maxima	148,4	Chevrolet Malibu	137,4		
Infiniti I30	152,9	Oldsmobile Intrigue	140,9		
Toyota Avalon	162,7	Pontiac Grand Prix	141,1		
		Chevrolet Lumina	144,3		
		Ford Taurus	148,0		
		Mercury Sable	148,7		
		Chrysler 300M	150,1		
		Chrysler LHS	150,1		
		Chrysler Concorde	150,3		
		Dodge Intrepid	150,3		
		Chevrolet Impala	153,1		

Class 4: High–Price – Rear Wheel Drive – V–engine – Sedans

ASIA		USA		EUROPE	
Infiniti Q45	164,5	Cadillac Catera	141,3	Jaguar S–type	184,9
Lexus GS 300	170,8	Lincoln Town Car	160,5	Mercedes Benz C280	186,2
Lexus LS400	181,7	Lincoln LS series	161,5	BMW 540iA	197,0
				BMW 750iL	198,8
				Mercedes–Benz E430	206,9
				Jaguar XJ8	207,8

Table 19. Car model comparison, year 2005.

Class 1: Low–Price – Front Wheel Drive – Inline (straight) engine – Sedans					
ASIA		USA		EUROPE	
Kia Rio	123,0	Saturn ION	120,6	Volkswagen Jetta	151,2
Hyundai Accent	126,3	Dodge Neon	121,6		
Hundai Elantra	128,3	Chevrolet Aveo	136,8		
Kia Spectra	133,8	Ford Focus	146,1		
Toyota ECHO	139,8	Chevrolet Cobalt	158,8		
Suzuki Aerio	142,4				
Kia Optima	143,1				
Suzuki Forenza	145,1				
Nissan Sentra	145,6				
Honda Civic	151,7				
Mitsubishi Lancer	152,7				
Mazda 3	153,5				
Toyota Corolla	158,7				

Class 2: Mid–Price – Front Wheel Drive – Inline (straight) engine – Sedans					
ASIA		USA		EUROPE	
Hyundai Sonata	134,2	N/A		Saab 9–3	149,7
Nissan Altima	150,2			Volvo S40	157,0
Mazda6	153,5			Volkswagen Passat	160,9
Acura TSX	155,0				
Honda Accord	169,7				
Toyota Camry	171,2				

Class 3: Mid–High–Price – Front Wheel Drive – V–engine – Sedans					
ASIA		USA		EUROPE	
Hyundai XG350	146,8	Buick LeSabre	136,5	Audi A4	172,2
Kia Amanti	149,2	Pontiac Bonneville	138,0		
Nissan Maxima	153,6	Chevrolet Malibu	139,0		
Mitsubishi Galant	161,8	Chrysler Sebring	139,9		
Lexus ES 330	166,0	Dodge Stratus	139,9		
Acura TL	167,4	Buick Century	140,6		
		Buick LaCrosse	142,9		
		Pontiac G6	143,1		
		Chevrolet Impala	144,4		
		Pontiac Grand Prix	149,3		
		Chrysler 300	149,6		
		Ford Taurus	154,3		
		Ford Five Hundred	154,5		
		Mercury Montego	155,4		

Class 4: High–Price – Rear Wheel Drive – V–engine – Sedans					
ASIA		USA		EUROPE	
Infiniti Q45	163,0	Lincoln Town Car Signature	151,4	Jaguar S–Type	182,6
Lexus LS 430	172,5	Lincolm LS	158,1	Jaguar XJ8	185,7
Lexus GS 430	179,4	Cadillac CTS–V	170,5	Mercedes–Benz S430	202,1
		Cadillac STS	176,4	BMW 545i	213,3
				Mercedes–Benz E500	215,0
				BMW 745i	216,9

Table 20. Car model comparison, year 2010.

Class 1: Low–Price – Front Wheel Drive – Inline (straight) engine – Sedans

ASIA		USA		EUROPE	
Hyundai Accent	125,3	Chevrolet Aveo	139,9	N/A	
Kia Rio	132,3	Chevrolet Cobalt	161,3		
Nissan Sentra	136,5	Ford Focus	162,2		
Nissan Versa	141,8				
Kia Forte	145,6				
Hyundai Elantra	145,9				
Honda Civic	146,9				
Toyota Yaris	148,3				
Mazda 3	159,0				
Toyota Corolla	161,5				
Suzuki SX4	162,8				
Mitsubishi Lancer	167,6				

Class 2: Mid–Price – Front Wheel Drive – Inline (straight) engine – Sedans

ASIA		USA		EUROPE	
Nissan Altima	130,4	Chevrolet Malibu	142,0	Volvo S40	152,8
Kia Optima	138,6	Dodge Avenger	151,1	Volkswagen Jetta	153,5
Hyundai Sonata	146,4	Chrysler Sebring	151,3	Volkswagen Passat	165,7
Suzuki Kizashi	152,6	Mercury Milan	159,1		
Mazda 6	158,8	Ford Fusion	160,2		
Mitsubishi Galant	164,6				
Honda Accord	165,6				
Toyota Camry	179,1				

Class 3: Mid–High–Price – Front Wheel Drive – V–engine – Sedans

ASIA		USA		EUROPE	
Hyundai Azera	158,8	Chevrolet Impala	145,7	N/A	
Acura TL	167,2	Buick Lucerne	151,2		
Nissan Maxima	171,6	Buick Lacrosse	154,6		
Toyota Avalon	176,3	Lincoln MKZ	166,9		
Acura TSX	178,3	Ford Taurus	174,5		
Lexus ES 350	185,4				

Class 4: High–Price – All Wheel Drive – V–engine – Sedans

ASIA		USA		EUROPE	
Infiniti M35	164,1	Lincoln MKS	165,6	Saab 9–5	167,0
Infiniti G37	165,7	Cadillac STS	179,6	Audi A6	183,3
Acura RL	173,3	Cadillac CTS	187,9	Volvo S80	192,8
Lexus GS 350	180,8			Audi A8	193,3
Lexus IS 350	182,6			Audi S4	193,3
				BMW M3	220,3
				Mercedes–Benz C350	224,8
				BMW M5	229,5
				Mercedes–Benz E350	234,5

Company ranking

The tables are interesting to browse – we can see how well individual models have performed, and perhaps even developed over the years. Take for instance the example of the Ford Taurus. It is a popular model that has been a part of the comparison during all the five years. Furthermore it was the flagship of Ford's turnaround – Ford's effort to show that they could compete with the Japanese automakers in the end of the 80s (See for instance Womack et al. 1990; Maynard 2003, etc.) It is well known as an especially lean-designed model, with everything this entails. Observing it in the tables we see two problems – its repair time has deteriorated over the years, and its ranking has fallen. With each incremental redesign, it seems that the car has become less and less easy to assemble/disassemble.

However, despite their interesting points, the tables are still not providing us with an easy overview of what companies have "succeeded" or "failed" most often. To find this out we have to form a combination ranking system that allows us to weigh the companies against each other.

An extremely simple way of doing this is to look only at the top and bottom results and see how often a company shows up in either category. We take the top three and bottom three of each year-class, and simply count how often a corporation has a model on either list. The models in the middle we do not look at; they are "run-of-the-mill" and we are interested only in the best and worst.

In Table 21 we see the listing of how often each corporation has scored a model on either the top-three list or the bottom-three list. The most models by far have been produced by General Motors – this is only logical, since GM was for a long time the largest automaker in the world, producing the largest amount of cars. Ford, Chrysler and the Asian companies follow, and at the end of the list we see the European companies (only from the North American market perspective of course). As we remember from earlier on in the analysis, the Asian and North American car companies have about the same amount of models in the comparison; the GM dominance might seem large but we must remember that their models are spread out over several brands. It is true that there are fewer European cars in the comparison – this is simply an effect of the choice of region to study. There are certainly more European sedans available, spread out over several more companies not studied in this analysis.

GM is at the top of the top-three list, but since we know that this corporations has a very large amount of models in the comparison, it is only natural to suspect that the reason the company is at the top is simply that they have such a large lineup that they inevitably have many "good" models and "bad" models in the mix.

The best way to compensate for this and get a real overview is simply to make each result relative: we divide each corporation's result by the total amount of models the corporation has in the comparison. This way we have a percentage, something that shows how often a company succeeds or fails depending on how often they launch a new model. These relative values are displayed in Table 22.

Table 21. Car model ranking lists, by corporation.

Total no of cars in comparison		**No of cars placing top-3 in category**		**No of cars placing bottom-3 in category**	
GM	74	GM	20	Toyota	10
Ford	30	Chrysler	9	BMW	7
Toyota	28	Ford	7	Honda	6
Nissan	26	Honda	5	Ford	6
Chrysler	26	Nissan	5	Volkswagen	5
Honda	21	Kia	3	Mazda	5
Hyundai	16	Mazda	2	Mercedes	5
Mazda	13	Hyundai	2	GM	4
Mitsubishi	12	Mitsubishi	1	Audi	4
Volkswagen	11	Suzuki	1	Nissan	2
Kia	9	Volvo	1	Jaguar	2
BMW	9	Peugeot	0	Mitsubishi	1
Mercedes	8	Saab	0	Suzuki	1
Audi	8	Mercedes	0	Chrysler	1
Suzuki	7	BMW	0	Saab	0
Volvo	5	Toyota	0	Volvo	0
Jaguar	5	Volkswagen	0	Hyundai	0
Saab	3	Jaguar	0	Kia	0
Peugeot	1	Audi	0	Peugeot	0

Table 22. Car model (relative) ranking lists, by corporation.

% of cars placing top-3 in category		**% of cars placing bottom-3 in category**	
Chrysler	35 %	BMW	78 %
Kia	33 %	Mercedes	63 %
GM	27 %	Audi	50 %
Honda	24 %	Volkswagen	45 %
Ford	23 %	Jaguar	40 %
Volvo	20 %	Mazda	38 %
Nissan	19 %	Toyota	36 %
Mazda	15 %	Honda	29 %
Suzuki	14 %	Ford	20 %
Hyundai	13 %	Suzuki	14 %
Mitsubishi	8 %	Mitsubishi	8 %
		Nissan	8 %
		GM	5 %
		Chrysler	4 %

Looking at the list of the best performing companies we see that Chrysler, Kia and GM top the list. Chrysler and Kia show impressive numbers – over a third of their cars are winners in terms of repair time. GM is no longer first but third: they have had a lot of winners, but also a lot of models that haven't made the top. Honda and Ford follow and surprisingly enough we also see Volvo. Despite having few cars in the comparison, they had a lot of winners relatively speaking (one out of five). The rest of the top list is all Asian companies – but Toyota is not among them. The South Korean companies Kia and Hyundai performed very well – none of their models are present on the list of worst-performing cars.

Looking at the list of the worst performing (in terms of repair time) cars we see several European companies at the top of the list: BMW, Mercedes, Audi, Volkswagen and Jaguar. Perhaps we can chalk this up to different design cultures, different quality classes, unfamiliarity with these brands in an American repair shop setting (see the discussion on this in the 'Limitations' section) – but nevertheless the results are quite bad. We see the North American car companies on this list too, as well as many of the same the Asian (Japanese) car companies we saw on the top list. Toyota is only on the list of the worse performers, though. Over a third of their cars are amongst those slowest to repair. Because of Toyota's strong track record in other fields of production and design this throws a curious light over the whole investigation.

7 DISCUSSION

In summary – an intriguing analysis. We were able to draw several puzzling conclusions about the usage of assembly-friendly design from our comparison, conclusions that were not entirely expected at the outset. The North American expertise in easily repairable/assemblable cars, the European bottom ranking in the same, Toyota's limited success – all of these must be discussed further. We will also see the answers to the original three research questions:

1. *What are the trends in automotive assembly time, looking at the last 20 years?*
2. *What companies consistently produce the cars with lowest (and highest) assembly times?*
3. *Can DFA time data reliably be extrapolated from certain types of repair data?*

7.1 Possible conclusions

In the following sections we go through the answers of the statistical analysis and the individual company comparison gave. We will look at each and try to interpret the connections to the theory section and the implications to the real world industry.

7.1.1 A rising trend in annual repair time

As we could see during the analysis, the average repair times have been rising steadily since 1990 – with about 10 hours between year groups since 2000, and with slightly less before that. Now this limits our conclusions to a few possibilities. Firstly, that cars have grown more complex or simply more cramped since the beginning of the 90s – a very logical conclusion. However, despite what we might have assumed in the beginning, the knowledge of efficient Design for Assembly methods does not seem to have resulted in industry-wide reductions in repair/assembly times, at least not over the last two decades. This despite the fact that the methodology has been well known for at least double that time and despite at least some of the automotive producers confessing to using the techniques.

That the cars have grown more complex does not come as a surprise at all – we all know that a remarkable amount of new equipment has been added to the new basic car model over the last 20 years; options that were only present on the most expensive cars are now commonplace on the cheapest models. More stringent safety measures have worked their way into the industry standards, probably increasing the amount of components included in a "normal" car.

It is also possible to assume that size has had something to do with the issue – perhaps cars were bigger in the beginning of the 90s and new design standards that incorporate fuel economy and better aerodynamics have produced cars somewhat smaller in dimensions. The really large sedan models may have found their successor in the SUVs and crossover models, both of which have been omitted from this comparison. Weight doesn't seem to come into the equation on the other hand, there is nothing that says a heavier vehicle would be easier or harder to disassemble.

There is also the option that certain assembly techniques have been taken into use that limit the possibility of opening up and repairing a car. The use of epoxy glue and snap fits that break when opened might certainly be two such techniques, and both are certainly used in automotive assembly today.

Possible outcomes of our results

We can loosely divide these possibilities into four groups:

1) there is no link between repair and assembly,

2) there is a link between repair and assembly, but Design for Assembly is simply not used in the automotive industry, at least not commonly,

3) there is a link between repair and assembly, and Design for Assembly is used in the automotive industry, but the cars are growing more complex at such a rate that Design for Assembly cannot compensate – the cars' repair times are growing anyway

4) the whole thing is a function of size – bigger cars are easier to repair and design doesn't really come into it.

Let us go through each of these possibilities and try to prove or disprove them, step by step,

Number 4 – size matters

The fourth possibility is actually the easiest to disprove. In the appendices we have lists of the models’ performances in terms of repair time, but also lists of the cars’ dimensions: length, width and height. If we sum up these three or better yet multiply them, we gain a metric of size. Analyzing this metric using the same ANOVA measures used in the repair time comparison, it is possible to see that the average car size has actually grown over the last twenty years (statistically significant at the 0,05 level) an that the total (outer cube) volume of the average car has grown with almost a cubic meter since 1990. Furthermore, if we choose, we can easily test to see whether there is any correlation between size and high or low repair time. Choosing to do so, we see a correlation (Pearson) of 0,43. This relatively strong positive correlation indicates that the larger the size of a vehicle, the higher its repair time – not lower! This follows more closely to our "class" theory than to the big-is-easy-to-repair theory. The higher-priced models are often bigger than the economy models, but the higher-priced models are also harder to repair as we saw earlier on. This line of reasoning seems to be able to produce the positive correlation.

Number 1 – no link

The first possibility, on the other hand, it's very hard to disprove. It is a central assumption of this comparison that repair times and assembly time are indeed somewhat related – not a 1:1 relation certainly, but we assume that improving a vehicle's assemblability will also show up positively when trying to repair said vehicle.

This work makes no attempts at numerically proving or disproving this hypothesis, and given that the results of the analysis are unexpected we naturally have to take the assumption under consideration. However, at this point in time there is no possibility to further prove or disprove the assumption, not without additional research in other areas – more about this in the section on suggestions for future research. At the moment we will just have to take that assumption as given and consider what our results mean if we can assume it to be true. If future research proves the assumption false, we shall just have to discard the evidence from this analysis.

Numbers 2 – 3 – some kind of link

Conclusions number three and four are both interesting and mind provoking options, since they both have something to say about the automotive industry that we did not already know.

First of all conclusion three – that Design for Assembly is already in extensive use amongst automotive designers, but that the techniques cannot keep up with the pace of developing complexity in the cars. As our analysis showed, the cars are undoubtedly getting more complex (or at least more cramped for repair) and we know that at least Ford Motor Company, Chrysler and GM have said that they are using the Design for Assembly techniques (see Chapter 2.3). Since best practices tend to move swiftly between competitors, it is only natural to assume that other automakers have also acquainted themselves with the methodology in some form or the other.

It is possible that the car is simply "too perfect" already – that no improvements can be made on the basic design already in use. We do know that the car has been in production for about 120 years already (from Gottlieb Daimler's and Carl Bentz' first creations late 1880s), and that the product has had a long time to mature. It is undoubtedly one of the most intensely developed products on earth. Perhaps all Design for Assembly modifications possible were made already during the 70s and 80s.

However, the two case studies presented in Chapter 3.3 – where Boothroyd-Dewhurst Inc. redesigns an instrument panel and a car seat – seem relevant to this question. If we compare the instrument panel with for instance the one off the European car model shown in Chapter 5,4 we see that there is quite a difference.

In fact, the average instrumentation panel Remove&Install time in this comparison is 6 hours 36 minutes. If we loosely consider that half of this time goes to removal, half to installation (a probably incorrect assumption, but enough for a rough measure) that means 3 hours 18 minutes of assembly time. The assembly time of the truck instrument panel before redesign in Boothroyd-Dewhursts example is 63 minutes. Even if we assume a generous measure of time for instrument insertions, finish, etc. and even revise our assumption on how much time goes to removal in a repair shop – the average car is still nowhere near the redesigned, DFA assembly time of Boothroyd-Dewhurst's new instrument panel (12 minutes).

But the really interesting thing is that there are cars that come close. The lowest instrumentation panel repair time in the comparison goes down to as low as 18 minutes – a 2010 Asian model . If we halve this number we get 9 minutes assembly/installation – very close to Boothroyd-Dewhurst's expected 12 minutes. A special case, but nevertheless an interesting thing to ponder. Perhaps Design for Assembly is not really as widely used as we had hoped.

Admittedly a truck's instrument panel may be somewhat simpler and more accessible than that of a sedan model, but there is enough of a difference here to raise our suspicion. Would there really be so much to improve on an already perfect product? If a 93% percent reduction in assembly time of an instrument panel is possible between average and DFA "ideal" (from 3 hours 18 minutes to 12 minutes) and that difference covers about a third of the average repair time increase we noticed between years 2005 and 2010 (10,6 hours) – it seems very possible that redesigning other components in addition could bring us at least to a standstill against the rising complexity, perhaps even to a decreasing trend in repair times.

The pickup seat example corroborates this train of thought. The average seat bottom Remove&Install time in this comparison is 42 minutes (which probably includes a certain degree of assembly and disassembly, since the seat bottom is not detachable right away). If we again loosely consider that half of this time goes to removal, half to installation, that means 21 minutes assembly/installation. The assembly time of the pickup seat before redesign in Boothroyd-Dewhursts example is 24 minutes – very close, in fact.

The lowest seat bottom repair times in the comparison go down to as low as 12 minutes. If we halve this number we get 6 minutes assembly/installation – also very close to Boothroyd-Dewhurst's expected redesign example of 4,3 minutes. 22 car models (out of 316) have 12 minute seat bottom repair times. So we can only conclude – some are better than others at DFA. The maximum seat repair time is 6 hours…

This leads us to consider possibility number three – that Design for Assembly is simply not used to its fullest extent in the automotive industry. Being an old and widely accepted methodology (at least in North America) this seems curious. As we saw earlier on in Chapter 3.3, assembly labor makes up about 10–20% percent of the product's price. Considering the automakers previous efforts to automatize their production – robotic welding, robotic spray painting, etc. – it seems odd that they would not strive to minimize the amount of labor needed to install the more complicated components towards the end of the process.

Human dexterity is necessary for such jobs, but why not minimize the efforts necessary? Especially considering that the established automakers are being challenged by companies in countries with lower wages. Perhaps the reason for not using Design for Assembly to its fullest extent simply lies elsewhere – the reason may be a balancing act between multiple considerations.

The strong automotive suppliers

In practice, a manufacturer of a complex product will rely upon the components offered by a subcontractor, or several subcontractors. This puts a whole range of considerations on the board: will the sub-contractors want to (or be allowed to) take part in the product design? Are they large enough (or small enough) to participate on the desired level? Are they in fact so large that they have no wish to modify their designs in a way more beneficial to the manufacturer, and if they are, at what price? Will the gains from the redesign outweigh the financial benefits of using an over-the-counter model of the component?

According to Maxton & Wormald 2004: 131–163, the automotive designer must walk a difficult path – pushing for innovation, while at the same time respecting the constraints of the marketplace. There is the inherent conservatism of the average customer take into account, but also the conservatism of the supplier market.

At the moment, only about a fourth (25%) of the value added on a car is done at the automotive assembly plant. The closest suppliers (Tier 1) stand for 38% value added, second tier 26% and third tier 11%. 75% of the cost of the vehicle was bought in from suppliers in 1995, as opposed to only 25% in 1955. (Maxton & Wormald 2004: 144). A clear shift from vertical integration to outsourcing.

The Japanese automakers probably led the way, focusing on close cooperation instead of forming mammoth corporations, and choosing to use the Just-in-Time system to integrate the suppliers more closely (most often) than an American company. The Keiretsu/Zaibatsu form of close company governance and equity ties supported this integration.

The subsequent Lean manufacturing explosion brought the ideas of Just-in-time production and supplier involvement to the international stage. For various reasons, the outsourcing of still more important assemblies and design choices became an important trend in the automotive industry. It is a question of the car companies choosing to focus on core competencies, of course, but also a question of inviting/forcing the suppliers to shoulder a greater responsibility for the success of new models.

Look for instance at German company Bosch, providing fuel injection systems and electronic systems internationally. American Visteon, Japanese Denso, Canadian Magna, Swedish SKF – all of these and several more are good examples of first tier supplier that started out as local suppliers for the "home brands" but are now multi-billion dollar enterprises who supply not only the local companies, but work internationally without boundaries. In Europe this trend became especially clear when the European Union single market broke down barriers between the former national car industries and created an even playing field. Now there are Bosch electric systems in a significant part of the European cars, and SKF bearings as well.

Taking this development into consideration – how in-charge are the automotive engineers really of their own creation? What can an automotive engineer really design? The international strength of the largest suppliers, the suppliers own motivation to produce larger series of products to achieve economies of scale and on top of this, the automotive companies' wishes to reuse solutions in so-called product families – the automotive engineer is quite limited to specific set of solutions. Design for Assembly is at its most effective when radical changes can be made, in shape, material use and functionality. Perhaps the automotive industry is simply too rigid to become as cost effective as it could?

7.1.2 North American cars are the fastest to repair

The second surprising conclusion of the analysis was that North America as a region performed better in the comparison than Asia (if yet by a thin margin). Since the 80s, the Lean production methodologies of the Japanese automakers have been considered the best available and it has become the new industry standard for efficient productivity. However, in this particular comparison, the North American brands display a (somewhat) better result – an average of 142 hours versus an average of 148 hours.

Now, first of all we must look at the most obvious possibility: that there is not a strong connection between fast repair times and skill in Lean methods. This would be a somewhat surprising conclusion. The Japanese car manufacturers achieved their fame through the usage of efficient production methods, and have after that strived to achieve further success by utilizing Lean design (see (Cusumano & Nobeoka 1998) for as closer view on the Japanese Lean design practices). We could easily assume, therefore, that a company striving to achieve Lean design methods will tend towards adapting Design for Assembly techniques of some kind. This does not seem to be the case – if we assume that the Japanese producers are the only experts in Lean production.

It is possible that what we are looking at is simply a more level playing field after the Japanese dominance during the 70s and 80s. Lean production methods is the industry standard now and achieving lean design is the prerogative of everyone. The American automakers have as good a chance as anyone to achieve this – perhaps even better considering that they struggled hard to overcome their deficiencies against the Japanese earlier on.

Be this how it may, it is clearly possible to conclude that there is no real link between Design for Assembly and overall company success in the automotive market. The North American automakers faced possible bankruptcy several times during the last decades, especially in the wake of oil price shocks (see for instance Maynard 2003 for a closer look on the ups and downs of the American auto industry). Also, we also saw that Toyota – the company that grew to usurp GM's place as the biggest car producer of the world – is nowhere to be seen in the list of fastest repair times. This is something we'll discuss more below.

7.1.3 Chrysler and Kia produce the most repair/assembly friendly cars

Overall the American car companies do very well in the analysis. Looking at the individual companies, we see that the American Big Three are all in the top five. They are joined there by Kia and Honda. Chrysler and Kia are in fact the big winners with over a third of their cars being at the top of the fastest repair time comparison.

That Chrysler (first) and Honda (fourth) are present at the top is understandable. According to Cusumano & Nobeoka (1998: 78–79) Honda has a reputation for innovative product designs among the Japanese automakers. They have a history of strong project managers, strategic component sharing between models and a corporate structure that is very suitable for concurrent engineering – the prerequisite of DFA. And Chrysler (According to Jones 1995) when faced with bankruptcy in the early 1980’s (temporarily saved by a Government rescue package) turned to Honda for help on reviving its design culture. Honda taught Chrysler its product development technique, based around platform teams, which operated on a concurrent engineering principle. Chrysler was able to produce a new model, the Neon – that was developed fast (31 months compared to the usual 60), with less manpower (about 700 engineers instead of 1400) and that was also faster to manufacture. It included fewer parts and manufacturing steps, and the man hours needed to weld, paint and assemble the car fell from a normal 35 hours/per car to 22 hours/per car. Interestingly enough, though, Honda has almost equally many cars on the bottom list, making their performance less strong overall. Chrysler only has one car on the bottom list.

Also interesting is South Korean Kia on the second place in the list – a mere upstart compared to the North American and Japanese car companies. The somewhat older Hyundai (tenth) is also present on the top list, but with nowhere near as good results. Of course, since 1998, the two companies are part of the same corporation, but the two brands have been allowed to continue without much inter-mixing, so the strong result of Kia still stands on its own.

Kia has no cars on the bottom list. This is quite a mean feat, in many ways. According to Griffiths (2006), Rechtin (2005) and Jackson (2007) Kia models have had a utilitarian reputation – good vehicles with good content, but nothing that turns heads on the street. This might reflects the relative youth of Kia's exports (US introduction in 1994), or simply a difference in value culture. But Kia models are by no means tin boxes, they are have everything their competitors offer (plus a 10-year warranty) mostly at a lower price. Design for Assembly does not equal basic products – Chrysler's, GM's, and Honda's rankings disprove that theory. But apparently Kia has managed to combine DFA with overall company success – something its fellow top list companies have not done equally well. A company to study closer, certainly.

Ford's fifth place in the top list we can almost discount, because they have an equally large presence on the bottom list – basically about 20% of their cars are very good, and about 20% of their cars are very bad (at least in terms of repair/assembly). They simply have an uneven performance record. It is also worth noting that their bad and good performances have come evenly dispersed throughout the last two decades. According to Jones (1995) a similar story to Chrysler's is true for Ford, with its Taurus model that was developed under an experiment with cross-functional platform teams in 1985. Ford too faced bankruptcy in 1981, but the success of the Taurus, which ranked very high on manufacturability (see the comparison with GM’s Grand Prix model in Section 2.4), gave them a chance to recover. Afterwards, however, the old organizational structure returned, with the problematic product development processes that entailed. According to Maynard (2003) the tradition of strong leaders that occasionally reshuffle the entire production deck has meant the American Big Tree have a somewhat irregular history of success and failure.

GM's third place is, in comparison, more impressive. They've produced by far the largest amount of different models (74 sedans in the comparison) and nevertheless close to a third of them have been winners in terms of repair/assembly. Furthermore, a very few of their products have gone to the bottom of the list (about 5%).

More unexpectedly, we see Volvo at sixth place. Sure enough, they only have five cars comparison, and one winner is enough to secure a place on the top list. But on the other hand none of Volvo's cars are on the bottom of the list either. A strong performance from a small manufacturer. The rest of the top list is made up of the large Japanese car companies, all of which have some good models and some bad models.

7.1.4 European cars (and Toyota's) are the slowest to repair

Focusing instead on the bottom list, we can clearly see that it is dominated by the European brands. BMW, Mercedes, Audi, Volkswagen and Jaguar have the dubious honor of being the bottom five of the bottom list. This is no surprise; the regional comparison showed that the European brands performed worst by far when compared to North America and Asia (179 hours on average, compared with 142 and 148 respectively). In BMWs case seven of their nine cars in the comparison ended up on the bottom list, resulting in a "loss rate" of almost 80%. The runners-up do not fare well either – Mercedes at about 60%, Audi at about 50%, Volkswagen at 45% and Jaguar at 40%.

Womack et al. 1990:118 showed that the European automaker were no better than their American counterparts in the art of lean design (in the mid 80s), looking at such indicators as average engineering hours per new car, average development time per new car, number of body types per new car, return to normal productivity after new model, return to normal quality after new model, etc. The Japanese automakers were better than both. There is no way to directly link these finding to those we have seen in this comparison, however.

An alternative explanation that could probably explain the poor results of the European brands could be the subjective nature of the source data. Using only one, North American source of repair data could have a negative impact on the European models. Most of the Asian models are in fact very common in North America (see Figures 6 and 15, showing the mix of the car fleet in North America), and some of them are even produced domestically. The European brands on the other hand are mostly imported and are markedly more unusual than the Asian and North American brands. It may be that some of the time differential can be explained by unfamiliarity with the brands – the repair shops that have supplied data for the repair guides will naturally be less proficient at repairing uncommon and unusual. In the case of the Asian cars, such an unfamiliarity cannot be said to exist (by 1990 and forwards).

7.1.5 High Quality and Repair/Assembly might not mix

It is strange to notice that two of the world's brands most noted for their quality and dependability – Toyota and Mercedes – end up so low on the list. Ten out of

28 Toyota models end up on the bottom list, and for Mercedes it's five out of eight. Interestingly enough, even though we may have previously combined the Toyota and Lexus models under one brand, it's only the normal Toyota models that end up on the bottom list. The "higher class" Lexus models could understandably be harder to repair, as the Kruskal-Wallis test of the Class-factor indicated.

Why does Toyota have no models on the top list while the other Japanese companies do? Honda performs much better in comparison. We are forced towards a strange conclusion: that Toyota would use design methods that perform worse on repair (assembly), possibly because Toyota focuses more on other factors (detrimental to ease of assembly).

This conclusion seems quite counterintuitive. Toyota has been a star producer of high quality affordable vehicles during the last decades – it is only during the last few years some concerns have surfaced in connection with Toyota cars, more specifically the jamming gas pedals models that were recalled during 2009–2010. Before that (and still now) Toyota has had a cast-iron solid reputation for good design and generally performed very well in the market. They rose to become the largest producer of cars in the world in 2008; a company with bad design techniques could hardly achieve something like that.

However, we did find earlier on that success in this comparison has very little to do with overall company success. It is possible that Design for Assembly is not in prominent use at Toyota, but that their other successful business practices might compensate for any hypothetical "loss" from slow assembly. It is well known that Toyota favors conservative, well-proved technology solutions in its models – this is something even old Taichi Ohno himself dictated (Ohno 1988:63; Liker 2003:31). That could be a reason why extensive redesign according to Design for Assembly would not be favored by Toyota. But as we remember from Sections 2 and 4, Design for assembly is in fact supposed to improve product quality. Furthermore, concurrent engineering is certainly being used at Toyota and there is no reason why ease of assembly would not be taken into consideration under such a regimen.

In fact, this whole last possible result of the analysis stands on very unsteady legs. Any possible link between quality and DFA would have to be investigated much more closely to be able to say anything tangible at all. Results that are so counter-intuitive that they would force you to re-evaluate the data itself rather than accept the results are generally speaking not good results. It is possible that Toyota's results are more a fluke than anything else, and we already stated that the most probable reason for the poor European results is the skewed, small sample. Therefore we leave this conclusion as unsubstantiated in the wait for more material to study.

7.2 Limitations

In this section we look at the limitations in our methods, sources and analysis.

Single source of data

One limitation that springs readily to mind is the choice of one single source of data. The Mitchell International Collision Estimating Guides are an excellent source of data with a high degree of detail and reliability. They are, however, based in a certain environment. They are North American guides, giving estimates of how long it will take to repair a car in an American workshop. A workshop recommended by the car manufacturer, a brand approved workshop, but nevertheless an American workshop.

Therefore there is the possibility that such American workshops will have a greater amount of experience in dealing with cars of North American origin – the models produced by the American Big Three. This is not a foregone conclusion, of course – we know that the North American market has long been open to extensive import from both Asia and Europe and that a significant part of the American car fleet consists of non-American brands (see the beginning of Chapter 5 for a breakdown of the American car market).

In effect, the North American perspective may or may not have an influence on the data, but there is a slight chance that the good results of the North American brands come in part from a higher degree of familiarity – the repair shops asked to evaluate how long a certain repair will take might give a lower quote for a model that they are highly familiar with. And a higher quote for an unfamiliar car. It only seems logical.

However, the only way to really make sure that this effect has not played a part in the analysis would be to repeat the analysis with sources from other countries, or alternatively to perform similar analyses for the European and Asian markets, looking only at sources relevant to those markets.

It is quite possible that the latter option is the only possible one, given what we saw in the data selection chapter: European sources of repair data tend to focus on the European market and the American sources on the American market. There are probably similar sources of repair data for the Asian markets, but it is doubtful whether these sources are translated to other languages. Again, we must be flexible when facing practical difficulties in the research.

Different time concepts for repair and assembly

One of the things that cannot be measured without access to more detailed assembly time data is whether the time concepts of the repair manuals approximate that actual assembly. There is a certain value difference between the two sectors. The repair shop bills the customer by time spent on the vehicle, and might tend to overestimate time requirements. Assembly lines on the other hand are mainly interested in producing as many cars as possible and might therefore focus on speed. On the other hand, we might as well consider that this is a systematic bias that will even out for the entire data set – even if repair times are inflated compared to assembly times, that should not form a problem if only all times are inflated equally. But best not to consider the repair times an exact source of assembly time data.

Small data sample

The data that we looked at was undoubtedly small (316 models), and furthermore divided into several year groups and/or classes. In some classes, some regions did not produce any suitable models, some years. The European models were furthermore always in minority when compared to the Asian and American models. It would have been beneficial to have a) a larger set of data and b) a more uniform set of data, with more similar sized groups.

However, the dataset was the biggest possible, given our standards of comparability. There were simply no more sedan type models of a comparable type/price/drive to add to the comparison for each year, when only looking at the American market. Historically, only about 70–80 different four-door sedan models have ever been on offer from the larger automakers (on the North American market) at any given year. The only way to expand the dataset would be to relax some constrictions, the easiest of which would probably be the market chosen for study.

DFA-DFD link assumption

This shortcoming has been discussed in previous sections and it is without doubt a problem to be solved. However, rather than discuss problems further, we will focus more on the issue in the next section – suggestions for future research.

7.3 Suggestions for future research

A European comparison

To solve the problems of small data sample size and of a subjective data source, the best option would probably be to repeat the experiment for the European market, using one or several of the databases that handle more of the European brands (Renault, Citroen, etc.) as opposed to the North American brands (Plymouth, Oldsmobile, etc.). To a large extent, the two comparisons would probably feature the same cars, but the different data sources and any possible differences in "preferred workshop make" – faster repairs on well-known brands – should make the European analysis an interesting addition. A new set of car models would have to be collected from European car guides, the best European sources of repair data determined and time data collected for a suitable amount of subassemblies. None of these tasks are in any way impossible.

In the interest of fairness, a similar investigation should probably be made for the Asian car markets, but because of the language issue this seems a difficult task. A joint venture with other researchers interested in the same issues might solve the problem, however.

Investigating the Design for Assembly/Disassembly/Repair link

A more complex but much more pressing issue would be to quantify the link between fast assembly and fast disassembly. With only one empirical study on the correlation between DFA and DFD (limited to quite small consumer products) we cannot be sure of the link. However, if the link between fast assembly and fast repair can be numerically proven, the results of this work are certainly interesting on a wider scale, together with the fact that the link itself might have strong repercussions on the field of efficient industrial design.

Such a relationship could even prove interesting to automotive companies. If it could be shown that efficient assembly goes hand-in-hand with easy-to-disassemble car models, this could revitalize the industry's interest in DFA techniques. The need to create greener, "made-for-recycling" cars would no longer be an additional burden, but rather a side-effect of an already desirable design method.

However, to prove this relationship could be difficult. The repair data is easy to obtain, but assembly time data is most often a closely guarded secret of the automotive industry companies. Securing such data could be very problematic. However, it may not be impossible, given that the research in question could prove beneficial to the automakers themselves in the longer run. Employees of several of the global automotive companies have published studies on Design for Disassembly (Hartman, Hernborg & Malmsten 2000; Paul, Chung & Raney 2004; Gwon, Hong, Hong & Cho 2007) and even on integrated Design for Assembly and Disassembly (Koganti, Zaluzec, Chen & Defersha 2006).

It might be possible that some car company would even be willing to do an actual assembly/disassembly comparison of some of their own models. In the SAE (Society of Automotive Engineers) article Actual Recyclability of Selected Honda Vehicles (2004), Richard Paul (and automotive recycling consultant), Dennis Chung (of Honda R&D Americas, Inc) and David Raney (of American Honda Motor Co.) outline their actual disassembly of several Honda vehicles to find their level of DFD readiness. A similar cooperation between University and Car Company may well be possible for the DFA/DFD link too.

In the unfortunate event that no actual assembly data can be found from the automotive industry, some other source of data could possibly act as a proxy. A sufficiently large and complex mechanical vehicle should show some similar tendencies when you consider assembly and repair. Motorcycles would be a prime choice, but also tractors, combine harvesters, forest machines etc. could prove a natural source of comparison data. For all of these, repair data is relatively easy to get, and assembly data might be more forth-coming. The objective would be to achieve an average correlation figure (if a product is fast to produce how much faster can we expect that it is to repair?) and vice versa.

This type of investigation is the natural next step and should be undertaken as soon as possible to complete the validity of this work.

7.4 Research contribution

Despite these limitations, the findings from this analysis prove an interesting addition to the very scarce supply of investigations around the usage of "design for" methods made to date. First of all, this analysis is an attempt to bring more objectivity into the field of automotive industry best practices -research.

As we could see earlier on, not many academic surveys have been done to measure the usage of certain design practices in the automotive industry. This is entirely natural, since this type of information is a secret of the companies in the automotive industry. The information may be available to some degree outside the automobile producing companies, for instance in certain industry organizations that specialize in comparing and benchmarking the practices of the automotive industry. Such data will unfortunately be restricted either by membership in the organization or by high costs.

Using information that is available relatively freely to infer the status of a company's practices in another process is an uncertain affair. But if performed with all due diligence and interpreted skeptically, such an analysis will undoubtedly be quite objective, since there is no prestige at stake in the issue. The repair data that we have used in this comparison is hardly subject to intense debate – rather it is a tool only for professionals in an almost completely unrelated sector. When looking at industry organization surveys or automotive company surveys we cannot be sure that brand loyalty or preconceptions do not play a part.

Secondly, this investigation is an attempt to establish where best practices can be found. As is the case with benchmarking, it is important to compare many different companies to establish where to look for advice and guidance in certain fields. Now – the conclusions of the comparison may have been surprising (that the cars with the most efficient design in terms of repair/assembly are found in America, for instance) but the results may nevertheless be of help in future studies and even to the automotive industry companies themselves.

A company doesn't have to be the most successful in the industry to be the leader in certain areas – production, design, marketing, etc. However, without the help of closer comparisons such as those offered by benchmarking organizations or by institutions of academic research it is hard to know who is best at what. One might stare blindly at the company with the largest market share and never think to look elsewhere for even better practices in a certain field. This comparison can be a part of that advice.

8 CONCLUSION

In the close future, the established car companies of the older industrialized countries will certainly be challenged by the new car companies of especially China and India. As we saw in Chapter 3.3, the move from local production to exports is logical, and we also established that the new car companies will probably attack the low end of the market, by providing cheap, but quite dependable compact cars for the international markets. Faced with this competition, established car companies can choose to retreat up-market (only providing more expensive, luxury models) and slowly see their former market share eroded. Alternatively, they can choose to fight for the low-end car market – and given that automotive production demands huge investments and large production runs to be profitable, this is probably the path they *must* take.

However, in challenging the Chinese and Indian automakers with their low assembly costs throughout the supply chain, the established car companies must find a method of achieving similarly low costs of assembly. While current day technology (robotic assembly) can only do so much, and is furthermore commonly used throughout the auto industry to a high degree – an alternative is offered by Design for Assembly. Changing a product so that it demands less in terms of assembly and material costs while keeping the same functionality, may allow the established car companies to compete.

The comparison of different car models in this work showed that the American manufacturers seem to be the best at producing DFA cars, something which is surprising considering their recent troubles with profitability. It seems that the American Big Three were indeed focusing strongly on Design for Assembly at one point in time – and they continue to be experts in this area – but their current financial troubles are the result of different shortcomings. A problematic lack of foresight when it comes to fuel efficiency and model popularity, for instance.

However, as the automotive interviews indicated, Design for Assembly is not being stressed in today's automotive industry. Rather other design methodologies (such as Design for Disassembly) are taking over as leading philosophy. This, coupled with the fact that the modular and platform strategies that the automotive industry companies have been adopting over the last few decades have started to shift a substantial part of the design work to the suppliers, seems to predict the demise of Design for Assembly in the automotive industry.

But let us turn the whole argument around. If only about 25% of vehicle's value is added at the OEMs factory these days, and the rest is being produced by the suppliers (Maxton & Wormald 2004:144), it is clearly in the suppliers' ranks that Design for Assembly must be promoted in the future.

It is unclear whether the automotive industry's large suppliers have studied and implemented Design-for methodologies to the same extent as the OEMs – academic literature is scarce on this subject. Certainly it seems that the automotive suppliers outside of America have less interest and experience of DFA than those in America, and have only started seeing the Design-for methodologies' benefits rather recently, as a result of several automotive manufacturers’ campaigns on improving recyclability (Design for Disassembly).

It is clear then what must happen – the whole supply chain of the old established car companies must undergo a DFA overhaul. These important techniques must be implemented already at the module stage, ensuring that the final cost of the vehicle stays on a reasonable level when compared to the vehicles produced in countries with lower assembly costs. Spread these practices throughout the supply chain, and significant cost reductions to the end product can be had.

It is also clear where the expertise lies. The American car companies in general, and specific companies that perform well on assembly (for instance Hyundai-Kia Motors) should be the teachers and mentors of the automotive supply industry in implementing leaner, faster and more assembly-friendly design practices. The expertise of companies should be recognized and held up as an example, much in the same way that the Japanese expertise in lean production was recognized and promoted in the 1990s.

Implementing Design for Assembly for an entire industry is not an easy task, however. The automotive supply chains are among the most complex in the world, with companies ranging from small to global supplying several thousand parts and modules for each new car model produced. A gradual implementation from the top down seems a feasible way forward. The largest automotive suppliers, with their responsibility for large modules and their global customer markets, are well set-up to lead the way for the rest of the industry. Piloting the implementation of lean design methods together with the automotive manufacturers should provide the proof of concept and experience needed to start the process. The smaller automotive suppliers can in turn become the "system suppliers" of the module suppliers – the first tier suppliers of a new type of OEM.

In this way, a new renaissance of automotive supply chain savings seems possible: a way for the automotive industries of the older industrialized countries to not only survive but actively take up the challenge of the Chinese and Indian automakers. It is time to move away from islands of excellence in the supply chain –

even when it comes to efficient design. The managers of the established car companies must take the issue of DFA to discussion with their module suppliers, point out the benefits and cost reductions that are possible with these methods and analyze especially the American car models’ solutions for inspiring designs.

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Appendix 1. Explore Time Data

YEAR

Case Processing Summary

	Year	**Cases**					
		Valid		**Missing**		**Total**	
		N	**Percent**	**N**	**Percent**	**N**	**Percent**
Sum of time measurements	**1990**	59	100,0%	0	,0%	59	100,0%
	1995	67	100,0%	0	,0%	67	100,0%
	2000	69	100,0%	0	,0%	69	100,0%
	2005	62	100,0%	0	,0%	62	100,0%
	2010	59	100,0%	0	,0%	59	100,0%

Descriptives

	Year			**Statistic**	**Std. Error**
Sum of time measurements	**1990**	Mean		139,920	2,1076
		95% Conf. Interval	Lower Bound	135,702	
			Upper Bound	144,139	
		5% Trimmed Mean		138,529	
		Median		139,000	
		Variance		262,074	
		Std. Deviation		16,1887	
		Minimum		114,8	
		Maximum		204,9	
		Range		90,1	
		Interquartile Range		14,4	
		Skewness		1,569	,311
		Kurtosis		4,358	,613
	1995	Mean		145,431	2,7060
		95% Conf. Interval	Lower Bound	140,029	
			Upper Bound	150,834	
		5% Trimmed Mean		142,988	
		Median		139,600	
		Variance		490,609	
		Std. Deviation		22,1497	
		Minimum		114,2	
		Maximum		257,6	
		Range		143,4	
		Interquartile Range		17,9	
		Skewness		2,616	,293
		Kurtosis		10,135	,578
	2000	Mean		147,538	2,4099
		95% Conf. Interval	Lower Bound	142,729	
			Upper Bound	152,346	
		5% Trimmed Mean		145,914	
		Median		141,900	
		Variance		400,713	
		Std. Deviation		20,0178	
		Minimum		118,0	
		Maximum		207,8	
		Range		89,8	
		Interquartile Range		18,5	
		Skewness		1,365	,289
		Kurtosis		1,724	,570

Appendix 1. Continued...

Descriptives

	Year			Statistic	Std. Error
Sum of time measurements	**2005**	Mean		155,029	2,6557
		95% Conf. Interval	Lower Bound	149,719	
			Upper Bound	160,340	
		5% Trimmed Mean		153,558	
		Median		151,550	
		Variance		437,283	
		Std. Deviation		20,9113	
		Minimum		120,6	
		Maximum		216,9	
		Range		96,3	
		Interquartile Range		21,8	
		Skewness		1,176	,304
		Kurtosis		1,808	,599
	2010	Mean		165,722	3,0187
		95% Conf. Interval	Lower Bound	159,679	
			Upper Bound	171,765	
		5% Trimmed Mean		164,193	
		Median		162,800	
		Variance		537,643	
		Std. Deviation		23,1871	
		Minimum		125,3	
		Maximum		234,5	
		Range		109,2	
		Interquartile Range		27,2	
		Skewness		1,086	,311
		Kurtosis		1,556	,613

Tests of Normality

	Year	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Sum of time measurements	**1990**	,158	59	,001	,877	59	,000
	1995	,204	67	,000	,776	67	,000
	2000	,184	69	,000	,877	69	,000
	2005	,138	62	,005	,911	62	,000
	2010	,146	59	,003	,924	59	,001

a. Lilliefors Significance Correction

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Sum of time measurements	**Based on Mean**	1,379	4	311	,241
	Based on Median	1,160	4	311	,328
	Based on Median with adjusted df	1,160	4	291,263	,329
	Based on trimmed mean	1,257	4	311	,287

Appendix 1. Continued...

YEAR

Case Processing Summary

Class		Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
Sum of time measurements	**Class 1**	96	100,0%	0	,0%	96	100,0%
	Class 2	64	100,0%	0	,0%	64	100,0%
	Class 3	96	100,0%	0	,0%	96	100,0%
	Class 4	60	100,0%	0	,0%	60	100,0%

Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

Descriptives

Class				Statistic	Std. Error
Sum of time measurements	**1. Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans**	Mean		136,779	1,2689
		95% Conf. Interval	Lower Bound	134,260	
			Upper Bound	139,298	
		5% Trimmed Mean		136,488	
		Median		137,550	
		Variance		154,562	
		Std. Deviation		12,4323	
		Minimum		114,2	
		Maximum		167,6	
		Range		53,4	
		Interquartile Range		18,6	
		Skewness		,281	,246
		Kurtosis		-,384	,488
	2. Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans	Mean		144,416	1,7205
		95% Conf. Interval	Lower Bound	140,978	
			Upper Bound	147,854	
		5% Trimmed Mean		143,981	
		Median		141,450	
		Variance		189,442	
		Std. Deviation		13,7638	
		Minimum		122,1	
		Maximum		179,1	
		Range		57,0	
		Interquartile Range		20,6	
		Skewness		,452	,299
		Kurtosis		-,598	,590

Appendix 1. Continued...

Descriptives

	Class			**Statistic**	**Std. Error**
Sum of time measurements	**3. Mid-High-Price - Front Wheel Drive - V-engine - Sedans**	Mean		148,733	1,1614
		95% Conf. Interval	Lower Bound	146,428	
			Upper Bound	151,039	
		5% Trimmed Mean		147,925	
		Median		145,500	
		Variance		129,485	
		Std. Deviation		11,3791	
		Minimum		133,8	
		Maximum		185,4	
		Range		51,6	
		Interquartile Range		14,4	
		Skewness		1,047	,246
		Kurtosis		,584	,488
	4. High-Price - Rear Wheel Drive - V-engine - Sedans	Mean		181,948	3,2573
		95% Conf. Interval	Lower Bound	175,431	
			Upper Bound	188,466	
		5% Trimmed Mean		181,222	
		Median		180,200	
		Variance		636,589	
		Std. Deviation		25,2307	
		Minimum		127,5	
		Maximum		257,6	
		Range		130,1	
		Interquartile Range		31,5	
		Skewness		,533	,309
		Kurtosis		,485	,608

Tests of Normality

	Class	**Kolmogorov-Smirnov[a]**			**Shapiro-Wilk**		
		Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Sum of time measurements	**Class 1**	,064	96	,200*	,977	96	,087
	Class 2	,121	64	,021	,960	64	,038
	Class 3	,126	96	,001	,910	96	,000
	Class 4	,100	60	,200*	,979	60	,375

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Test of Homogeneity of Variance

		Levene Statistic	**df1**	**df2**	**Sig.**
Sum of time measurements	**Based on Mean**	16,592	3	312	,000
	Based on Median	15,546	3	312	,000
	Based on Median with adjusted df	15,546	3	189,044	,000
	Based on trimmed mean	16,445	3	312	,000

Appendix 1. Continued...

REGION

Case Processing Summary

	Region	**Cases**					
		Valid		**Missing**		**Total**	
		N	**Percent**	**N**	**Percent**	**N**	**Percent**
Sum of time measurements	**Asia**	137	100,0%	0	,0%	137	100,0%
	USA	129	100,0%	0	,0%	129	100,0%
	Europe	50	100,0%	0	,0%	50	100,0%

Descriptives

	Region			**Statistic**	**Std. Error**
Sum of time measurements	**Asia**	Mean		147,961	1,4314
		95% Conf. Interval	Lower Bound	145,130	
			Upper Bound	150,791	
		5% Trimmed Mean		147,632	
		Median		145,600	
		Variance		280,690	
		Std. Deviation		16,7538	
		Minimum		116,2	
		Maximum		185,4	
		Range		69,2	
		Interquartile Range		27,3	
		Skewness		,316	,207
		Kurtosis		-,755	,411
	USA	Mean		142,219	1,1675
		95% Conf. Interval	Lower Bound	139,908	
			Upper Bound	144,529	
		5% Trimmed Mean		141,777	
		Median		140,600	
		Variance		175,842	
		Std. Deviation		13,2605	
		Minimum		114,2	
		Maximum		187,9	
		Range		73,7	
		Interquartile Range		14,6	
		Skewness		,535	,213
		Kurtosis		1,024	,423
	Europe	Mean		179,038	4,3060
		95% Conf. Interval	Lower Bound	170,385	
			Upper Bound	187,691	
		5% Trimmed Mean		178,014	
		Median		178,050	
		Variance		927,081	
		Std. Deviation		30,4480	
		Minimum		131,9	
		Maximum		257,6	
		Range		125,7	
		Interquartile Range		51,7	
		Skewness		,400	,337
		Kurtosis		-,600	,662

Appendix 1. Continued...

Tests of Normality

	Region	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Sum of time measurements	Asia	,080	137	,032	,972	137	,007
	USA	,086	129	,019	,970	129	,006
	Europe	,099	50	,200*	,962	50	,112

a. Lilliefors Significance Correction

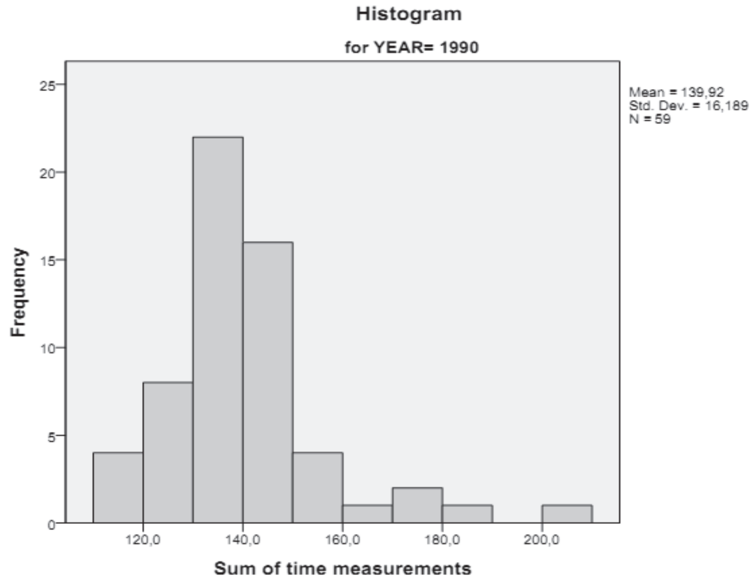
*. This is a lower bound of the true significance.

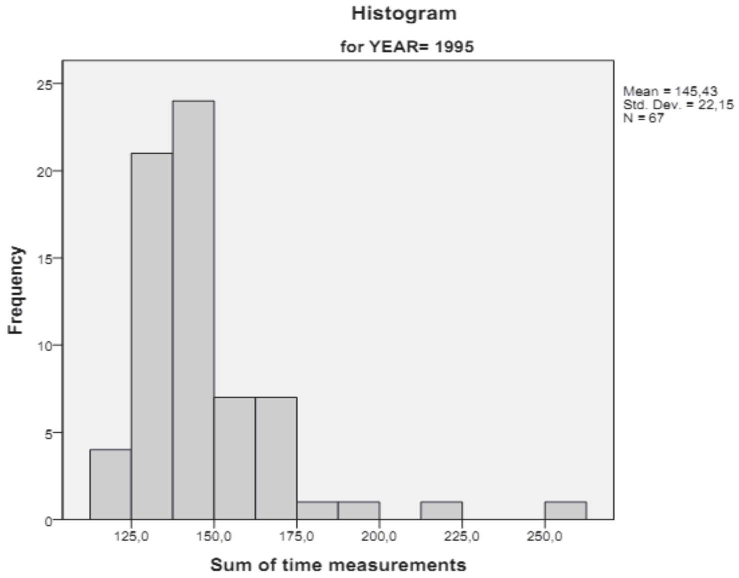
Test of Homogeneity of Variance

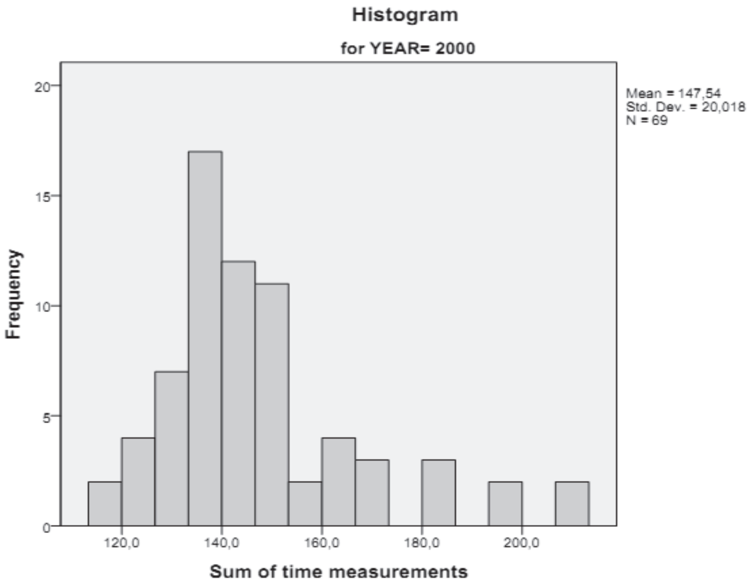
		Levene Statistic	df1	df2	Sig.
Sum of time measurements	Based on Mean	42,883	2	313	,000
	Based on Median	40,942	2	313	,000
	Based on Median and adjusted df	40,942	2	249,158	,000
	Based on trimmed mean	42,706	2	313	,000

Appendix 2. Histograms & Boxplots

YEAR

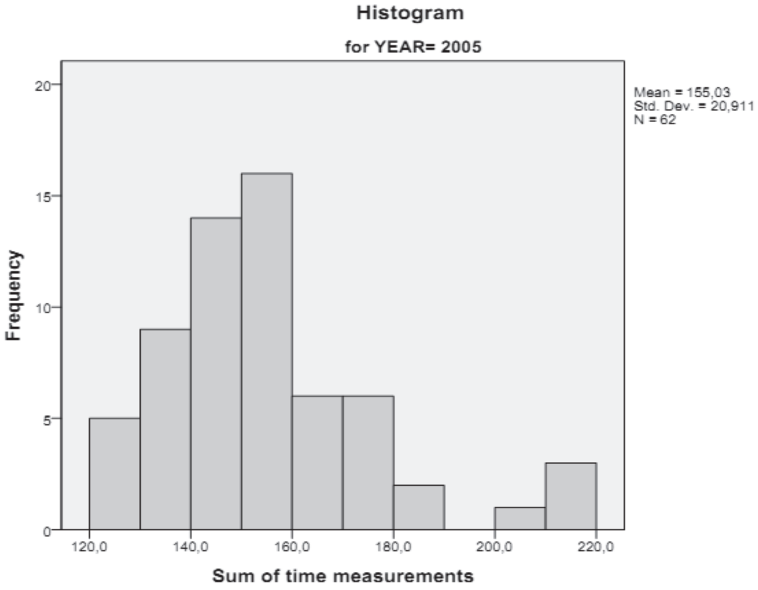


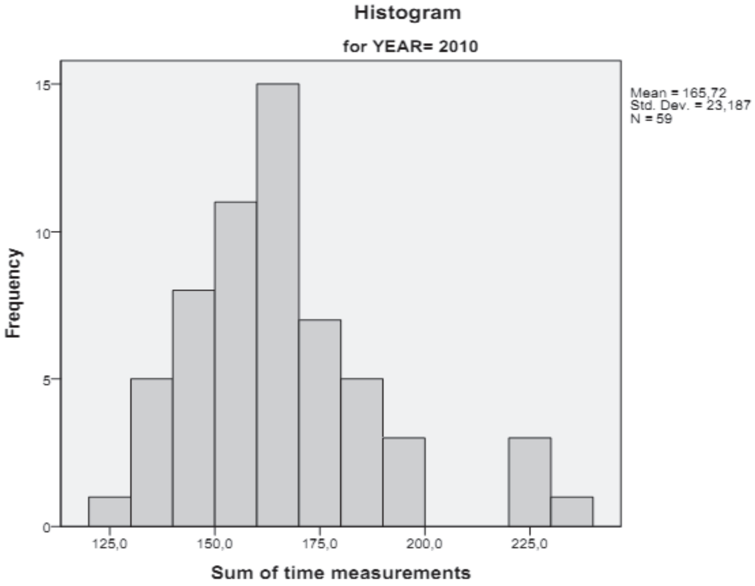




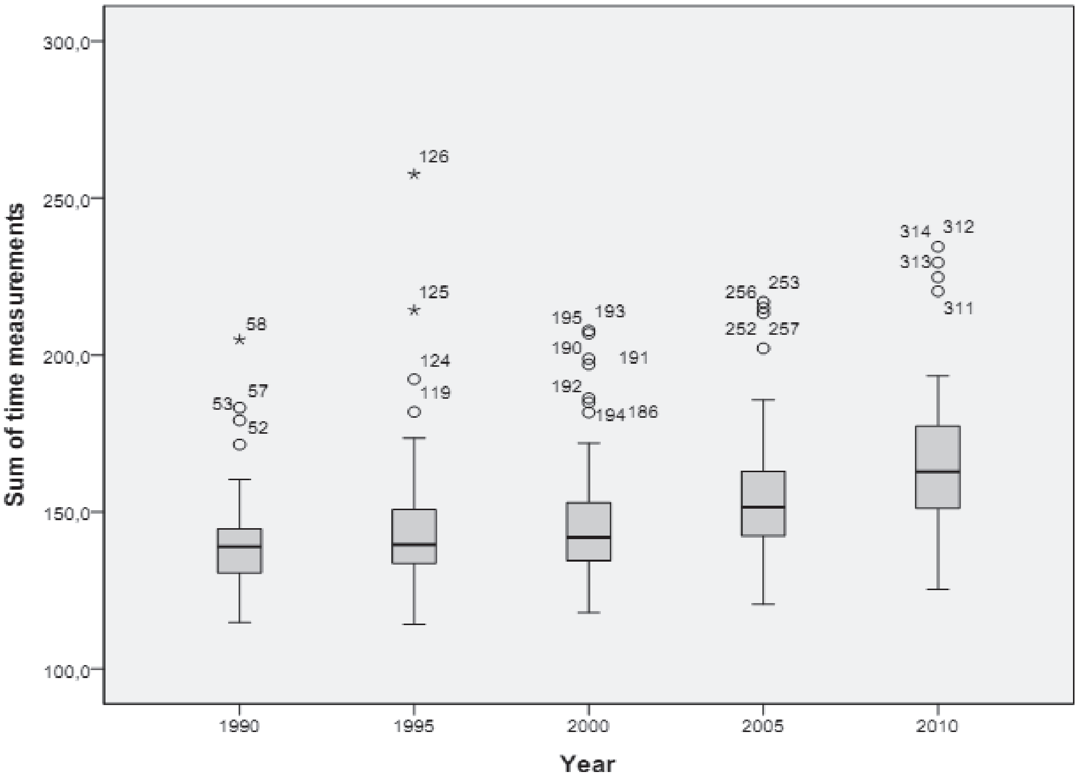
Appendix 2. Continued...

YEAR

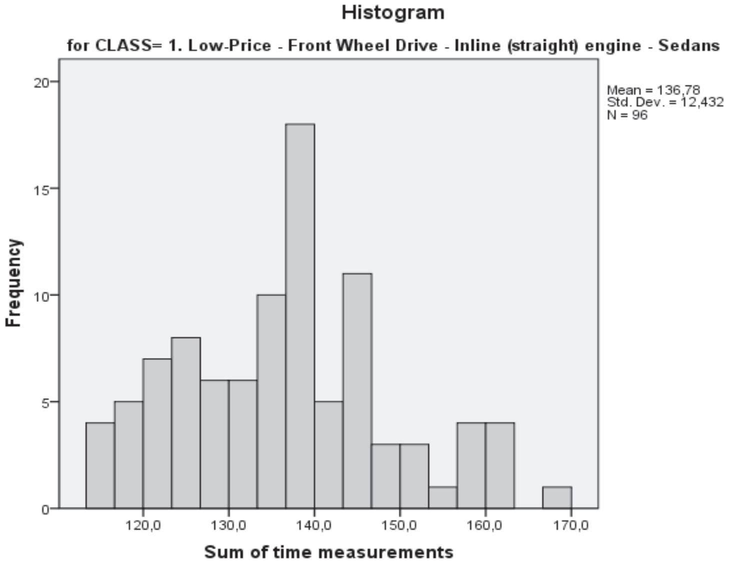


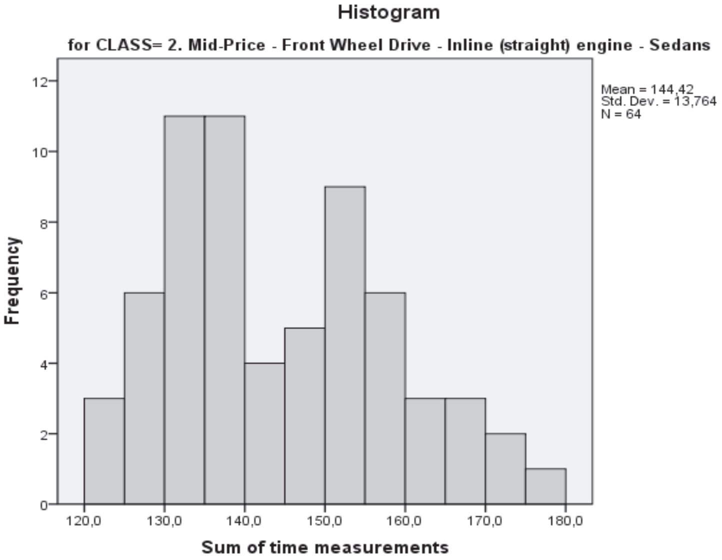


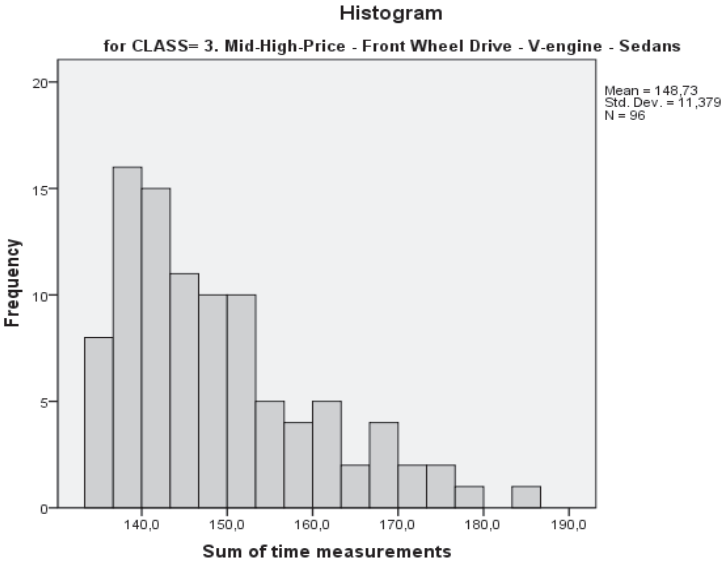
Appendix 2. Continued...
YEAR



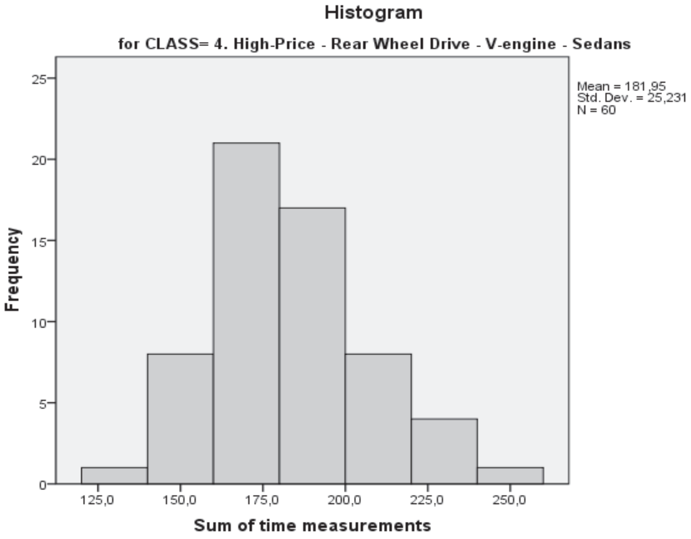
Appendix 2. Continued...
CLASS

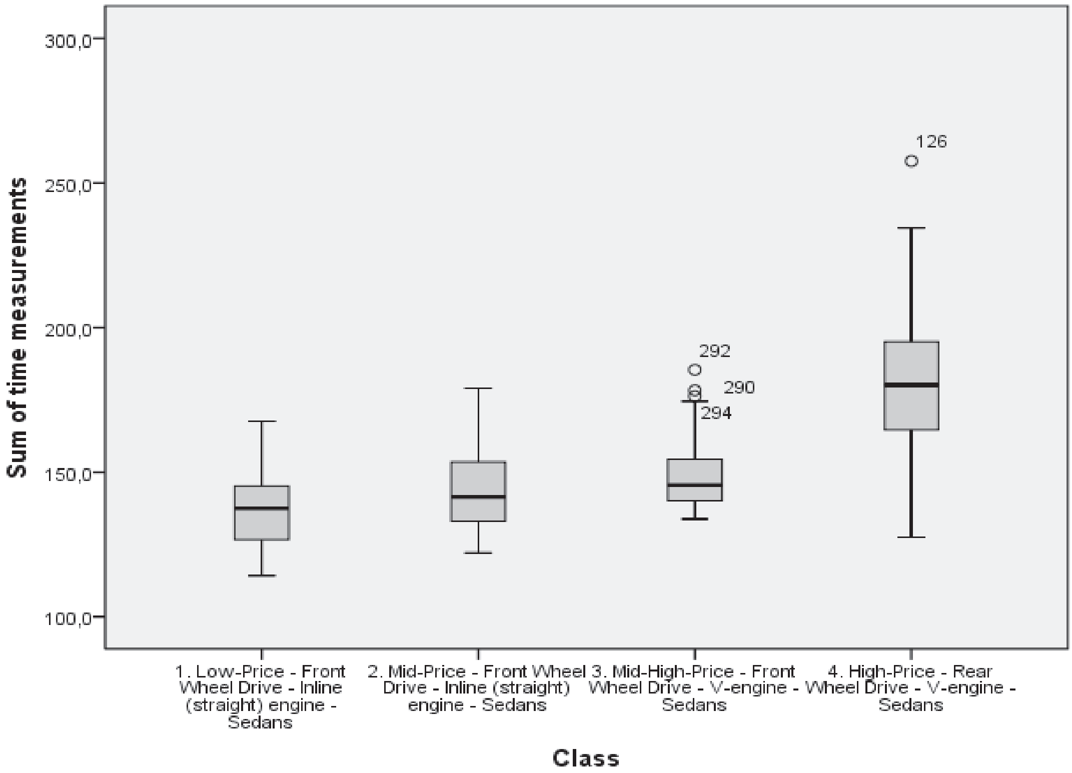




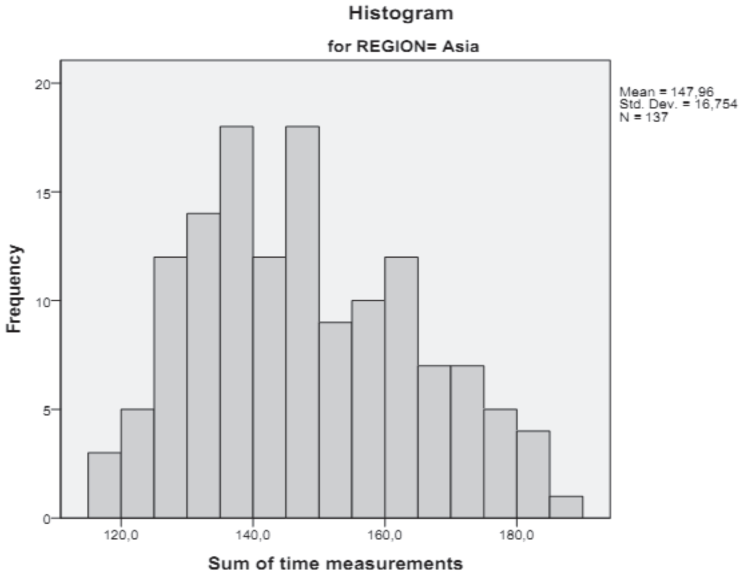


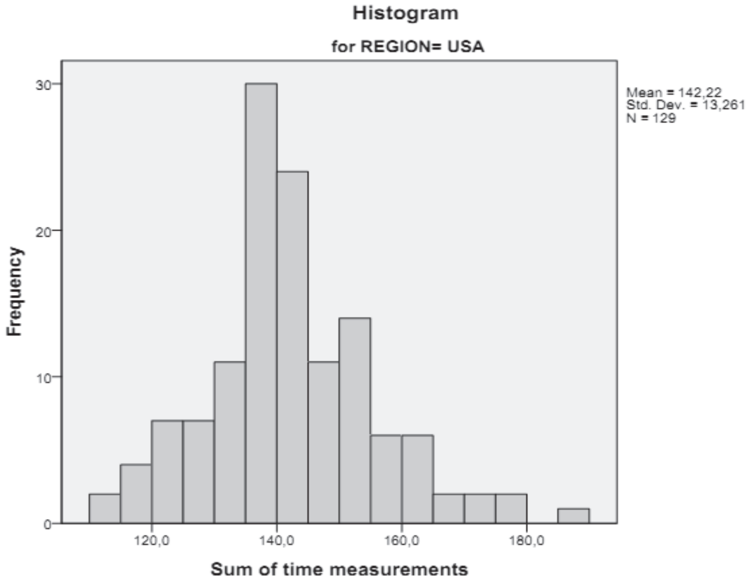
Appendix 2. Continued...
CLASS

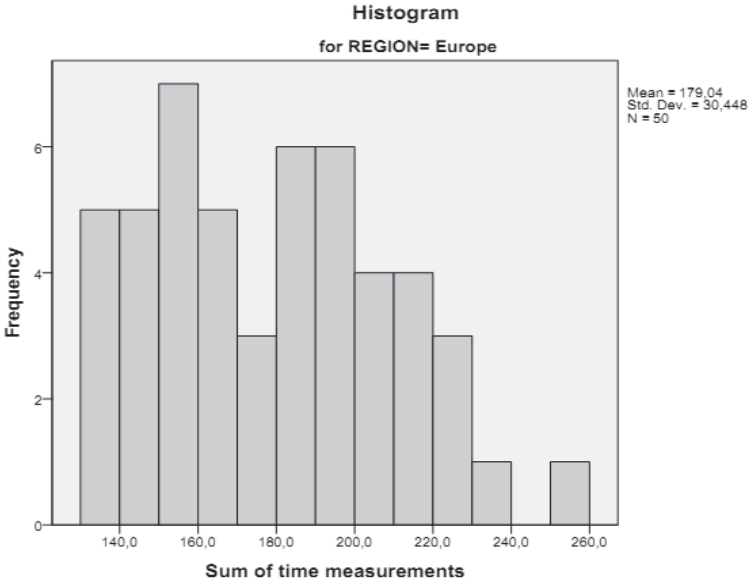




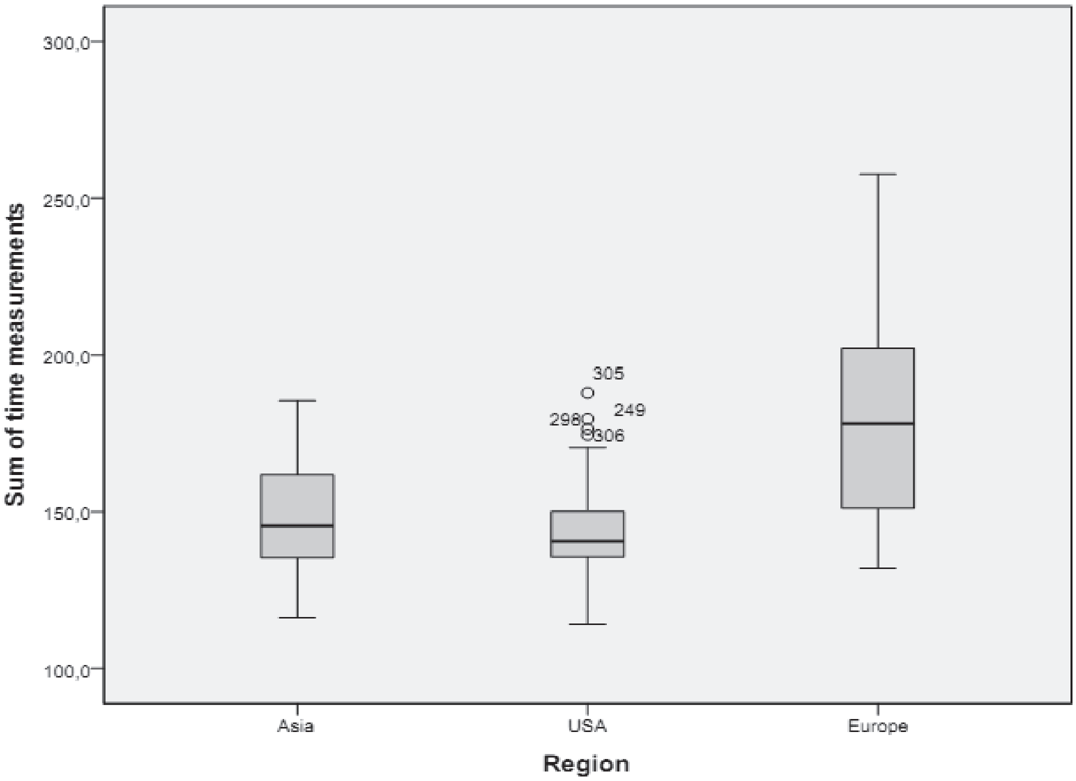
Appendix 2. Continued...
REGION







Appendix 2. Continued...
REGION



Appendix 3. Transformation results

YEAR

Test of Normality		**Original**			**Natural Logarithm Trans. (x**0)**			**Quadratic Trans. (x**2)**			**Square Root Trans. (x**0.5)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measure-ments	**1990**	,877	59	,000	,925	59	,001	,813	59	,000	,903	59	,000
	1995	,776	67	,000	,870	67	,000	,662	67	,000	,826	67	,000
	2000	,877	69	,000	,922	69	,000	,825	69	,000	,901	69	,000
	2005	,911	62	,000	,951	62	,015	,856	62	,000	,933	62	,002
	2010	,924	59	,001	,963	59	,069	,870	59	,000	,945	59	,010

Test of Normality		**Reciprocal Trans. (x**-1)**			**Rec. Square Root Trans. (x**-0.5)**			**Rec. Quadratic Trans. (x**-2)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measure-ments	**1990**	,955	59	,028	,942	59	,007	,966	59	,103
	1995	,935	67	,002	,906	67	,000	,971	67	,126
	2000	,955	69	,015	,940	69	,002	,977	69	,224
	2005	,975	62	,228	,965	62	,077	,980	62	,394
	2010	,984	59	,625	,976	59	,285	,986	59	,755

Levene Test of Homogeneity of Variance		**Original**				**Natural Logarithm Trans. (x**0)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	1,379	4	311	,241	,693	4	311	,597
	Based on Median	1,160	4	311	,328	,596	4	311	,666
	Based on Median, adj. df	1,160	4	291,3	,329	,596	4	299,6	,666
	Based on trimmed mean	1,257	4	311	,287	,625	4	311	,645

Levene Test of Homogeneity of Variance		**Quadratic Trans. (x**2)**				**Square Root Trans. (x**0.5)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	2,162	4	311	,073	1,024	4	311	,395
	Based on Median	1,682	4	311	,154	,871	4	311	,481
	Based on Median, adj. df	1,682	4	278,2	,154	,871	4	296,0	,481
	Based on trimmed mean	1,867	4	311	,116	,932	4	311	,445

Levene Test of Homogeneity of Variance		**Reciprocal Trans. (x**-1)**				**Reciprocal Square Root Trans. (x**-0.5)**				**Reciprocal Quadratic Trans. (x**-2)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	,247	4	311	,912	,427	4	311	,789	,221	4	311	,927
	Based on Median	,203	4	311	,936	,363	4	311	,835	,194	4	311	,942
	Based on Median, adj. df	,203	4	303,9	,936	,363	4	302,2	,835	,194	4	303,9	,942
	Based on trimmed mean	,203	4	311	,937	,372	4	311	,829	,212	4	311	,931

Appendix 3. Continued...

CLASS

Test of Normality		**Original**			**Natural Logarithm Trans. (x**0)**			**Quadratic Trans. (x**2)**			**Square Root Trans. (x**0.5)**		
	Year	**Shapiro-Wilk**			**Shapiro-Wilk**			**Shapiro-Wilk**			**Shapiro-Wilk**		
		Stat.	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measure-ments	**Class 1**	,977	96	,087	,981	96	,185	,967	96	,016	,980	96	,143
	Class 2	,960	64	,038	,968	64	,097	,949	64	,010	,965	64	,064
	Class 3	,910	96	,000	,927	96	,000	,890	96	,000	,919	96	,000
	Class 4	,979	60	,375	,992	60	,973	,947	60	,012	,988	60	,817

Test of Normality		**Reciprocal Trans. (x**-1)**			**Rec. Square Root Trans. (x**-0.5)**			**Rec. Quadratic Trans. (x**-2)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measure-ments	**Class 1**	,980	96	,158	,981	96	,191	,974	96	,057
	Class 2	,972	64	,157	,971	64	,131	,973	64	,166
	Class 3	,942	96	,000	,935	96	,000	,953	96	,002
	Class 4	,987	60	,779	,992	60	,969	,962	60	,062

Levene Test of Homogeneity of Variance		**Original**				**Natural Logarithm Trans. (x**0)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	16,59	3	312	,000	8,319	3	312	,000
	Based on Median	15,55	3	312	,000	8,074	3	312	,000
	Based on Median, adj. df	15,55	3	189,0	,000	8,074	3	245,7	,000
	Based on trimmed mean	16,44	3	312	,000	8,415	3	312	,000

Levene Test of Homogeneity of Variance		**Quadratic Trans. (x**2)**				**Square Root Trans. (x**0.5)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	28,27	3	312	,000	11,94	3	312	,000
	Based on Median	24,25	3	312	,000	11,44	3	312	,000
	Based on Median, adj. df	24,25	3	136,3	,000	11,44	3	218,6	,000
	Based on trimmed mean	26,43	3	312	,000	11,98	3	312	,000

Levene Test of Homogeneity of Variance		**Reciprocal Trans. (x**-1)**				**Reciprocal Square Root Trans. (x**-0.5)**				**Reciprocal Quadratic Trans. (x**-2)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	4,816	3	312	,003	5,896	3	312	,001	6,111	3	312	,000
	Based on Median	4,554	3	312	,004	5,743	3	312	,001	5,308	3	312	,001
	Based on Median, adj. df	4,554	3	278,8	,004	5,743	3	266,6	,001	5,308	3	276,4	,001
	Based on trimmed mean	4,844	3	312	,003	5,988	3	312	,001	6,076	3	312	,000

Appendix 3. Continued...

REGION

Test of Normality		**Original**			**Natural Logarithm Trans. (x**0)**			**Quadratic Trans. (x**2)**			**Square Root Trans. (x**0.5)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measure-ments	**Asia**	,972	137	,007	,980	137	,040	,959	137	,000	,977	137	,019
	USA	,970	129	,006	,981	129	,064	,948	129	,000	,977	129	,026
	Europe	,962	50	,112	,970	50	,237	,942	50	,017	,968	50	,187

Test of Normality		**Reciprocal Trans. (x**-1)**			**Rec. Square Root Trans. (x**-0.5)**			**Rec. Quadratic Trans. (x**-2)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measure-ments	**Asia**	,982	137	,061	,981	137	,059	,977	137	,021
	USA	,980	129	,059	,982	129	,084	,970	129	,006
	Europe	,967	50	,180	,970	50	,233	,955	50	,056

Levene Test of Homogeneity of Variance		**Original**				**Natural Logarithm Trans. (x**0)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	42,88	2	313	,000	24,49	2	313	,000
	Based on Median	40,94	2	313	,000	23,93	2	313	,000
	Based on Median, adj. df	40,94	2	249,2	,000	23,93	2	293,6	,000
	Based on trimmed mean	42,71	2	313	,000	24,49	2	313	,000

Levene Test of Homogeneity of Variance		**Quadratic Trans. (x**2)**				**Square Root Trans. (x**0.5)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	62,86	2	313	,000	33,16	2	313	,000
	Based on Median	57,99	2	313	,000	32,07	2	313	,000
	Based on Median, adj. df	57,99	2	181,2	,000	32,07	2	275,6	,000
	Based on trimmed mean	62,14	2	313	,000	33,10	2	313	,000

Levene Test of Homogeneity of Variance		**Reciprocal Trans. (x**-1)**				**Reciprocal Square Root Trans. (x**-0.5)**				**Reciprocal Quadratic Trans. (x**-2)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	11,67	2	313	,000	17,29	2	313	,000	4,833	2	313	,009
	Based on Median	11,49	2	313	,000	17,00	2	313	,000	4,630	2	313	,010
	Based on Median, adj. df	11,49	2	309,8	,000	17,00	2	304,3	,000	4,630	2	312,1	,010
	Based on trimmed mean	11,68	2	313	,000	17,31	2	313	,000	4,756	2	313	,009

Appendix 4. Continued...

Descriptives

Reciprocal Quadratic (time)

	N	Mean	Std. Deviation	Std. Error	95% Conf. Interval		Minimum	Maximum
					Low Bound	Up Bound		
1990	59	0,0000528	0,0000106	0,0000014	0,0000501	0,0000556	0,0000238	0,0000759
1995	67	0,0000497	0,0000112	0,0000014	0,0000470	0,0000524	0,0000151	0,0000767
2000	69	0,0000481	0,0000109	0,0000013	0,0000455	0,0000507	0,0000232	0,0000718
2005	62	0,0000436	0,0000104	0,0000013	0,0000410	0,0000463	0,0000213	0,0000688
2010	59	0,0000383	0,0000096	0,0000013	0,0000358	0,0000408	0,0000182	0,0000637
Total	316	0,0000466	0,0000116	0,0000007	0,0000453	0,0000479	0,0000151	0,0000767

Test of Homogeneity of Variances

Reciprocal Quadratic (time)

Levene Statistic	df1	df2	Sig.
,221	4	311	,927

ANOVA

Reciprocal Quadratic (time)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,000	4	,000	17,096	,000
Within Groups	,000	311	,000		
Total	,000	315			

Robust Tests of Equality of Means

Reciprocal Quadratic (time)

	Statistic[a]	df1	df2	Sig.
Welch	18,487	4	154,851	,000
Brown-Forsythe	17,202	4	309,617	,000

a. Asymptotically F distributed.

Appendix 4. Continued...

POST HOC TESTS

Multiple Comparisons

Reciprocal Quadratic (time) Gabriel

(I) Year	(J) Year	Mean Diff. (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1990	**1995**	0,00000315	0,00000189	0,635	-0,00000218	0,00000848
	2000	0,00000475	0,00000188	0,113	-0,00000055	0,00001004
	2005	0,00000922*	0,00000193	0,000	0,00000379	0,00001466
	2010	0,00001451*	0,00000195	0,000	0,00000901	0,00002001
1995	**1990**	-0,00000315	0,00000189	0,635	-0,00000848	0,00000218
	2000	0,00000160	0,00000182	0,991	-0,00000353	0,00000672
	2005	0,00000607*	0,00000187	0,013	0,00000081	0,00001134
	2010	0,00001136*	0,00000189	0,000	0,00000603	0,00001670
2000	**1990**	-0,00000475	0,00000188	0,113	-0,00001004	0,00000055
	1995	-0,00000160	0,00000182	0,991	-0,00000672	0,00000353
	2005	0,00000448	0,00000185	0,151	-0,00000075	0,00000970
	2010	0,00000976*	0,00000188	0,000	0,00000447	0,00001506
2005	**1990**	-0,00000922*	0,00000193	0,000	-0,00001466	-0,00000379
	1995	-0,00000607*	0,00000187	0,013	-0,00001134	-0,00000081
	2000	-0,00000448	0,00000185	0,151	-0,00000970	0,00000075
	2010	0,00000529	0,00000193	0,062	-0,00000014	0,00001072
2010	**1990**	-0,00001451*	0,00000195	0,000	-0,00002001	-0,00000901
	1995	-0,00001136*	0,00000189	0,000	-0,00001670	-0,00000603
	2000	-0,00000976*	0,00000188	0,000	-0,00001506	-0,00000447
	2005	-0,00000529	0,00000193	0,062	-0,00001072	0,00000014

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

Reciprocal Quadratic (time)

Gabriel[a,b]

Year	N	Subset for alpha = 0.05		
		1	2	3
2010	59	0,0000383		
2005	62	0,0000436	0,0000436	
2000	69		0,0000481	0,0000481
1995	67			0,0000497
1990	59			0,0000528
Sig.		,053	,169	,117

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 62,936.

b. The group sizes are unequal. The harmonic mean of the group sizes is u

Type I error levels are not guaranteed.

Appendix 5. Explore Time Data (4th class omitted)

YEAR

Case Processing Summary

		Cases					
		Valid		**Missing**		**Total**	
	Year	**N**	**Percent**	**N**	**Percent**	**N**	**Percent**
Sum of time measurements	**1990**	51	100,0%	0	,0%	51	100,0%
	1995	57	100,0%	0	,0%	57	100,0%
	2000	57	100,0%	0	,0%	57	100,0%
	2005	49	100,0%	0	,0%	49	100,0%
	2010	42	100,0%	0	,0%	42	100,0%

Descriptives

	Year			**Statistic**	**Std. Error**
Sum of time measurements	**1990**	Mean		136,090	1,4382
		95% Conf. Interval	Lower Bound	133,201	
			Upper Bound	138,979	
		5% Trimmed Mean		136,204	
		Median		138,400	
		Variance		105,497	
		Std. Deviation		10,2711	
		Minimum		114,8	
		Maximum		160,4	
		Range		45,6	
		Interquartile Range		11,9	
		Skewness		-,289	,333
		Kurtosis		-,197	,656
	1995	Mean		139,104	1,4747
		95% Conf. Interval	Lower Bound	136,149	
			Upper Bound	142,058	
		5% Trimmed Mean		138,967	
		Median		138,300	
		Variance		123,966	
		Std. Deviation		11,1340	
		Minimum		114,2	
		Maximum		164,6	
		Range		50,4	
		Interquartile Range		12,0	
		Skewness		,301	,316
		Kurtosis		,198	,623
	2000	Mean		140,670	1,4853
		95% Conf. Interval	Lower Bound	137,695	
			Upper Bound	143,646	
		5% Trimmed Mean		140,330	
		Median		139,400	
		Variance		125,749	
		Std. Deviation		11,2138	
		Minimum		118,0	
		Maximum		171,9	
		Range		53,9	
		Interquartile Range		13,9	
		Skewness		,406	,316
		Kurtosis		,397	,623

Appendix 5. Continued...

Descriptives

	Year			Statistic	Std. Error
Sum of time measurements	**2005**	Mean		147,447	1,7785
		95% Conf. Interval	Lower Bound	143,871	
			Upper Bound	151,023	
		5% Trimmed Mean		147,564	
		Median		149,200	
		Variance		154,987	
		Std. Deviation		12,4494	
		Minimum		120,6	
		Maximum		172,2	
		Range		51,6	
		Interquartile Range		14,9	
		Skewness		-,145	,340
		Kurtosis		-,124	,668
	2010	Mean		155,695	2,1381
		95% Conf. Interval	Lower Bound	151,377	
			Upper Bound	160,013	
		5% Trimmed Mean		155,766	
		Median		156,700	
		Variance		192,002	
		Std. Deviation		13,8565	
		Minimum		125,3	
		Maximum		185,4	
		Range		60,1	
		Interquartile Range		19,8	
		Skewness		-,048	,365
		Kurtosis		-,352	,717

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Year	Statistic	df	Sig.	Statistic	df	Sig.
Sum of time measurements	**1990**	,101	51	,200*	,967	51	,167
	1995	,099	57	,200*	,973	57	,229
	2000	,072	57	,200*	,983	57	,581
	2005	,066	49	,200*	,982	49	,649
	2010	,089	42	,200*	,992	42	,988

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Sum of time measurements	**Based on Mean**	1,598	4	251	,175
	Based on Median	1,586	4	251	,179
	Based on Median with adjusted df	1,586	4	248,462	,179
	Based on trimmed mean	1,606	4	251	,173

Appendix 5. Continued...

CLASS

Case Processing Summary

		Cases					
		Valid		Missing		Total	
	Class	N	Percent	N	Percent	N	Percent
Sum of time measurements	**Class 1**	96	100,0%	0	,0%	96	100,0%
	Class 2	64	100,0%	0	,0%	64	100,0%
	Class 3	96	100,0%	0	,0%	96	100,0%

Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

Descriptives

	Class			Statistic	Std. Error
Sum of time measurements	**1. Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans**	Mean		136,779	1,2689
		95% Conf. Interval	Lower Bound	134,260	
			Upper Bound	139,298	
		5% Trimmed Mean		136,488	
		Median		137,550	
		Variance		154,562	
		Std. Deviation		12,4323	
		Minimum		114,2	
		Maximum		167,6	
		Range		53,4	
		Interquartile Range		18,6	
		Skewness		,281	,246
		Kurtosis		-,384	,488
	2. Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans	Mean		144,416	1,7205
		95% Conf. Interval	Lower Bound	140,978	
			Upper Bound	147,854	
		5% Trimmed Mean		143,981	
		Median		141,450	
		Variance		189,442	
		Std. Deviation		13,7638	
		Minimum		122,1	
		Maximum		179,1	
		Range		57,0	
		Interquartile Range		20,6	
		Skewness		,452	,299
		Kurtosis		-,598	,590
	3. Mid-High-Price - Front Wheel Drive - V-engine - Sedans	Mean		148,733	1,1614
		95% Conf. Interval	Lower Bound	146,428	
			Upper Bound	151,039	
		5% Trimmed Mean		147,925	
		Median		145,500	
		Variance		129,485	
		Std. Deviation		11,3791	
		Minimum		133,8	
		Maximum		185,4	
		Range		51,6	
		Interquartile Range		14,4	
		Skewness		1,047	,246
		Kurtosis		,584	,488

Appendix 5. Continued...

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Class	**Statistic**	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Sum of time measurements	**Class 1**	,064	96	,200*	,977	96	,087
	Class 2	,121	64	,021	,960	64	,038
	Class 3	,126	96	,001	,910	96	,000

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans
Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans
Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans
Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Sum of time measurements	**Based on Mean**	2,875	2	253	,058
	Based on Median	2,650	2	253	,073
	Based on Median with adjusted df	2,650	2	252,245	,073
	Based on trimmed mean	2,950	2	253	,054

Appendix 5. Continued...

CLASS

Case Processing Summary

	Region	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
Sum of time measurements	Asia	119	100,0%	0	,0%	119	100,0%
	USA	115	100,0%	0	,0%	115	100,0%
	Europe	22	100,0%	0	,0%	22	100,0%

Descriptives

	Region			Statistic	Std. Error
Sum of time measurements	Asia	Mean		144,641	1,3455
		95% Conf. Interval	Lower Bound	141,977	
			Upper Bound	147,306	
		5% Trimmed Mean		144,225	
		Median		143,200	
		Variance		215,419	
		Std. Deviation		14,6772	
		Minimum		116,2	
		Maximum		185,4	
		Range		69,2	
		Interquartile Range		19,8	
		Skewness		,417	,222
		Kurtosis		-,277	,440
	USA	Mean		139,924	1,0488
		95% Conf. Interval	Lower Bound	137,847	
			Upper Bound	142,002	
		5% Trimmed Mean		139,849	
		Median		139,800	
		Variance		126,488	
		Std. Deviation		11,2467	
		Minimum		114,2	
		Maximum		174,5	
		Range		60,3	
		Interquartile Range		11,2	
		Skewness		,070	,226
		Kurtosis		,445	,447
	Europe	Mean		152,191	2,4673
		95% Conf. Interval	Lower Bound	147,060	
			Upper Bound	157,322	
		5% Trimmed Mean		152,200	
		Median		151,000	
		Variance		133,922	
		Std. Deviation		11,5725	
		Minimum		131,9	
		Maximum		172,2	
		Range		40,3	
		Interquartile Range		16,9	
		Skewness		,035	,491
		Kurtosis		-,654	,953

Appendix 5. Continued...

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Region	**Statistic**	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Sum of time measurements	**Asia**	,069	119	,200[*]	,981	119	,101
	USA	,082	115	,053	,982	115	,131
	Europe	,091	22	,200[*]	,969	22	,684

a. Lilliefors Significance Correction

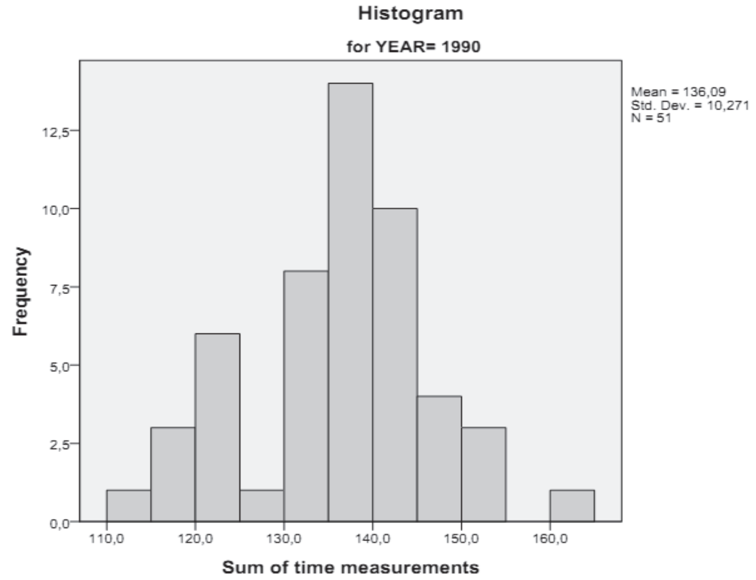
*. This is a lower bound of the true significance.

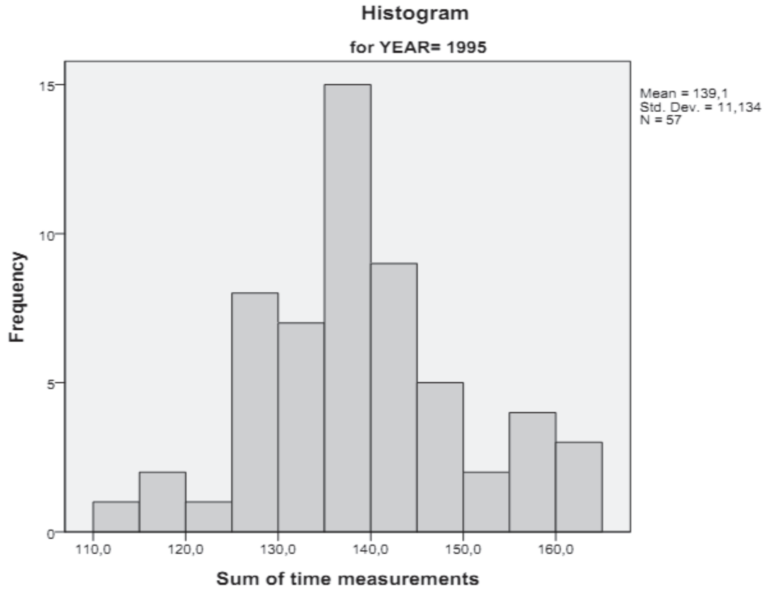
Test of Homogeneity of Variance

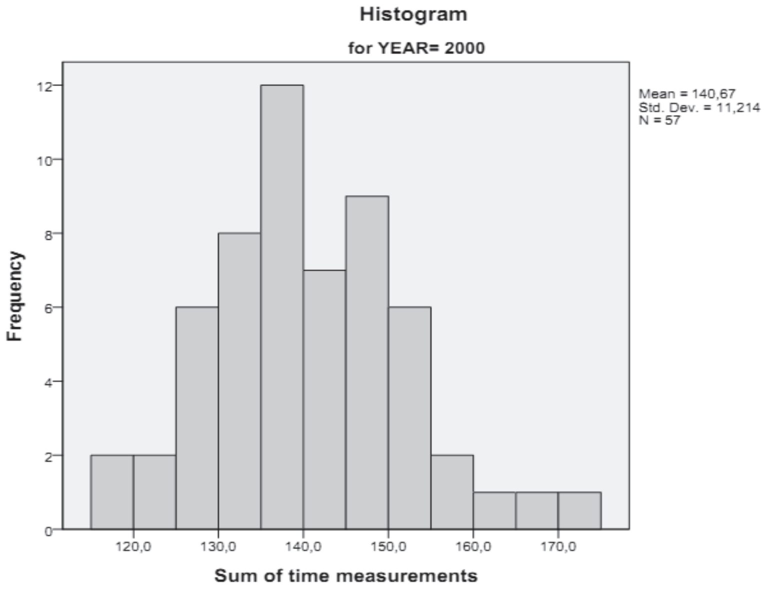
		Levene Statistic	df1	df2	Sig.
Sum of time measurements	**Based on Mean**	5,604	2	253	,004
	Based on Median	5,341	2	253	,005
	Based on Median with adjusted df	5,341	2	245,658	,005
	Based on trimmed mean	5,498	2	253	,005

Appendix 6. Histograms & Boxplots (4th class omitted)

YEAR

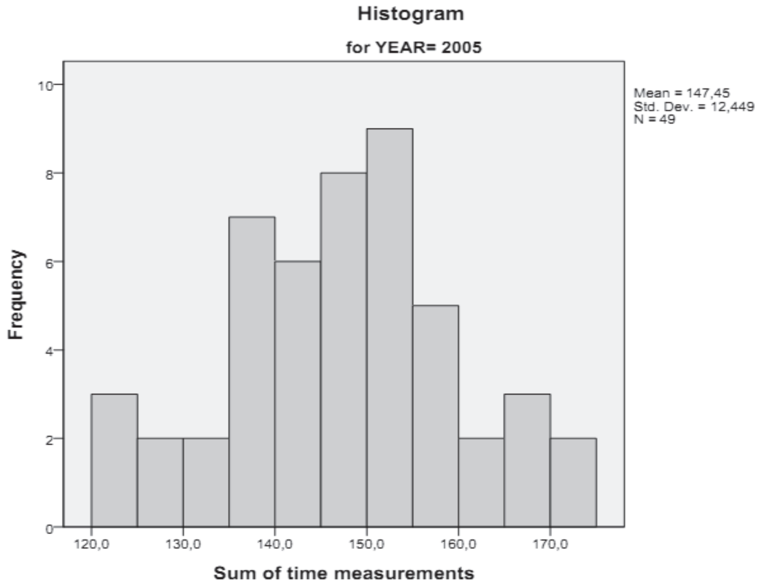


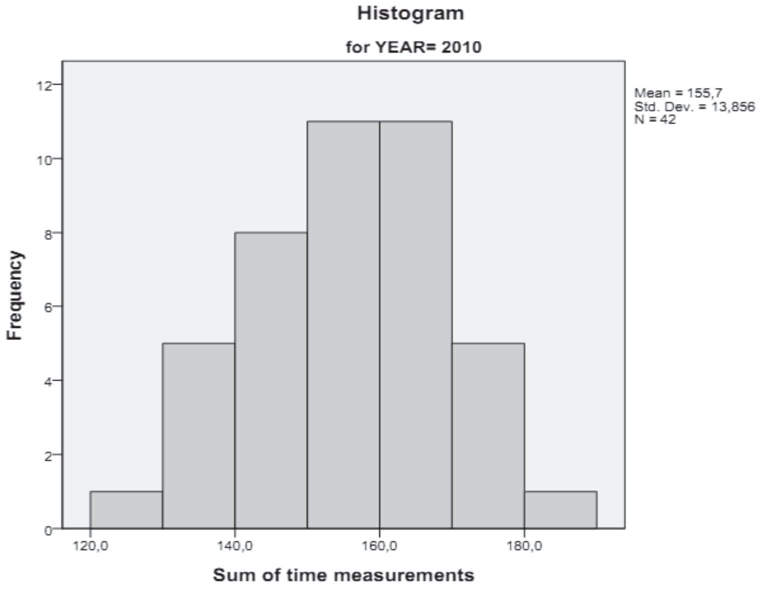




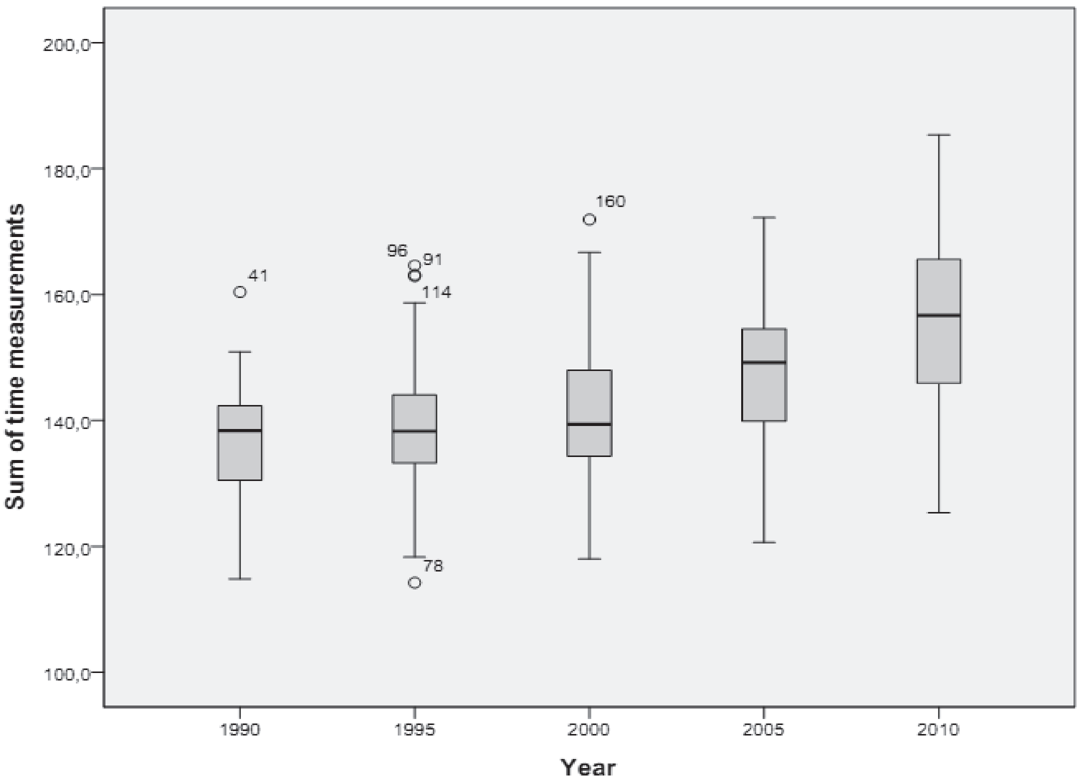
Appendix 6. Continued...

YEAR



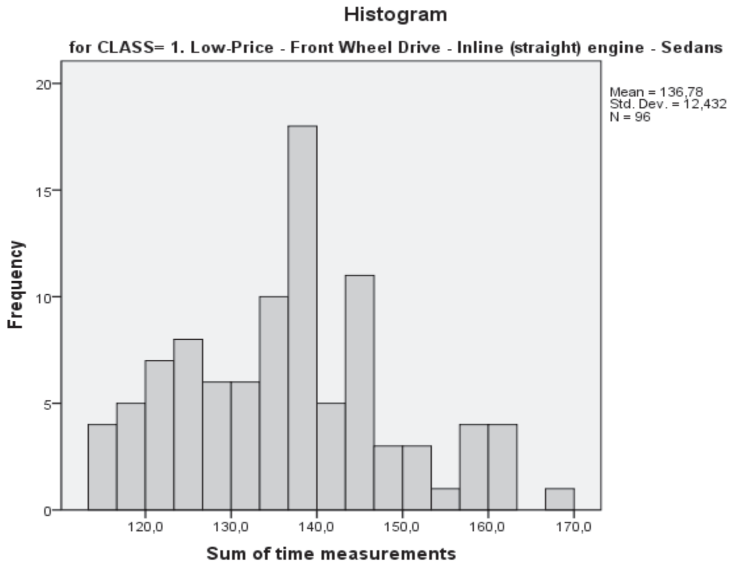


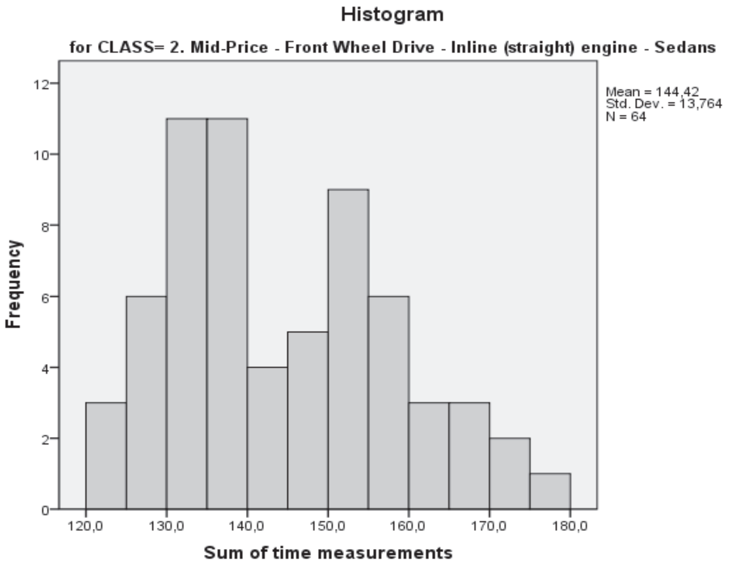
Appendix 6. Continued...
YEAR

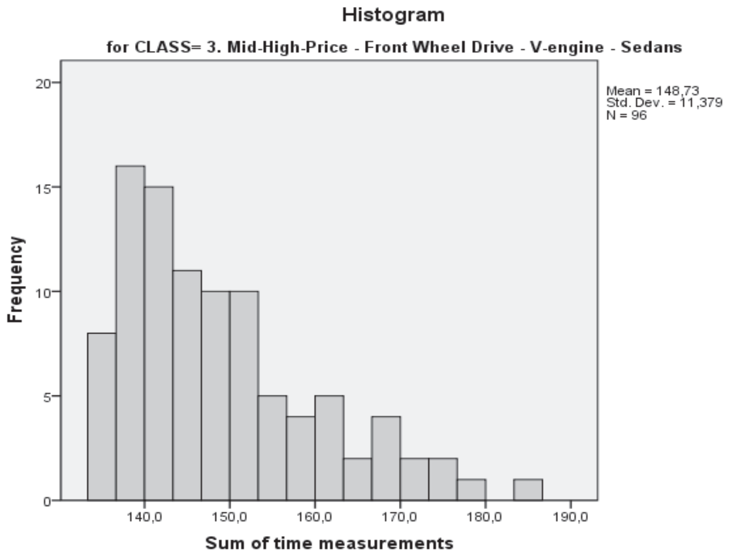


Appendix 6. Continued...

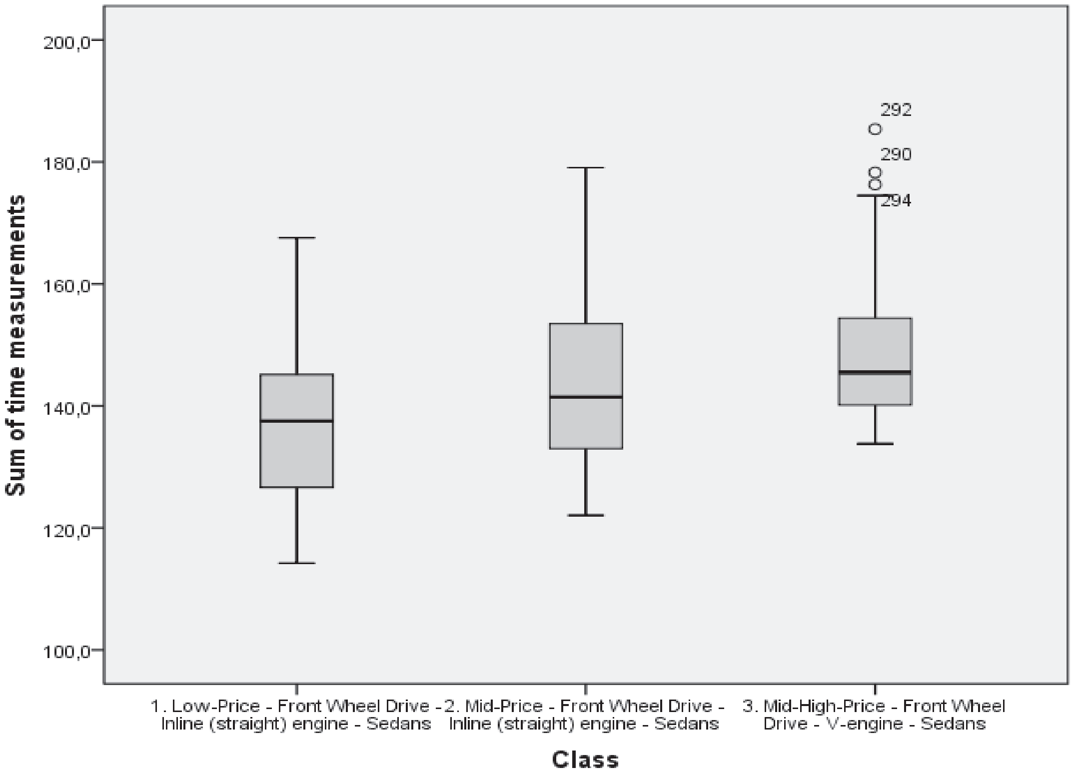
CLASS





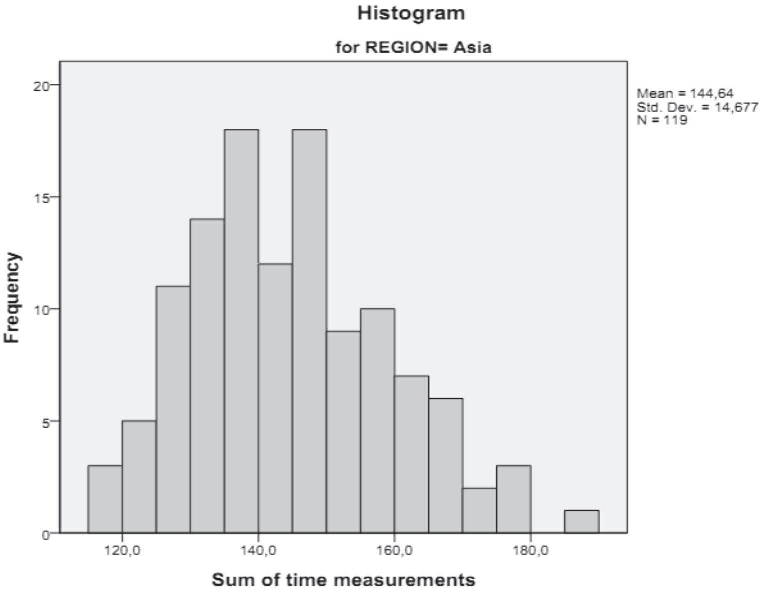


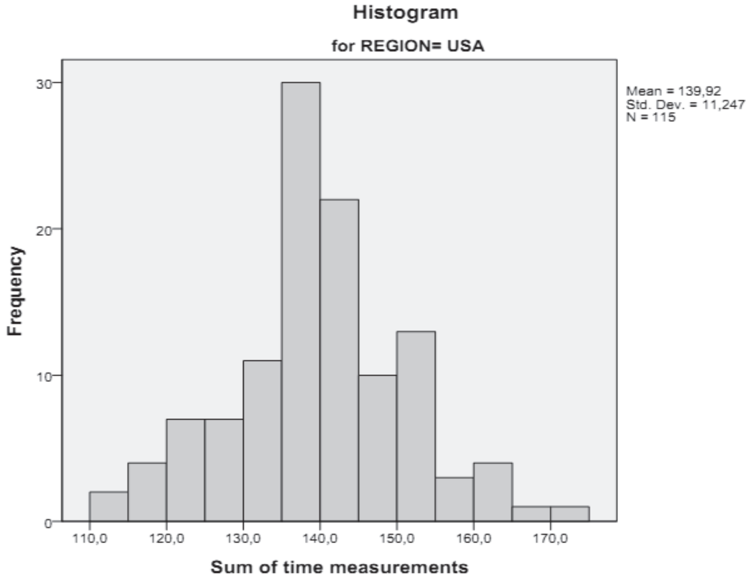
Appendix 6. Continued...
CLASS

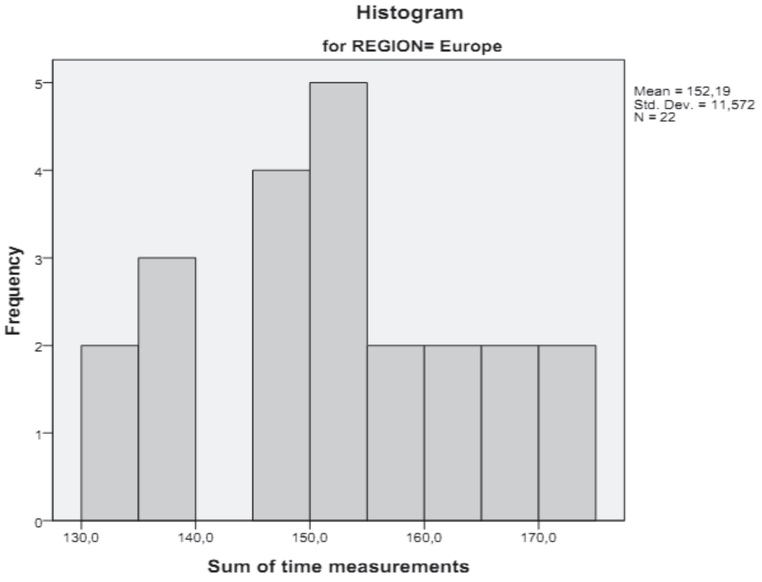


Appendix 6. Continued...

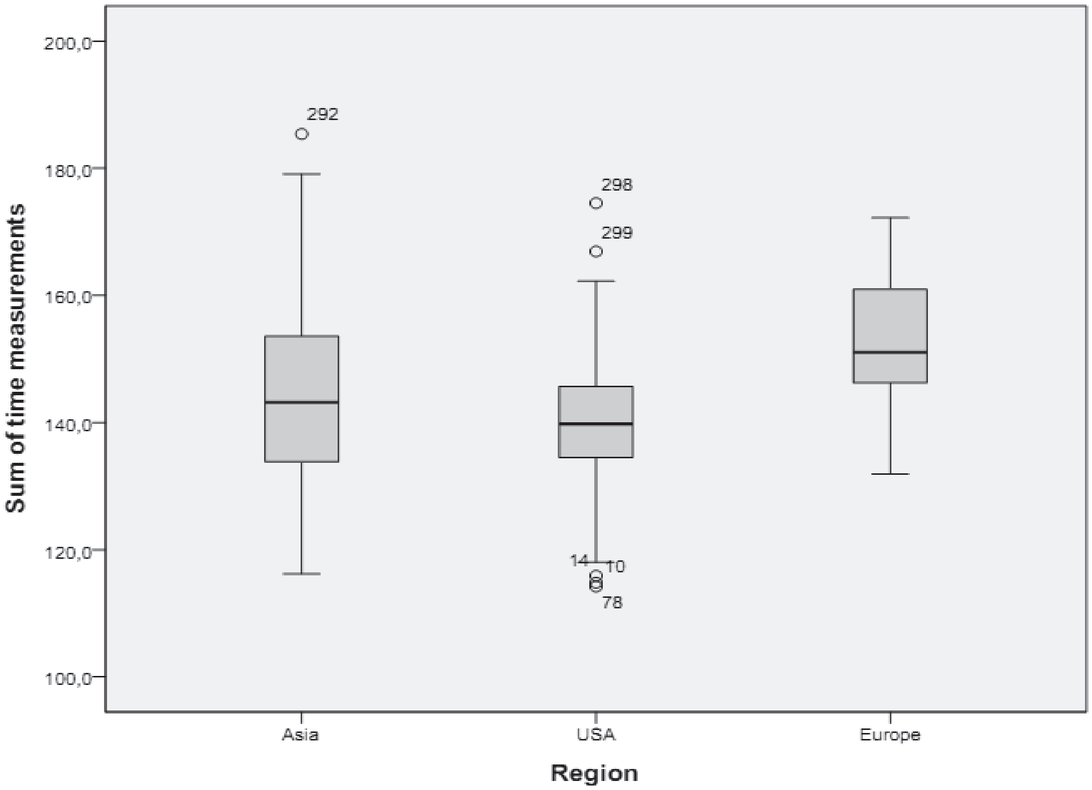
REGION







Appendix 6. Continued...
REGION



Appendix 7. Transformation results (4th class omitted)

YEAR

Test of Normality		**Original**			**Natural Logarithm Trans. (x**0)**			**Quadratic Trans. (x**2)**			**Square Root Trans. (x**0.5)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measure-ments	**1990**	,967	51	,167	,957	51	,063	,973	51	,290	,963	51	,108
	1995	,973	57	,229	,979	57	,403	,961	57	,065	,977	57	,331
	2000	,983	57	,581	,990	57	,911	,969	57	,153	,987	57	,796
	2005	,982	49	,649	,975	49	,371	,983	49	,692	,979	49	,530
	2010	,992	42	,988	,988	42	,927	,990	42	,966	,990	42	,975

Test of Normality		**Reciprocal Trans. (x**-1)**			**Rec. Square Root Trans. (x**-0.5)**			**Rec. Quadratic Trans. (x**-2)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measure-ments	**1990**	,944	51	,017	,951	51	,034	,927	51	,004
	1995	,978	57	,368	,979	57	,418	,970	57	,166
	2000	,991	57	,939	,991	57	,948	,986	57	,731
	2005	,961	49	,109	,969	49	,219	,942	49	,018
	2010	,978	42	,593	,984	42	,802	,963	42	,189

Levene Test of Homogeneity of Variance		**Original**				**Natural Logarithm Trans. (x**0)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	1,598	4	251	,175	,608	4	251	,657
	Based on Median	1,586	4	251	,179	,611	4	251	,655
	Based on Median, adj. df	1,586	4	248,5	,179	,611	4	250,0	,655
	Based on trimmed mean	1,606	4	251	,173	,613	4	251	,654

Levene Test of Homogeneity of Variance		**Quadratic Trans. (x**2)**				**Square Root Trans. (x**0.5)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	3,060	4	251	,017	1,040	4	251	,387
	Based on Median	3,023	4	251	,018	1,037	4	251	,388
	Based on Median, adj. df	3,023	4	242,8	,019	1,037	4	249,7	,388
	Based on trimmed mean	3,075	4	251	,017	1,046	4	251	,384

Levene Test of Homogeneity of Variance		**Reciprocal Trans. (x**-1)**				**Reciprocal Square Root Trans. (x**-0.5)**				**Reciprocal Quadratic Trans. (x**-2)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measure-ments	**Based on Mean**	,133	4	251	,970	,307	4	251	,873	,131	4	251	,971
	Based on Median	,117	4	251	,976	,307	4	251	,873	,038	4	251	,997
	Based on Median, adj. df	,117	4	247,8	,976	,307	4	249,3	,873	,038	4	242,7	,997
	Based on trimmed mean	,126	4	251	,973	,307	4	251	,873	,095	4	251	,984

Appendix 7. Continued...

CLASS

Test of Normality		**Original**			**Natural Logarithm Trans. (x**0)**			**Quadratic Trans. (x**2)**			**Square Root Trans. (x**0.5)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measurements	**Class 1**	,977	96	,087	,981	96	,185	,967	96	,016	,980	96	,143
	Class 2	,960	64	,038	,968	64	,097	,949	64	,010	,965	64	,064
	Class 3	,910	96	,000	,927	96	,000	,890	96	,000	,919	96	,000

Test of Normality		**Reciprocal Trans. (x**-1)**			**Rec. Square Root Trans. (x**-0.5)**			**Rec. Quadratic Trans. (x**-2)**		
		Shapiro-Wilk			**Shapiro-Wilk**			**Shapiro-Wilk**		
	Year	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**	**Stat.**	**df**	**Sig.**
Sum of time measurements	**Class 1**	,980	96	,158	,981	96	,191	,974	96	,057
	Class 2	,972	64	,157	,971	64	,131	,973	64	,166
	Class 3	,942	96	,000	,935	96	,000	,953	96	,002

Levene Test of Homogeneity of Variance		**Original**				**Natural Logarithm Trans. (x**0)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measurements	**Based on Mean**	2,875	2	253	,058	4,100	2	253	,018
	Based on Median	2,650	2	253	,073	3,880	2	253	,022
	Based on Median, adj. df	2,650	2	252,2	,073	3,880	2	251,3	,022
	Based on trimmed mean	2,950	2	253	,054	4,245	2	253	,015

Levene Test of Homogeneity of Variance		**Quadratic Trans. (x**2)**				**Square Root Trans. (x**0.5)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measurements	**Based on Mean**	2,591	2	253	,077	3,345	2	253	,037
	Based on Median	2,114	2	253	,123	3,170	2	253	,044
	Based on Median, adj. df	2,114	2	245,9	,123	3,170	2	253,0	,044
	Based on trimmed mean	2,550	2	253	,080	3,475	2	253	,032

Levene Test of Homogeneity of Variance		**Reciprocal Trans. (x**-1)**				**Reciprocal Square Root Trans. (x**-0.5)**				**Reciprocal Quadratic Trans. (x**-2)**			
		Stat.	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**	**Stat.**	**df1**	**df2**	**Sig.**
Sum of time measurements	**Based on Mean**	6,438	2	253	,002	5,130	2	253	,007	9,886	2	253	,000
	Based on Median	5,861	2	253	,003	4,781	2	253	,009	8,447	2	253	,000
	Based on Median, adj. df	5,861	2	239,5	,003	4,781	2	246,8	,009	8,447	2	218,6	,000
	Based on trimmed mean	6,544	2	253	,002	5,267	2	253	,006	9,849	2	253	,000

Appendix 7. Continued...

REGION

Test of Normality		Original			Natural Logarithm Trans. (x**0)			Quadratic Trans. (x**2)			Square Root Trans. (x**0.5)		
		Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk		
	Year	Stat.	df	Sig.	Stat.	df	Sig.	Stat.	df	Sig.	Stat.	df	Sig.
Sum of time measure-ments	Asia	,981	119	,101	,990	119	,573	,966	119	,004	,987	119	,299
	USA	,982	115	,131	,979	115	,073	,977	115	,048	,982	115	,119
	Europe	,969	22	,684	,968	22	,672	,966	22	,626	,969	22	,687

Test of Normality		Reciprocal Trans. (x**-1)			Rec. Square Root Trans. (x**-0.5)			Rec. Quadratic Trans. (x**-2)		
		Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk		
	Year	Stat.	df	Sig.	Stat.	df	Sig.	Stat.	df	Sig.
Sum of time measure-ments	Asia	,993	119	,782	,992	119	,755	,988	119	,401
	USA	,969	115	,009	,975	115	,031	,952	115	,000
	Europe	,965	22	,590	,967	22	,639	,958	22	,453

Levene Test of Homogeneity of Variance		Original				Natural Logarithm Trans. (x**0)			
		Stat.	df1	df2	Sig.	Stat.	df1	df2	Sig.
Sum of time measure-ments	Based on Mean	5,604	2	253	,004	4,668	2	253	,010
	Based on Median	5,341	2	253	,005	4,647	2	253	,010
	Based on Median, adj. df	5,341	2	245,7	,005	4,647	2	249,2	,010
	Based on trimmed mean	5,498	2	253	,005	4,659	2	253	,010

Levene Test of Homogeneity of Variance		Quadratic Trans. (x**2)				Square Root Trans. (x**0.5)			
		Stat.	df1	df2	Sig.	Stat.	df1	df2	Sig.
Sum of time measure-ments	Based on Mean	6,560	2	253	,002	5,124	2	253	,007
	Based on Median	5,972	2	253	,003	4,998	2	253	,007
	Based on Median, adj. df	5,972	2	239,3	,003	4,998	2	247,8	,007
	Based on trimmed mean	6,364	2	253	,002	5,058	2	253	,007

Levene Test of Homogeneity of Variance		Reciprocal Trans. (x**-1)				Reciprocal Square Root Trans.(x**-0.5)				Reciprocal Quadratic Trans. (x**-2)			
		Stat.	df1	df2	Sig.	Stat.	df1	df2	Sig.	Stat.	df1	df2	Sig.
Sum of time measure-ments	Based on Mean	3,911	2	253	,021	4,274	2	253	,015	3,373	2	253	,036
	Based on Median	3,968	2	253	,020	4,301	2	253	,015	3,377	2	253	,036
	Based on Median, adj. df	3,968	2	249,6	,020	4,301	2	249,8	,015	3,377	2	247,6	,036
	Based on trimmed mean	3,942	2	253	,021	4,286	2	253	,015	3,395	2	253	,035

Appendix 8. ANOVA Analysis by Factor 'Year' on Time Measurements (4th class omitted)

Descriptives

Sum of time measurements

	N	Mean	Std. Deviation	Std. Error	95% Conf. Interval Lower Bound	95% Conf. Interval Upper Bound	Minimum	Maximum
1990	51	136,090	10,2711	1,4382	133,201	138,979	114,8	160,4
1995	57	139,104	11,1340	1,4747	136,149	142,058	114,2	164,6
2000	57	140,670	11,2138	1,4853	137,695	143,646	118,0	171,9
2005	49	147,447	12,4494	1,7785	143,871	151,023	120,6	172,2
2010	42	155,695	13,8565	2,1381	151,377	160,013	125,3	185,4
Total	256	143,171	13,4180	,8386	141,520	144,823	114,2	185,4

Test of Homogeneity of Variances

Sum of time measurements

Levene Statistic	df1	df2	Sig.
1,598	4	251	,175

ANOVA

Sum of time measurements

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11340,421	4	2835,105	20,584	,000
Within Groups	34570,325	251	137,730		
Total	45910,746	255			

Appendix 8. Continued...

POST HOC TEST

Multiple Comparisons

Dependent Variable:Sum of time measurements

	(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Gabriel	**1990**	**1995**	-3,0133	2,2621	,866	-9,397	3,371
		2000	-4,5800	2,2621	,359	-10,964	1,804
		2005	-11,3567*	2,3476	,000	-17,984	-4,729
		2010	-19,6050*	2,4454	,000	-26,501	-12,709
	1995	**1990**	3,0133	2,2621	,866	-3,371	9,397
		2000	-1,5667	2,1983	,998	-7,773	4,640
		2005	-8,3434*	2,2863	,003	-14,794	-1,893
		2010	-16,5917*	2,3865	,000	-23,310	-9,873
	2000	**1990**	4,5800	2,2621	,359	-1,804	10,964
		1995	1,5667	2,1983	,998	-4,640	7,773
		2005	-6,7768*	2,2863	,032	-13,227	-,327
		2010	-15,0251*	2,3865	,000	-21,743	-8,307
	2005	**1990**	11,3567*	2,3476	,000	4,729	17,984
		1995	8,3434*	2,2863	,003	1,893	14,794
		2000	6,7768*	2,2863	,032	,327	13,227
		2010	-8,2483*	2,4678	,009	-15,210	-1,286
	2010	**1990**	19,6050*	2,4454	,000	12,709	26,501
		1995	16,5917*	2,3865	,000	9,873	23,310
		2000	15,0251*	2,3865	,000	8,307	21,743
		2005	8,2483*	2,4678	,009	1,286	15,210

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

Sum of time measurements

	Year	N	Subset for alpha = 0.05		
			1	2	3
Gabriel[a,b]	**1990**	51	136,090		
	1995	57	139,104		
	2000	57	140,670		
	2005	49		147,447	
	2010	42			155,695
	Sig.		,404	1,000	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 50,549.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I

Appendix 9. Kuskal-Wallis Analysis by Factor 'Class' on Time Measurements (4th class omitted)

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Sum of time measurements	256	143,171	13,4180	114,2	185,4
Class	256	2,00	,868	1	3

Kruskal-Wallis Test

Ranks

	Class	N	Mean Rank
Sum of time measurements	**1. Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans**	96	94,40
	2. Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans	64	132,30
	3. Mid-High-Price - Front Wheel Drive - V-engine - Sedans	96	160,07
	Total	256	

Test Statistics[a,b]

	Sum of time measurements
Chi-Square	37,989
df	2
Asymp. Sig.	,000

a. Kruskal Wallis Test

b. Grouping Variable: Class

Appendix 10. ANOVA Analysis by Factor 'Region' on Time Measurements (4th class omitted)

Descriptives

Sum of time measurements

	N	Mean	Std. Deviation	Std. Error	95% Conf. Interval		Minimum	Maximum
					Lower Bound	Upper Bound		
Asia	119	144,641	14,6772	1,3455	141,977	147,306	116,2	185,4
USA	115	139,924	11,2467	1,0488	137,847	142,002	114,2	174,5
Europe	22	152,191	11,5725	2,4673	147,060	157,322	131,9	172,2
Total	256	143,171	13,4180	,8386	141,520	144,823	114,2	185,4

Test of Homogeneity of Variances

Sum of time measurements

Levene Statistic	df1	df2	Sig.
5,604	2	253	,004

ANOVA

Sum of time measurements

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3259,288	2	1629,644	9,667	,000
Within Groups	42651,458	253	168,583		
Total	45910,746	255			

Robust Tests of Equality of Means

Sum of time measurements

	Statistic[a]	df1	df2	Sig.
Welch	11,809	2	60,770	,000
Brown-Forsythe	10,604	2	108,742	,000

a. Asymptotically F distributed.

Appendix 10. Continued...

POST HOC TESTS

Multiple Comparisons

Dependent Variable:Sum of time measurements

	(I) Region	(J) Region	Mean Diff. (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tamhane	**Asia**	**USA**	4,7168*	1,7059	,018	,612	8,821
		Europe	-7,5497*	2,8103	,033	-14,598	-,501
	USA	**Asia**	-4,7168*	1,7059	,018	-8,821	-,612
		Europe	-12,2666*	2,6809	,000	-19,057	-5,476
	Europe	**Asia**	7,5497*	2,8103	,033	,501	14,598
		USA	12,2666*	2,6809	,000	5,476	19,057
Dunnett T3	**Asia**	**USA**	4,7168*	1,7059	,018	,613	8,820
		Europe	-7,5497*	2,8103	,032	-14,584	-,515
	USA	**Asia**	-4,7168*	1,7059	,018	-8,820	-,613
		Europe	-12,2666*	2,6809	,000	-19,040	-5,493
	Europe	**Asia**	7,5497*	2,8103	,032	,515	14,584
		USA	12,2666*	2,6809	,000	5,493	19,040
Games-Howell	**Asia**	**USA**	4,7168*	1,7059	,017	,691	8,742
		Europe	-7,5497*	2,8103	,029	-14,429	-,670
	USA	**Asia**	-4,7168*	1,7059	,017	-8,742	-,691
		Europe	-12,2666*	2,6809	,000	-18,886	-5,647
	Europe	**Asia**	7,5497*	2,8103	,029	,670	14,429
		USA	12,2666*	2,6809	,000	5,647	18,886
Dunnett C	**Asia**	**USA**	4,7168*	1,7059		,667	8,767
		Europe	-7,5497*	2,8103		-14,539	-,561
	USA	**Asia**	-4,7168*	1,7059		-8,767	-,667
		Europe	-12,2666*	2,6809		-18,964	-5,569
	Europe	**Asia**	7,5497*	2,8103		,561	14,539
		USA	12,2666*	2,6809		5,569	18,964

*. The mean difference is significant at the 0.05 level.

Appendix 11. Car Specifications

Glossary

inline-4 = an engine with the pistons in a row, the number of pistons being four
V6 = an engine with the pistons i a v-shape, two opposite, six pistons in all

16V = the total number of valves on the engine, often four per cylinder
SOHC = Single OverHead Cam-axle - single cam (for raising valves) top of engine
DOHC = Double OverHead Cam-axle - double cams (for raising valves) top of engine
OHV = OverHead Valve, cam inside cylinder block, uses pushrods to raise valves

bhp = Break HorsePower, a measurment of power, equivalent to 735,5-750 watts

FF = Front engine, Front drive
F/R = Front engine, Rear drive
FAWD = Front drive, All Wheel Drive

5M = 5 Manual - manual gearbox with 5 gears
4A = 4 Automatic - automatic gearbox with 4 gears
CVT = Continuously Variable Transmission, gearbox with an infinite number of ratios

1990 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Daihatsu Charade	Base 4-door sedan	FF	405	162	138	1024	16V SOHC inline-4	80	1,3	5M
Honda Civic	DX 4-door sedan	FF	429	169	136	1026	16V SOHC inline-4	70	1,4	5M
Hyundai Excel	Base 4-door sedan	FF	421	163	127	992	SOHC inline-4	81	1,5	5M
Mazda Protegé	SE 4-door sedan	FF	436	167	137	1101	16V DOHC inline-4	125	1,8	5M
Mitsubishi Mirage	Base 4-door sedan	FF	403	167	132	1017	SOHC inline-4	81	1,5	5M
Nissan Sentra	Base 4-door sedan	FF	433	167	137	1096	16V DOHC inline-4	110	2,0	5M
Suzuki Swift	GA 4-door sedan	FF	371	159	133	849	SOHC inline-4	70	1,3	5M
Toyota Corolla	Base 4-door sedan	FF	437	167	126	1090	16V DOHC inline-4	102	1,6	5M
USA										
Chevrolet Cavalier	VL 4-door sedan	FF	435	171	134	1187	SOHC inline-4	93	2,2	5M
Eagle Summit	Base 4-door sedan	FF	403	167	132	1017	12V SOHC inline-4	92	1,5	5M
Ford Tempo	GL 4-door sedan	FF	450	173	134	1174	OHV inline-4	98	2,3	5M
Geo Prizm	Base 4-door sedan	FF	434	166	133	1135	16V DOHC inline-4	102	1,6	5M
Mercury Topaz	GS 4-door sedan	FF	450	173	134	1174	OHV inline-4	98	2,3	5M
Pontiac LeMans	LE 4-door sedan	FF	416	166	136	1044	12V SOHC inline-4	74	1,6	5M
Pontiac Sunbird	Base 4-door sedan	FF	435	171	134	1187	SOHC inline-4	96	2,0	5M
EUROPE										
Wolkswagen Fox	GL 4-door sedan	FF	415	160	136	976	SOHC inline-4	81	1,8	5M
Volkswagen Jetta GL L4	GL 4-door sedan	FF	435	17	141	1028	SOHC inline-4	100	1,8	5M

1990 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura Integra	RS 4-door sedan	FF	439	171	133	1158	16V DOHC inline-4	130	1,8	5M
Honda Accord	DX 4-door sedan	FF	469	172	137	1244	16V SOHC inline-4	125	2,2	5M
Hyundai Sonata	GL 4-door sedan	FF	468	175	141	1287	16V SOHC inline-4	116	2,4	5M
Mitsubishi Galant	Base 4-door sedan	FF	467	169	136	1180	SOHC inline-4	103	2,0	5M
Nissan Stanza	XE 4-door sedan	FF	457	170	137	1296	SOHC inline-4	138	2,4	5M
Toyota Camry	2.0 4-door sedan	FF	463	171	137	1401	16V SOHC inline-4	115	2,0	5M
Mazda 626	DX 4-door sedan	FF	455	169	141	1283	SOHC inline-4	110	2,2	5M
USA										
Chevrolet Corsica	Base 4-door sedan	FF	466	173	143	1244	SOHC inline-4	95	2,0	5M
Chevrolet Lumina	Base 4-door sedan	FF	504	182	135	1471	OHV inline-4	110	2,5	5M
Chrysler LeBaron Sedan	Base 4-door sedan	FF	460	173	136	1292	SOHC inline-4	100	2,5	5M
Dodge Spirit	Base 4-door sedan	FF	460	173	136	1292	SOHC inline-4	100	2,5	5M
Ford Taurus	L 4-door sedan	FF	479	180	137	1385	OHV 8V Inline4	105	2,5	5M
Oldsmobile Cutlass Calais	Base 4-door sedan	FF	454	169	133	1144	OHV inline-4	110	2,3	5M
Plymouth Acclaim	Base 4-door sedan	FF	460	173	136	1292	SOHC inline-4	100	2,5	5M
Pontiac Grand Am	LE 4-door sedan	FF	457	169	133	1283	OHV inline-4	110	2,3	5M
EUROPE										
Audi 80	2.0E 4-door sedan	FF	447	172	138	1439	SOHC inline-4	110	2,0	5M
Peugeot 405	Gri 4-door sedan	FF	451	171	140	1233	SOHC inline-4	110	2,0	5M
Volkswagen Passat GL	GL 4-door sedan	FF	457	170	143	1185	16V DOHC inline-4	134	2,0	5M

1990 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Nissan Maxima	GXE 4-door sedan	FF	477	176	140	1432	SOHC V6	160	3,0	4A
USA										
Buick Century	Custom V6 4-door sedan	FF	480	176	138	1122	OHV V6	160	3,3	4A
Buick LeSabre	Custom 4-door sedan	FF	499	184	139	1485	OHV V6	165	3,8	4A
Buick Regal	Custom 4-door sedan	FF	488	184	135	1505	OHV V6	140	3,1	4A
Buick Skylark	Base V6 4-door sedan	FF	457	169	132	1178	OHV V6	160	3,3	3A
Chrysler New Yorker	Salon 4-door sedan	FF	488	174	139	1357	OHV V6	147	3,3	4A
Dodge Dynasty	Base V6 4-door sedan	FF	488	174	139	1360	OHV V6	147	3,3	4A
Dodge Monaco	LE 4-door sedan	FF	490	178	139	1401	SOHC V6	150	3,0	4A
Eagle Premier	LX 4-door sedan	FF	490	178	139	1401	SOHC V6	150	3,0	4A
Mercury Sable	GS 4-door sedan	FF	479	180	138	1421	OHV V6	140	3,0	4A
Oldsmobile Cutlass Ciera	SL V6 4-door sedan	FF	480	176	138	1122	OHV V6	160	3,3	4A
Oldsmobile Cutlass Supr.	Base V6 4-door sedan	FF	488	179	139	1462	OHV V6	140	3,1	4A
Oldsmobile 88 Royale	Base 4-door sedan	FF	499	184	139	1485	OHV V6	165	3,8	4A
Pontiac 6000	LE V6 4-door sedan	FF	491	183	137	1498	OHV V6	140	3,1	4A
Pontiac Bonneville	LE 4-door sedan	FF	505	183	141	1612	OHV V6	165	3,8	4A
Pontiac Grand Prix	LE 4-door sedan	FF	493	180	134	1455	OHV V6	140	3,1	4A

1990 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Infiniti Q45	Base 4-door sedan	F/R	507	183	143	1793	32V DOHC V8	278	4,5	4A
Lexus LS400	Base 4-door sedan	F/R	500	182	140	1707	32V V8	250	4,0	4A
Mazda 929	Base 4-door sedan	F/R	493	172	138	1625	DOHC V6	190	3,0	4A
USA										
Cadillac Brougham	Base 4-door sedan	F/R	561	194	144	1943	OHV V8	170	5,0	4A
Lincoln Town Car	Standard 4-door sedan	F/R	556	198	144	1832	SOHC V8	190	5,0	4A
EUROPE										
BMW 750i	V12 4-door sedan	F/R	502	184	141	1741	SOHC 24V V-12	296	5,0	4A
Mercedes-Benz 420	SEL 4-door sedan	F/R	529	182	144	1777	SOHC V8	201	4,2	4A
Volvo 760	GLE V6 4-door sedan	F/R	484	176	141	1540	SOHC V6	170	2,9	4A

1995 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura Integra	Base 4-door sedan	FF	452	170	133	1210	16V DOHC inline-4	142	1,8	5M
Honda Civic	DX 4-door sedan	FF	439	170	131	1153	16V SOHC inline-4	102	1,5	5M
Hyundai Accent	Base 4-door sedan	FF	411	163	139	1021	SOHC inline-4	92	1,5	5M
Hyundai Elantra	Base 4-door sedan	FF	440	168	139	1145	DOHC inline-4	113	1,6	5M
Kia Sephia	RS 4-door sedan	FF	436	169	139	1076	SOHC inline-4	88	1,6	5M
Mazda Protegé	DX 4-door sedan	FF	445	170	138	1194	16V DOHC inline-4	92	1,5	5M
Mercury Tracer	Base 4-door sedan	FF	434	169	134	1134	SOHC inline-4	88	1,9	5M
Mitsubishi Mirage	S 4-door sedan	FF	250	168	131	947	SOHC inline-4	113	1,8	5M
Nissan Sentra	E 4-door sedan	FF	432	169	138	1135	16V DOHC inline-4	115	1,6	5M
Suzuki Swift	GA 4-door sedan	FF	409	159	138	831	SOHC inline-4	70	1,3	5M
Toyota Corolla	Standard 4-door sedan	FF	442	169	138	1096	16V DOHC inline-4	105	1,6	5M
Toyota Tercel	DX 4-door sedan	FF	412	165	135	997	16V DOHC inline-4	93	1,5	5M
USA										
Chevrolet Cavallier	Base 4-door sedan	FF	460	165	139	1255	SOHC inline-4	120	2,2	5M
Dodge Neon	Base 4-door sedan	FF	436	171	134	1158	16V SOHC inline-4	132	2,0	5M
Eagle Sumit	LX 4-door sedan	FF	250	168	131	947	SOHC inline-4	113	1,8	5M
Ford Escort	LX 4-door sedan	FF	432	169	134	1165	SOHC inline-4	88	1,9	5M
Geo Metro	Base 4-door sedan	FF	417	160	141	899	SOHC inline-4	70	1,3	5M
Geo Prizm	Base 4-door sedan	FF	439	168	135	1140	16V DOHC inline-4	105	1,6	5M
Saturn SL	SL 4-door sedan	FF	448	172	133	1110	SOHC inline-4	100	1,9	5M
EUROPE										
Volkswagen Jetta III	GL 4-door sedan	FF	440	169	143	1342	SOHC inline-4	115	2,0	5M

1995 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Hyundai Sonata	Base 4-door sedan	FF	470	177	140	1405	16V DOHC inline-4	137	2,0	5M
Infiniti G20	Base 4-door sedan	FF	445	169	136	1301	16V DOHC inline-4	140	2,0	5M
Mazda 626	DX 4-door sedan	FF	468	175	137	1298	16V DOHC inline-4	118	2,0	5M
Mitsubishi Galant	S 4-door sedan	FF	463	173	139	1373	16V SOHC inline-4	141	2,4	5M
Nissan Altima	XE 4-door sedan	FF	458	170	142	1344	16V DOHC inline-4	150	2,4	5M
USA										
Ford Contour	GL 4-door sedan	FF	467	176	138	1321	16V DOHC inline-4	125	2,0	5M
Mercury Mystique	GS 4-door sedan	FF	466	176	138	1412	16V DOHC inline-4	125	2,0	5M
Oldsmobile Achieva	Series I S 4-door sedan	FF	477	174	136	1319	DOHC inline-4	150	2,3	5M
Pontiac Grand Am	SE 4-door sedan	FF	476	174	136	1378	16V DOHC inline-4	150	2,3	5M
Pontiac Sunfire	SE 4-door sedan	FF	462	171	139	1216	OVH inline-4	120	2,2	5M
EUROPE										
Volvo 850	850 Level I 4-door sedar	FF	466	176	141	1429	20V DOHC inline-5	168	2,4	5M

1995 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura Legend	4-door sedan	FF	495	181	140	1589	24V SOHC V6	200	3,2	4A
Honda Accord	DX 4-door sedan	FF	467	178	140	1296	SOHC V6	130	2,2	4A
Lexus ES300	Base 4-door sedan	FF	477	178	137	1526	DOHC V6	188	3,0	4A
Mitsubishi Diamante	ES 4-door sedan	FF	483	178	134	1556	DOHC V6	202	3,0	4A
Nissan Maxima	GXE 4-door sedan	FF	491	182	148	1367	24V DOHC V6	190	3,0	4A
Toyota Avalon	XL 4-door sedan	FF	483	179	142	1532	24V DOHC V6	192	3,0	4A
Toyota Camry	LE V6 4-door sed.	FF	463	169	144	1336	24V DOHC V6	185	3,0	4A
USA										
Buick Century	Custom 4-door sedan	FF	480	176	136	1350	OVH V6	160	3,1	4A
Buick LeSabre	Base 4-door sedan	FF	508	190	141	1566	OVH V6	170	3,8	4A
Buick Regal	Custom Sedan 4-door	FF	492	184	138	1569	OHV V6	160	3,1	4A
Chevrolet Lumina	Base 4-door sedan	FF	510	184	140	1541	OVH V6	160	3,1	4A
Chrysler Concorde	Base 4-door sedan	FF	512	189	143	1533	OVH V6	161	3,3	4A
Dodge Intrepid	Base 4-door sedan	FF	513	189	143	1503	OVH V6	161	3,3	4A
Eagle Vision	ESi 4-door sedan	FF	512	189	143	1547	OVH V6	161	3,3	4A
Ford Taurus	GL 4-door sedan	FF	488	181	137	1416	OVH V6	140	3,8	4A
Mercury Sable	GS 4-door sedan	FF	488	181	138	1419	OVH V6	140	3,0	4A
Oldsmobile Aurora	Base 4-door sedan	FF	522	189	141	1816	32V DOHC V8	250	4,0	4A
Oldsmobile Cutlass Ciera	Series II SL 4-door s.	FF	483	177	137	1286	OVH V6	160	3,1	4A
Oldsmobile Cutlass Supr.	Series I S 4-door sedan	FF	492	180	139	1530	OVH V6	160	3,1	4A
Oldsmobile Eighty Eight	LSS 4-door sedan	FF	509	188	141	1544	OVH V6	205	3,8	4A
Pontiac Bonneville	Bonneville SE 6 Cyl	FF	507	189	141	1564	OVH V6	205	3,8	4A
Pontiac Grand Prix	Base 4-door sedan	FF	497	183	143	1472	OVH V6	160	3,1	4A
EUROPE										
Audi A6	S 4-door sedan	FF	480	181	145	1546	SOHC V6	172	2,8	4A
Audi 90	S 4-door sedan	FF	458	169	140	1532	SOHC V6	172	2,8	4A
Saab 9000	CDE 4-door sedan	FF	479	176	142	1487	DOHC V6	210	2,5	4A
Volkswagen Passat	GLX 4-door sedan	FF	461	171	143	1444	SOHC V6	172	2,8	4A

1995 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Infiniti J30	Base 4-door sedan	FR	486	177	139	1601	DOHC V8	210	3,0	4A
Infiniti Q45	Base 4-door sedan	FR	507	183	137	1834	DOHC V8	278	4,5	4A
Lexus LS400	Base 4-door sedan	FR	500	183	142	1658	32V DOHC V8	270	4,0	4A
Mazda 929	Base 4-door sedan	FR	492	180	139	1633	24V DOHC V6	195	3,0	4A
USA										
Cadillac Fleetwood	L Fleetwood 4-d.	FR	572	198	145	2033	DOHC V8	260	5,7	4A
Lincoln Town Car	Executive 4-door sedan	FR	556	195	145	1834	SOHC V8	210	4,6	4A
EUROPE										
BMW 530 i	Base 4-door sedan	FR	472	175	141	1668	32V DOHC V8	215	3,0	4A
BMW 740	740i 4-door sedan	FR	498	186	144	1882	DOHC V8	282	4,0	5A
Jaguar XJ12	Base 4-door sedan	FR	502	180	135	1771	SOHC V12	301	6,0	4A
Mercedes-Benz E420	E420 4-door sedan	FR	475	174	143	1703	32V DOHC V8	275	4,2	4A

2000 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura Integra	LS 4-door sedan	FF	452	171	137	1231	16V DOHC inline-4	140	1,8	5M
Daewoo Lanos	S 4-door sedan	FF	424	168	143	1145	16V DOHC inline-4	105	1,6	5M
Daewoo Leganza	SE 4-door sedan	FF	467	178	144	1408	16V DOHC inline-4	131	2,2	5M
Daewoo Nubira	SX 4-door sedan	FF	446	170	143	1165	16V DOHC inline-4	129	2,0	5M
Honda Accord	DX 2.3 4-door sedan	FF	480	179	145	1331	16V SOHC inline-4	135	2,3	5M
Honda Civic	DX 4-door sedan	FF	445	170	139	1062	16V SOHC inline-4	106	1,6	5M
Hyundai Accent	GL 4-door sedan	FF	412	162	139	962	SOHC inline-4	92	1,5	5M
Hyundai Elantra	GLS 4-door sedan	FF	442	170	139	1162	16V DOHC inline-4	140	2,0	5M
Hyundai Sonata	Base 4-door sedan	FF	471	182	141	1395	16V DOHC inline-4	149	2,4	5M
Kia Sephia	LS Base 4-door sedan	FF	443	170	141	1125	16V DOHC inline-4	125	1,8	5M
Mazda Protegé	DX 4-door sedan	FF	442	170	141	1112	16V DOHC inline-4	105	1,6	5M
Mitsubishi Mirage	DE 4-door sedan	FF	441	169	136	1010	SOHC inline-4	92	1,5	5M
Nissan Altima	XE 4-door sedan	FF	466	176	142	1298	16V DOHC inline-4	155	2,4	5M
Nissan Sentra	XE 4-door sedan	FF	435	169	138	1080	16V DOHC inline-4	125	1,8	5M
Suzuki Esteem	GL 1.6 4-door sedan	FF	422	168	137	1011	16V DOHC inline-4	122	1,8	5M
Toyota Corolla LE	VE 4-door sedan	FF	442	169	138	1099	16V DOHC inline-4	125	1,8	5M
Toyota Echo	Base 4-door sedan	FF	415	166	151	922	16V DOHC inline-4	108	1,5	5M
USA										
Chevrolet Cavalier	Base 4-door sedan	FF	459	172	139	1215	OHV inline-4	115	2,2	5M
Chevrolet Prizm	Base 4-door sedan	FF	443	169	136	1089	16V DOHC inline-4	125	1,8	5M
Dodge Neon	Highline 4-door sedan	FF	443	189	142	1165	16V SOHC inline-4	132	2,0	5M
Ford Escort	LX 4-door sedan	FF	445	171	133	1125	16V SOHC inline-4	110	2,0	5M
Ford Focus	LX 4-door sedan	FF	444	170	143	1120	DOHC inline-4	110	2,0	5M
Pontiac Sunfire	SE 4-door sedan	FF	462	172	139	1212	16V DOHC inline-4	150	2,4	5M
Saturn SL2	SL 4-door sedan	FF	449	169	140	1059	16V DOHC inline-4	124	1,9	5M
EUROPE										
Volkswagen Jetta	GL 4-door sedan	FF	438	173	145	1304	SOHC inline-4	115	2,0	5M

2000 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura Integra	LS 4-door sedan	FF	452	171	137	1231	16V DOHC inline-4	140	1,8	5M
Infiniti G20	Luxury 4-door sedan	FF	451	169	140	1333	16V DOHC inline-4	145	2,0	5M
Mazda 626	LX 4-door sedan	FF	476	176	140	1300	16V DOHC inline-4	130	2,0	5M
Toyota Camry	CE 4-door sedan	FF	479	178	141	1441	16V DOHC inline-4	136	2,2	5M
USA										
Dodge Stratus	SE 4-door sedan	FF	472	180	137	1322	16V SOHC inline-4	132	2,0	5M
Chrysler Cirrus	LX 4-door sedan	FF	472	180	137	1322	16V SOHC inline-4	150	2,4	5M
Oldsmobile Alero	GX 4-door sedan	FF	474	178	138	1372	16V DOHC inline-4	150	2,4	5M
Pontiac Grand Am	SE 4-door sedan	FF	473	179	140	1392	16V DOHC inline-4	150	2,4	5M
EUROPE										
Volkswagen Passat	GLS 4-door sedan	FF	468	174	146	1417	20V turboDOHC i-4	150	1,8	5M

2000 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura 3.2 TL	Base 4-door sedan	FF	490	179	141	1586	24V DOHC V6	225	3,2	5A
Infiniti I30	Luxury 4-door sedan	FF	492	178	144	1517	24V DOHC V6	227	3,0	4A
Mazda Millennia	Base 4-door sedan	FF	482	177	139	1471	24V DOHC V6	170	2,5	4A
Mitsubishi Diamante	Base 4-door sedan	FF	493	179	137	1562	24V SOHC V6	210	3,5	4A
Mitsubishi Galant	ES V6 4-door sedan	FF	477	174	141	1426	24V DOHC V6	195	3,0	4A
Nissan Maxima	GXE 4-door sedan	FF	484	179	144	1507	24V DOHC V6	222	3,0	4A
Toyota Avalon	XL 4-door sedan	FF	487	179	144	1516	24V DOHC V6	210	3,0	4A
USA										
Buick Century	Custom 4-door sedan	FF	494	185	144	1529	OHV V6	175	3,1	4A
Buick LeSabre	Custom 4-door sedan	FF	510	189	141	1563	OHV V6	205	3,8	4A
Buick Regal	LS 4-door sedan	FF	498	185	144	1609	OHV V6	200	3,8	4A
Chevrolet Impala	Base 4-door sedan	FF	508	185	146	1539	OHV V6	180	3,4	4A
Chevrolet Lumina	Base 4-door sedan	FF	510	184	139	1512	OHV V6	175	3,1	4A
Chevrolet Malibu	Base 4-door sedan	FF	484	176	144	1385	OHV V6	170	3,1	4A
Chrysler 300M	Base 4-door sedan	FF	502	189	142	1619	24V SOHC V6	253	3,5	4A
Chrysler Concorde	LX 4-door sedan	FF	531	189	142	1567	24V DOHC V6	200	2,7	4A
Chrysler LHS	Base 4-door sedan	FF	528	189	142	1629	24V SOHC V6	253	3,5	4A
Dodge Intrepid	Base 4-door sedan	FF	517	190	142	1554	24V DOHC V6	202	2,7	4A
Ford Taurus	LX 4-door sedan	FF	502	185	142	1512	OHV V6	153	3,0	4A
Mercury Sable	GS 4-door sedan	FF	507	185	141	1499	OHV V6	153	3,0	4A
Oldsmobile Intrigue	GX 4-door sedan	FF	498	187	144	1569	24V DOHC V6	215	3,5	4A
Pontiac Bonneville	SE 4-door sedan	FF	514	184	144	1628	OHV V6	205	3,8	4A
Pontiac Grand Prix	SE 4-door sedan	FF	499	185	139	1550	OHV V6	175	3,4	4A
EUROPE										
Audi A4	2.8 V6 4-door sedan	FF	452	173	142	1436	30V DOHC V6	200	2,8	5A

2000 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Infiniti Q45	Base 4-door sedan	FR	507	182	145	1768	32V DOHC V8	266	4,1	4A
Lexus GS 300	Base 4-door sedan	FR	481	180	142	1652	24V DOHC V6	220	3,0	5A
Lexus LS400	Base 4-door sedan	FR	500	183	144	1766	32V DOHC V8	290	4,0	5A
USA										
Cadillac Catera	Base 4-door sedan	FR	493	179	143	1712	24V DOHC V6	200	3,0	4A
Lincoln LS series	V8 Auto 4-door sedan	FR	493	186	142	1676	32V DOHC V8	252	3,9	5A
Lincoln Town Car	Executive 4-door sedan	FR	547	199	147	1823	SOHC V8	205	4,6	4A
EUROPE										
BMW 540iA	Base 4-door sedan	FR	478	180	144	1702	32V DOHC V8	282	4,4	5A
BMW 750iL	Base 4-door sedan	FR	512	186	142	1725	32V DOHC V8	282	4,4	5A
Jaguar S-type	3.0 V6 4-door sedan	FR	486	182	141	1657	24V DOHC V6	240	3,0	5A
Jaguar XJ8	4.0 V8 4-door sedan	FR	515	180	135	1791	32V DOHC V8	290	4,0	5A
Mercedes Benz C280	Base 4-door sedan	FR	451	172	142	1505	SOHC V6	194	2,8	5A
Mercedes-Benz E430	RWD 4-door sedan	FR	481	180	144	1653	SOHC V8	275	4,3	5A

2005 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Honda Civic	DX 4-door sedan	FF	443	171	144	1099	16V SOHC inline-4	115	1,7	5M
Hyundai Accent	GLS 4-door sedan	FF	423	167	139	1035	16V DOHC inline-4	104	1,6	5M
Hundai Elantra	GLS 4-door sedan	FF	452	172	142	1196	16V DOHC inline-4	138	2,0	5M
Kia Optima	LX 4-door sedan	FF	472	182	141	1393	16V DOHC inline-4	138	2,4	5M
Kia Spectra	LX 4-door sedan	FF	448	173	147	1226	16V DOHC inline-4	138	2,0	5M
Kia Rio	Base 4-door sedan	FF	424	168	144	1091	16V DOHC inline-4	104	1,6	5M
Mazda 3	Base 4-door sedan	FF	453	176	147	1224	16V DOHC inline-4	148	2,3	5M
Mitsubishi Lancer	ES 4-door sedan	FF	451	170	137	1201	16V SOHC inline-4	120	2,0	5M
Nissan Sentra	1.8 4-door sedan	FF	451	171	141	1141	16V DOHC inline-4	126	1,8	5M
Suzuki Aerio	S 4-door sedan	FF	435	172	154	1215	16V DOHC inline-4	155	2,3	5M
Suzuki Forenza	S 4-door sedan	FF	450	172	145	1226	16V DOHC inline-4	126	2,0	5M
Toyota Corolla	CE 4-door sedan	FF	453	170	146	1137	16V DOHC inline-4	130	1,8	5M
Toyota ECHO	Base 4-door sedan	FF	419	166	151	924	16V DOHC inline-4	108	1,5	5M
USA										
Chevrolet Aveo	LS 4-door sedan	FF	423	167	150	1076	16V DOHC inline-4	103	1,6	5M
Chevrolet Cobalt	Base 4-door sedan	FF	458	172	145	1302	16V DOHC inline-4	145	2,2	5M
Dodge Neon	SE 4-door sedan	FF	443	171	142	1172	16V SOHC inline-4	132	2,0	5M
Ford Focus	ZX4 S 4-door sedan	FF	445	169	144	1224	16V DOHC inline-4	136	2,0	5M
Saturn ION	Base 4-door sedan	FF	470	172	142	1260	16V DOHC inline-4	140	2,2	5M
EUROPE										
Volkswagen Jetta	GL 4-door sedan	FF	441	173	149	1377	SOHC inline-4	115	2,0	5M

2005 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura TSX	Base 4-door sedan	FF	466	176	146	1466	16V DOHC inline-4	200	2,4	6M
Honda Accord	DX 4-door sedan	FF	481	182	145	1386	16V DOHC inline-4	160	2,4	5M
Hyundai Sonata	GL 4-door sedan	FF	475	182	142	1444	16V DOHC inline-4	138	2,4	5M
Mazda6	6i 4-door sedan	FF	474	178	144	1382	16V DOHC inline-4	160	2,3	5M
Nissan Altima	2.5S 4-door sedan	FF	488	179	147	1362	16V DOHC inline-4	175	2,5	5M
Toyota Camry	Standard 4-door sedan	FF	481	180	149	1411	16V DOHC inline-4	160	2,4	5M
EUROPE										
Saab 9-3	Linear 4-door sedan	FF	464	173	144	1441	16V turboDOHC i-4	175	2,0	5M
Volkswagen Passat	GLS 1.8t 4-door sedan	FF	470	174	146	1458	16V turboDOHC i-4	170	1,8	5M
Volvo S40	2.4i 4-door sedan	FF	447	177	145	1400	20V DOHC inline-5	168	2,4	5M

2005 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura TL	Base 4-door sedan	FF	473	183	144	1580	24V SOHC V6	270	3,2	5A
Hyundai XG350	Base 4-door sedan	FF	487	183	142	1658	24V DOHC V6	216	3,5	5A
Kia Amanti	Base 4-door sedan	FF	483	185	149	1826	24V DOHC V6	200	3,5	5A
Lexus ES 330	Base 4-door sedan	FF	485	181	146	1576	24V DOHC V6	225	3,3	5A
Nissan Maxima	3.5 SE 4-door sedan	FF	491	182	148	1560	24V DOHC V6	265	3,5	5A
USA										
Buick Century	Base 4-door sedan	FF	494	185	144	1517	OHV V6	175	3,1	4A
Buick LaCrosse	CX 4-door sedan	FF	503	185	146	1587	24V DOHC V6	200	3,8	4A
Buick LeSabre	Custom 4-door sedan	FF	508	187	145	1619	OHV V6	205	3,8	4A
Chevrolet Impala	Base 4-door sedan	FF	508	185	146	1573	OHV V6	180	3,4	4A
Chevrolet Malibu	Base 4-door sedan	FF	478	178	146	1441	OHV V6	200	3,5	4A
Chrysler 300	Base 4-door sedan	FF	500	188	148	1689	24V DOHC V6	190	2,7	4A
Chrysler Sebring	Touring 4-door sedan	FF	484	179	139	1441	24V DOHC V6	200	2,7	4A
Dodge Stratus	SXT 4-door sedan	FF	486	179	139	1441	24V DOHC V6	200	2,7	4A
Ford Five Hundred	SE 4-door sedan	FF	510	189	156	1663	24V DOHC V6	203	3,0	6A
Ford Taurus	SE 4-door sedan	FF	502	185	141	1498	OHV V6	153	3,0	4A
Mercury Montego	Luxury fwd 4-door s.	FF	510	189	156	1671	DOHC V6	203	3,0	6A
Mitsubishi Galant	DE 4-door sedan	FF	484	184	147	1521	24V DOHC V6	230	3,8	4A
Pontiac G6	Base 4-door sedan	FF	480	179	145	1535	OHV V6	200	3,5	4A
Pontiac Grand Prix	Base 4-door sedan	FF	504	187	142	1579	OHV V6	200	3,8	4A
Pontiac Bonneville	SE 4-door sedan	FF	515	188	144	1630	OHV V6	205	3,8	4A
EUROPE										
Audi A4	3.2 FSI 4-door sedan	FF	459	177	143	1426	24V DOHC V6	255	3,1	6A

2005 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Infiniti Q45	Base 4-door sedan	FR	510	184	149	1839	32V DOHC V8	340	4,5	5A
Lexus GS 430	Base 4-door sedan	FR	481	180	142	1657	32V DOHC V8	300	4,3	5A
Lexus LS 430	Base 4-door sedan	FR	501	183	149	1811	32V DOHC V8	290	4,3	6A
USA										
Cadillac CTS-V	Base 4-door sedan	FR	483	179	144	1621	OHV V8	400	5,7	5A
Cadillac STS	V-8 4-door sedan	FR	499	184	146	1751	32V DOHC V8	320	4,6	5A
Lincolm LS	V-8 Ultimate	FR	494	186	142	1671	32V DOHC V8	280	3,9	5A
Lincoln Town Car Sign.	Signature 4-door sedan	FR	549	199	150	1973	SOHC V8	239	4,6	4A
EUROPE										
BMW 545i	Base 4-door sedan	FR	484	185	147	1556	32V DOHC V8	325	4,4	6A
BMW 745i	Base 4-door sedan	FR	503	190	149	1987	32V DOHC V8	325	4,4	6A
Jaguar S-Type	4.2 4-door sedan	FR	490	182	142	1712	32V DOHC V8	294	4,2	6A
Jaguar XJ8	Base 4-door sedan	FR	509	186	145	1709	32V DOHC V8	294	4,2	6A
Mercedes-Benz E500	Base 4-door sedan	FR	482	181	145	1452	SOHC V8	302	5,0	5A
Mercedes-Benz S430	Base 4-door sedan	FR	517	186	145	1889	SOHC V8	275	4,3	7A

2010 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Honda Civic	DX 4-door sedan	FF	450	175	144	1194	16V SOHC inline-4	140	1,8	5M
Hyundai Accent	GLS 4-door sedan	FF	405	169	147	1074	16V DOHC inline-4	110	1,6	5M
Hyundai Elantra	Blue 4-door sedan	FF	451	178	148	1236	16V DOHC inline-4	132	2,0	5M
Kia Forte	LX 4-door sedan	FF	448	177	140	1229	16V DOHC inline-4	156	2,0	5M
Kia Rio	Base 4-door sedan	FF	424	169	147	1074	16V DOHC inline-4	110	1,6	5M
Mazda 3	i SV 4-door sedan	FF	459	176	147	1302	16V DOHC inline-4	148	2,0	5M
Mitsubishi Lancer	DE 4-door sedan	FF	457	176	149	1326	16V DOHC inline-4	152	2,0	5M
Nissan Sentra	2.0 4-door sedan	FF	457	179	151	1299	16V DOHC inline-4	140	2,0	5M
Nissan Versa	1.6 4-door sedan	FF	430	169	153	1223	16V DOHC inline-4	107	1,6	5M
Suzuki SX4	Base 4-door sedan	FF	451	173	154	1236	16V DOHC inline-4	150	2,0	5M
Toyota Corolla	Base 4-door sedan	FF	454	176	147	1236	16V DOHC inline-4	132	1,8	5M
Toyota Yaris	Base 4-door sedan	FF	383	169	153	1042	16V DOHC inline-4	106	1,5	5M
USA										
Chevrolet Aveo	LS 4-door sedan	FF	431	171	151	1166	16V DOHC inline-4	108	1,6	5M
Chevrolet Cobalt	Base 4-door sedan	FF	458	172	141	1262	16V DOHC inline-4	155	2,2	5M
Ford Focus	S 4-door sedan	FF	445	172	149	1176	16V DOHC inline-4	143	2,0	5M

2010 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Honda Accord	LX 4-door sedan	FF	493	185	148	1466	16V DOHC inline 4	177	2,4	5A
Hyundai Sonata	GLS door sedan	FF	480	183	147	1495	16V DOHC inline 4	168	2,4	5A
Kia Optima	LX 4-door sedan	FF	480	181	148	1433	16V DOHC inline 4	175	2,4	5A
Mazda 6	i SV 4-door sedan	FF	492	184	147	1480	16V DOHC inline 4	170	2,5	5A
Mitsubishi Galant	ES 4-door sedan	FF	485	184	147	1581	16V DOHC inline 4	160	2,4	4A
Nissan Altima	2.5 4-door sedan	FF	482	180	147	1428	16V DOHC inline 4	175	2,5	CVA
Suzuki Kizashi	Base 4-door sedan	FF	465	182	148	1471	16V DOHC inline 4	185	2,4	CVA
Toyota Camry	Base 4-door sedan	FF	481	182	147	1481	16V DOHC inline 4	169	2,5	6A
USA										
Chevrolet Malibu	LS 4-door sedan	FF	487	179	145	1550	16V DOHC inline 4	169	2,4	4A
Chrysler Sebring	LX 4-door sedan	FF	484	181	152	1503	16V DOHC inline 4	173	2,4	4A
Dodge Avenger	SXT 4-door sedan	FF	485	182	150	1546	16V DOHC inline 4	173	2,4	4A
Ford Fusion	S 4-door sedan	FF	484	183	145	1491	16V DOHC inline 4	175	2,5	6A
Mercury Milan	Base 4-door sedan	FF	480	183	145	1502	16V DOHC inline 4	175	2,5	6A
EUROPE										
Volkswagen Jetta	S 4-door sedan	FF	455	178	146	1466	20V DOHC inline-5	170	2,5	6A
Volkswagen Passat	Base 4-door sedan	FF	478	182	147	1518	16V DOHC inline 4	200	2,0	6PSM
Volvo S40	2.4i 4-door sedan	FF	448	177	145	1487	20V DOHC inline-5	168	2,4	5A

2010 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura TL	Base 4-door sedan	FF	496	188	145	1683	24V SOHC V6	280	3,5	5A
Acura TSX	V6 4-door sedan	FF	473	184	144	1544	24V SOHC V6	280	3,5	5A
Hyundai Azera	GLS 4-door sedan	FF	489	185	149	1648	24V DOHC V6	234	3,3	5A
Lexus ES 350	Base 4-door sedan	FF	485	182	145	1625	24V DOHC V6	272	3,5	6A
Nissan Maxima	3.5 S 4-door sedan	FF	484	186	147	1614	24V DOHC V6	290	3,5	CVT
Toyota Avalon	XL 4-door sedan	FF	502	185	149	1591	24V DOHC V6	268	3,5	6A
USA										
Buick Lacrosse	CX V6 4-door sedan	FF	500	186	150	1793	24V DOHC V6	255	3,0	6A
Buick Lucerne	CX 4-door sedan	FF	516	187	147	1709	OHV V6	227	3,9	4A
Chevrolet Impala	LS 4-door sedan	FF	509	185	149	1614	OHV V6	207	3,5	4A
Ford Taurus	SE 4-door sedan	FF	515	194	154	1823	24V DOHC V6	263	3,5	6A
Lincoln MKZ	Base 4-door sedan	FF	482	183	145	1629	24V DOHC V6	263	3,5	6A

2010 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

	Specific model	Drive layout	Length, cm	Width, cm	Height, cm	Curb weight, kg	Engine	Horsepower, bhp	Displacement, l	Transmission
ASIA										
Acura RL	AWD 4-door sedan	FAWI	497	185	145	1854	24V SOHC V6	300	3,7	5A
Infiniti G37	AWD 4-door sedan	FAWI	475	177	145	1626	24V DOHC V6	328	3,7	7A
Infiniti M35	M35 4-door sedan	FAWI	489	180	151	1760	24V DOHC V6	303	3,5	7A
Lexus GS 350	350 4-door sedan	FAWI	485	182	142	1723	24V DOHC V6	303	3,5	6A
Lexus IS 350	AWD 4-door sedan	FAWI	458	180	142	1569	24V DOHC V6	306	3,5	6A
USA										
Cadillac CTS	AWD 4-door sedan	FAWI	487	184	147	1746	24V DOHC V6	270	3,0	6A
Cadillac STS	Luxury Sport 4-door s.	FAWI	499	184	146	1751	24V DOHC V6	302	3,6	6A
Lincoln MKS	AWD 4-door sedan	FAWI	518	193	156	1874	24V DOHC V6	273	3,7	6A
EUROPE										
Audi A6	Premium AWD 4-door	FAWI	491	181	146	1737	24V DOHC V6	265	3,2	6A
Audi A8	AWD 4-door sedan	FAWI	506	189	145	1961	32V DOHC V8	350	4,2	6A
Audi S4	S4 Premium Plus	FAWI	470	183	143	1606	24V Super V6	333	3,0	6A
BMW M3	M3 AWD 4-door s.	FAWI	454	182	142	1526	32V DOHC V8	414	4,0	6A
BMW M5	M5 AWD 4-door s.	FAWI	485	185	147	1591	40V DOHC V10	500	5,0	6A
Mercedes-Benz C350	C350 AWD	FAWI	463	177	145	1616	24V DOHC V6	268	3,5	7A
Mercedes-Benz E350	E350 AWD	FAWI	487	207	147	1737	24V DOHC V6	268	3,5	7A
Saab 9-5	AWD 4-door sedan	FAWI	501	187	147	1578	24V T-DOHC V6	300	2,8	6A
Volvo S80	V8 AWD	FAWI	485	186	149	1498	32V DOHC V8	311	4,4	6A

Appendix 12. Car Prices

1. The first five columns give the trim line price span of the models - the lowest and highest prices cited by each new-car guide.

2. The following five columns display the different classifications of the five new-car guides:

	Road&Track	**Edmund's**	**Consumer Reports**	**Motor Trend**	**Car & Driver**
1990	Economy Family car Sports & GT Luxury car		Small cars Compact cars Medium-size car Large car		
1995			Small car Medium car Large car Luxury car		
2000			Small car Family car Large car Upscale car Luxury car	$16000 and under $16000 to $20000 $20000 to $30000 $30000 to $40000 $40000 to $50000 $50000 & Up	
2005		S. under 15,000 S. under 25,000 S. under 35,000 S. under 45,000 S. over $45000	Small Car Family Sedan Upscale Sedan Large Sedan Luxury Sedan		
2010		S. less than $15,000 S. $15,000 - $25,000 S. $25,000 - $35,000 S. $35,000 - $45,000 S. $45,000 - $55,000	Small Sedan Entry-level Family S. Family Sedans Compact Sports S. Upscale Sedans Luxury Sedans		S. under $18000 S. $18000-$25000 S. $25000-$40000 S. over $40000

1990 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Daihatsu Charade	Min	6900	N/a	N/a	N/a	N/a	Econ.	N/a	N/a	N/a	N/a
	Max										
Honda Civic	Min	6895	N/a	9440	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max			11145							
Hyundai Excel	Min	6275	N/a	6999	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max			8479							
Mazda Protegé	Min	9359	N/a	9339	N/a	11250	Econ.	N/a	Small	N/a	N/a
	Max			11239							
Mitsubishi Mirage	Min	7029	N/a	8559	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max			9509							
Nissan Sentra	Min	7999	N/a	9249	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max										
Suzuki Swift	Min	6399	N/a	7399	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max			8599							
Toyota Corolla	Min	8998	N/a	8748	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max			10928							
USA											
Chevrolet Cavalier	Min	7699	7799	7777	N/a	N/a	Econ.	N/a	Compact	N/a	N/a
	Max		8270	8820							
Eagle Summit	Min	8995	7765	8895	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max		8618	11257							
Ford Tempo	Min	9920	8768	9633	N/a	N/a	Econ.	N/a	Compact	N/a	N/a
	Max		9691	11331							
Geo Prizm	Min	9680	8906	10125	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max		9680	11900							
Mercury Topaz	Min	10448	9248	10164	N/a	N/a	Econ.	N/a	Compact	N/a	N/a
	Max		10222	12567							
Pontiac LeMans	Min	7574	8054	8904	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max		8754								
Pontiac Sunbird	Min	7699	8108	8899	N/a	N/a	Econ.	N/a	Compact	N/a	N/a
	Max		8784								
EUROPE											
Wolkswagen Fox	Min	7500	N/a	8310	N/a	N/a	Econ.	N/a	Small	N/a	N/a
	Max										
Volkswagen Jetta GL L4	Min	10195	N/a	10295	N/a	N/a	Family	N/a	Small	N/a	N/a
	Max			13750							

1990 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura Integra	Min	11950	N/a	12850	N/a	N/a	Sports	N/a	Small	N/a	N/a
	Max			15950							
Honda Accord	Min	12345	N/a	12345	17000	N/a	Family	N/a	Compact	N/a	N/a
	Max			16595							
Hyundai Sonata	Min	10700	N/a	9999	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max			12349							
Mitsubishi Galant	Min	10999	N/a	10989	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max			16369							
Nissan Stanza	Min	11900	N/a	11650	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max			14975							
Toyota Camry	Min	11948	N/a	11588	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max			16648							
Mazda 626	Min	12009	N/a	12459	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max			13929							
USA											
Chevrolet Corsica	Min	10070	8993	9495	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max		10070	12795							
Chevrolet Lumina	Min	12670	11107	12140	15250	N/a	Family	N/a	Medium	N/a	N/a
	Max		12870	14040							
Chrysler LeBaron Sedan	Min	16450	14562	15595	16000	N/a	Family	N/a	Compact	N/a	N/a
	Max		16450								
Dodge Spirit	Min	10925	9784	10495	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max		10925	13205							
Ford Taurus	Min	13717	11548	12640	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		13352	16180							
Oldsmobile Cutlass Calai	Min	10295	9502	9995	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max		10295	14995							
Plymouth Acclaim	Min	10825	9696	10395	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max		10825	13865							
Pontiac Grand Am	Min	10174	9575	10744	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max		10374	15194							
EUROPE											
Audi 80	Min	20200	N/a	18900	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max			22800							
Peugeot 405	Min	15300	N/a	N/a	N/a	N/a	Family	N/a	N/a	N/a	N/a
	Max										
Volkswagen Passat GL	Min	14990	N/a	N/a	N/a	N/a	Family	N/a	N/a	N/a	N/a

1990 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Nissan Maxima	Min	18099	N/a	17899	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max			18949							
USA											
Buick Century	Min	13685	11810	13150	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		13685	14075							
Buick LeSabre	Min	17080	14740	16050	N/a	N/a	Family	N/a	Large	N/a	N/a
	Max		17080	17400							
Buick Regal	Min	15690	13730	N/a	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		15910								
Buick Skylark	Min	10725	9899	10465	N/a	N/a	Family	N/a	Compact	N/a	N/a
	Max		10725	13145							
Chrysler New Yorker Sal	Min	17919	15491	16342	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		17919	19080							
Dodge Dynasty	Min	13625	13032	12995	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		15085	14395							
Dodge Monaco	Min	13895	11861	15460	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		13695	18060							
Eagle Premier	Min	15250	12999	15350	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		14999	20284							
Mercury Sable	Min	15821	13224	15065	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		15311	16067							
Oldsmobile Cutlass Ciera	Min	12495	13717	11995	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		15895	12149							
Oldsmobile Cutlass Supre	Min	14995	13027	14595	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		15095	17995							
Oldsmobile 88 Royale	Min	17095	14839	15995	N/a	N/a	Family	N/a	Large	N/a	N/a
	Max		17195	17395							
Pontiac 6000	Min	12999	15878	16909	N/a	N/a	Family	N/a	Medium	N/a	N/a
	Max		18399								
Pontiac Bonneville	Min	16834	14528	15774	N/a	N/a	Family	N/a	Large	N/a	N/a
	Max		16834	23994							
Pontiac Grand Prix	Min	14294	12622	14564	20000	21500	Family	N/a	Medium	N/a	N/a
	Max		14294								

1990 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Infiniti Q45	Min	39000	N/a	38000	N/a	N/a	Luxury	N/a	Medium	N/a	N/a
	Max										
Lexus LS400	Min	38000	N/a	35000	N/a	N/a	Luxury	N/a	Medium	N/a	N/a
	Max										
Mazda 929	Min	23385	N/a	23300	N/a	N/a	Luxury	N/a	Medium	N/a	N/a
	Max			24800							
USA											
Cadillac Brougham	Min	30225	25782	27400	28000	N/a	Luxury	N/a	Large	N/a	N/a
	Max		30225								
Lincoln Town Car	Min	28581	25127	27986	25000	28000	Luxury	N/a	Large	N/a	N/a
	Max		29458	32809	32000	32000					
EUROPE											
BMW 750i	Min	49000	N/a	N/a	N/a	N/a	Luxury	N/a	N/a	N/a	N/a
	Max										
Mercedes-Benz 420	Min	53900	N/a	N/a	N/a	N/a	Luxury	N/a	N/a	N/a	N/a
	Max										
Volvo 760	Min	N/a	N/a	33185	N/a	N/a	N/a	N/a	Medium	N/a	N/a
	Max			33965							

1995 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura Integra	Min	15280	13513	16220	15000	17815	N/a	N/a	Small	N/a	N/a
	Max	20585	15740	20680	22000						
Honda Civic	Min	9690	10412	9750	9000	13210	N/a	N/a	Small	N/a	N/a
	Max	17000	11870	16950	17000						
Hyundai Accent	Min	8000	N/a	8079	8000	N/a	N/a	N/a	Small	N/a	N/a
	Max	10 000		8979	11000						
Hyundai Elantra	Min	9602	N/a	10199	9000	12965	N/a	N/a	Small	N/a	N/a
	Max	11711		12324	13000						
Kia Sephia	Min	8670	7518	N/a	9000	12065	N/a	N/a	N/a	N/a	N/a
	Max	10710	8495		14000						
Mazda Protegé	Min	11995	11174	11995	12000	13455	N/a	N/a	Small	N/a	N/a
	Max	16800	11995	16145	16000						
Mercury Tracer	Min	11260	10382	11380	11000	N/a	N/a	N/a	Small	N/a	N/a
	Max	13210	11260	13290	15000						
Mitsubishi Mirage	Min	9799	10336	9836	8000	N/a	N/a	N/a	Small	N/a	N/a
	Max	13299	11479	13025	14000						
Nissan Sentra	Min	11000	10584	10999	10000	13129	N/a	N/a	Small	N/a	N/a
	Max	16000	11169	14449	16000						
Suzuki Swift	Min	7962	8003	8699	8000	N/a	N/a	N/a	Small	N/a	N/a
	Max	11191	8699		12000						
Toyota Corolla	Min	13000	10767	12498	13000	13498	N/a	N/a	Small	N/a	N/a
	Max	17500	12098	16848	19000						
Toyota Tercel	Min	9500	9502	9998	9000	N/a	N/a	N/a	Small	N/a	N/a
	Max	11000	10558	11328	15000						
USA											
Chevrolet Cavallier	Min	10060	9700	10750	11000	12950	N/a	N/a	Small	N/a	N/a
	Max	12465	10265	14295	22000						
Dodge Neon	Min	9995	8814	9500	10000	13500	N/a	N/a	Small	N/a	N/a
	Max	13995	9500	13567	16000						
Eagle Sumit	Min	9990	10953	9836	10000	N/a	N/a	N/a	Small	N/a	N/a
	Max	13990	11545	13025	16000						
Ford Escort	Min	9560	10159	9680	9000	11580	N/a	N/a	Small	N/a	N/a
	Max	12700	11020	12820	15000						
Geo Metro	Min	8095	8467	8085	8000	9795	N/a	N/a	Small	N/a	N/a
	Max	9485	9085	9485	12000						
Geo Prizm	Min	11675	11115	11675	11000	N/a	N/a	N/a	Small	N/a	N/a
	Max	12340	11675	12340	15000						
Saturn SL	Min	9995	8996	9995	10000	13455	N/a	N/a	Small	N/a	N/a
	Max	16775	9995	12695	17000						
EUROPE											
Volkswagen Jetta III	Min	13475	14899	13475	14000	N/a	N/a	N/a	Small	N/a	N/a
	Max	15550	16450	19975	19000						

1995 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Hyundai Sonata	Min	12772	11937	13399	12000	19516	N/a	N/a	Medium	N/a	N/a
	Max	16203	13299	17399	17000						
Infiniti G20	Min	22000	18239	22875	21000	25325	N/a	N/a	Medium	N/a	N/a
	Max	27000	21975	25975	25000						
Mazda 626	Min	14695	13540	14795	15000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	24500	14695	22695	24000						
Mitsubishi Galant	Min	14349	12771	14349	14000	21838	N/a	N/a	Medium	N/a	N/a
	Max	22269	14349	20269	23000						
Nissan Altima	Min	14840	13185	14799	14000	17694	N/a	N/a	Medium	N/a	N/a
	Max	20500	14799	19889	22000						
USA											
Ford Contour	Min	13310	12011	13310	13000	17500	N/a	N/a	Medium	N/a	N/a
	Max	15695	13310	15695	22000						
Mercury Mystique	Min	13855	12506	13855	14000	14900	N/a	N/a	Medium	N/a	N/a
	Max	15230	13855	15230	23000						
Oldsmobile Achieva	Min	13500	12623	13500	13000	13995	N/a	N/a	Medium	N/a	N/a
	Max	15200	13500	15200	18000						
Pontiac Grand Am	Min	12904	11899	12904	14000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	14954	13004	14954	19000						
Pontiac Sunfire	Min	11074	10328	N/a	11000	N/a	N/a	N/a	N/a	N/a	N/a
	Max	11224	11224		22000						
EUROPE											
Volvo 850	Min	22900	22480	24680	26000	33266	N/a	N/a	Medium	N/a	N/a
	Max	32500	24680	32345	34000						

1995 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura Legend	Min	34845	28636	35500	33000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	42740	34160	43200	42000						
Honda Accord	Min	14565	13204	14800	16000	19537	N/a	N/a	Medium	N/a	N/a
	Max	22185	15230	22090	27000						
Lexus ES300	Min	34000	25584	31500	29000	33929	N/a	N/a	Medium	N/a	N/a
	Max	38000	31200		35000						
Mitsubishi Diamante	Min	27800	21638	27000	23000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	35250	25750	35250	31000						
Nissan Maxima	Min	22429	18493	19999	20000	27400	N/a	N/a	Medium	N/a	N/a
	Max	23529	20999	24819	28000						
Toyota Avalon	Min	22000	N/a	22758	24000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	27000		26668	29000						
Toyota Camry	Min	17750	18487	16128	16000	19978	N/a	N/a	Medium	N/a	N/a
	Max	23250	21878	24668	27000						
USA											
Buick Century	Min	15160	16079	15160	15000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	17965	17965	17965	21000						
Buick LeSabre	Min	20410	19018	20410	20000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	25465	21735	24010	27000						
Buick Regal	Min	17960	17430	17960	17000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	19995	19920	21870	24000						
Chevrolet Lumina	Min	15470	14000	15460	16000	18235	N/a	N/a	Medium	N/a	N/a
	Max	16970	15000	16960	23000						
Chrysler Concorde	Min	20895	18496	17974	20000	N/a	N/a	N/a	Large	N/a	N/a
	Max	26000	20550	20844	27000						
Dodge Intrepid	Min	17990	16277	17974	17000	19837	N/a	N/a	Large	N/a	N/a
	Max	20990	17974	20844	24000						
Eagle Vision	Min	20995	17750	17974	20000	24361	N/a	N/a	Large	N/a	N/a
	Max	24995	19697	20844	26000						
Ford Taurus	Min	17585	15862	17585	16000	18133	N/a	N/a	Medium	N/a	N/a
	Max	25140	17585	21000	28000						
Mercury Sable	Min	18210	16407	18210	18000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	21570	18210	21570	25000						
Oldsmobile Aurora	Min	31370	29017	31370	31000	32390	N/a	N/a	Medium	N/a	N/a
	Max		31370		33000						
Oldsmobile Cutlass Ciera	Min	14460	15177	14460	14000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	17060	16060	17570	19000						
Oldsmobile Cutlass Supre	Min	17460	16500	17460	16000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	25460	17460	25460	27000						
Oldsmobile Eighty Eight	Min	20410	22930	20410	19000	24595	N/a	N/a	Large	N/a	N/a
	Max	24010	24010	24010	26000						
Pontiac Bonneville	Min	20804	18828	20804	20000	N/a	N/a	N/a	Large	N/a	N/a
	Max	25804	20804	25804	33000						
Pontiac Grand Prix	Min	16634	15220	16634	16000	20956	N/a	N/a	Medium	N/a	N/a
	Max	17384	16634	19659	26000						
EUROPE											
Audi A6	Min	32239	29395	30600	35000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	49180	35120	45270	50000						
Audi 90	Min	27450	23614	25670	28000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	34040	27820	35900	38000						
Saab 9000	Min	29835	27684	29835	30000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	41300	32685	41300	43000						
Volkswagen Passat	Min	21000	20754	20890	18000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	23000	23075	21320	26000						

1995 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Infiniti J30	Min	37750	30299	38550	35000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	39500	36950	40550	37000						
Infiniti Q45	Min	54000	40055	52400	48000	54145	N/a	N/a	Luxury	N/a	N/a
	Max	59500	49450	59350	55000						
Lexus LS400	Min	55000	40960	51200	38000	56524	N/a	N/a	Luxury	N/a	N/a
	Max	60000	51200		45000						
Mazda 929	Min	32850	27708	35795	32000	N/a	N/a	N/a	Medium	N/a	N/a
	Max	37700	32200		35000						
USA											
Cadillac Fleetwood	Min	35595	32569	35595	34000	N/a	N/a	N/a	Large	N/a	N/a
	Max	37845	35595	36240	40000						
Lincoln Town Car	Min	36400	31664	36400	35000	N/a	N/a	N/a	Large	N/a	N/a
	Max	41200	36400	41200	41000						
EUROPE											
BMW 530 i	Min	39900	35300	34760	41000	42890	N/a	N/a	Luxury	N/a	N/a
	Max	49350	48600	41500	60000						
BMW 740	Min	57750	N/a	59900	59000	N/a	N/a	N/a	Luxury	N/a	N/a
	Max	86100		89900	85000						
Jaguar XJ12	Min	50000	42228	53450	54000	76563	N/a	N/a	Luxury	N/a	N/a
	Max	75000	51750	65000	84000						
Mercedes-Benz E420	Min	44000	34030	41000	42000	63022	N/a	N/a	Luxury	N/a	N/a
	Max	82000	40000	79000	80000						

2000 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura Integra	Min	20000	18033	20100	N/a	N/a	N/a	N/a	Small	N/a	N/a
	Max	24500	20000	22500							
Daewoo Lanos	Min	8800	8244	9449	8700	13296	N/a	N/a	Small	$16000 & under	N/a
	Max	13500	9699	11719	13500						
Daewoo Leganza	Min	14600	11630	13690	13900	18910	N/a	N/a	Small	$16000 & under	N/a
	Max	19200	13660	18660	19000						
Daewoo Nubira	Min	12300	10630	10990	11000	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	15900	12506	13560	15000						
Honda Accord	Min	15750	13661	15350	15500	24545	N/a	N/a	Small	$16000 & under	N/a
	Max	25500	15350	24550	25000						
Honda Civic	Min	11000	11645	12885	11000	17860	N/a	N/a	Small	$16000 & under	N/a
	Max	17500	12885	16830	17800						
Hyundai Accent	Min	9170	8891	9899	9000	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	13000	9499		12000						
Hyundai Elantra	Min	11570	10860	11799	12000	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	17200	11799		13500						
Hyundai Sonata	Min	14820	13850	14999	14000	18962	N/a	N/a	Small	$16000 & under	N/a
	Max	22200	14999	16999	18000						
Kia Sephia	Min	10000	8996	10195	10195	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	14500	9995	11795	14430						
Mazda Protegé	Min	12000	11445	11970	12100	16500	N/a	N/a	Small	$16000 & under	N/a
	Max	17500	11970	15040	16500						
Mitsubishi Mirage	Min	12600	12870	13987	11900	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	20200	13987	16974	17400						
Nissan Altima	Min	15900	14547	15140	15100	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	21000	15140	20390	20400						
Nissan Sentra	Min	12000	11097	11649	11700	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	17000	11799	14899	15700						
Suzuki Esteem	Min	12750	11903	12399	13199	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	15000	12399	13899	16699						
Toyota Corolla LE	Min	12800	11318	12418	12600	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	18500	12418	15068	17500						
Toyota Echo	Min	11900	9543	10395	9995	11000	N/a	N/a	Small	$16000 & under	N/a
	Max	13000	10295		14000						
USA											
Chevrolet Cavalier	Min	13575	12309	13260	13160	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	21000	13165	14805	17000						
Chevrolet Prizm	Min	12828	13153	13910	14460	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	18200	13816	15960	19000						
Dodge Neon	Min	12970	11499	12490	12500	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	16995	12460		16500						
Ford Escort	Min	11920	10769	12000	12400	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	17500	11505		17400						
Ford Focus	Min	12280	11319	12220	12500	20000	N/a	N/a	Small	$16000 & under	N/a
	Max	15795	12125	15165	18000						
Pontiac Sunfire	Min	14420	12959	14105	14175	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	22110	14010		18630						
Saturn SL2	Min	11185	9296	10685	11000	N/a	N/a	N/a	Small	$16000 & under	N/a
	Max	19495	10685	12895	16445						
EUROPE											
Volkswagen Jetta	Min	17200	15228	16700	N/a	N/a	N/a	N/a	Small	N/a	N/a
	Max	25000	16700	24170							

2000 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura Integra	Min	20000	18033	20100	20300	N/a	N/a	N/a	Small	$20000-	N/a
	Max	24500	20000	22500	24550					$30000	
Infiniti G20	Min	21500	19422	21395	21400	24190	N/a	N/a	Upscale	$20000-	N/a
	Max	23500	21395	22895	24000					$30000	
Mazda 626	Min	17000	16642	18245	18500	N/a	N/a	N/a	Family	$16000-	N/a
	Max	24000	18245	22445	24500					$20000	
Toyota Camry	Min	17600	15427	17518	17600	N/a	N/a	N/a	Family	$16000-	N/a
	Max	27700	17418	26198	31500					$20000	
USA											
Dodge Stratus	Min	16445	14628	16080	17500	N/a	N/a	N/a	Family	$16000-	N/a
	Max	21500	15930	20260	24500					$20000	
Chrysler Cirrus	Min	20400	14791	16230	N/a	N/a	N/a	N/a	Family	N/a	N/a
	Max	23000	16080	20085							
Oldsmobile Alero	Min	18185	14656	16005	17210	21200	N/a	N/a	Family	$16000-	N/a
	Max	21800	15675	21545	23000					$20000	
Pontiac Grand Am	Min	16455	14841	16340	16140	21195	N/a	N/a	Family	$16000-	N/a
	Max	20385	16220	19970	22640					$20000	
EUROPE											
Volkswagen Passat	Min	21500	19293	21200	21400	N/a	N/a	N/a	Family	$20000-	N/a
	Max	29000	21200	27655	31200					$30000	

2000 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura 3.2 TL	Min	28500	25191	28400	28700	N/a	N/a	N/a	Upscale	$20000-$30000	N/a
	Max		28400	30400	30700						
Infiniti I30	Min	30000	26835	29465	29500	28990	N/a	N/a	Upscale	$20000-$30000	N/a
	Max	34000	29465	31540	34500	30710					
Mazda Millennia	Min	27000	22840	24995	26000	N/a	N/a	N/a	Upscale	$20000-$30000	N/a
	Max	34000	24995	30995	35600						
Mitsubishi Diamante	Min	28100	24749	24997	25400	N/a	N/a	N/a	Upscale	$20000-$30000	N/a
	Max	36600	27199	27897	29200						
Mitsubishi Galant	Min	17500	18338	17375	17600	N/a	N/a	N/a	Family	$16000-$20000	N/a
	Max	25000	20157	23757	24000						
Nissan Maxima	Min	21049	19247	21049	21100	28400	N/a	N/a	Family	$20000-$30000	N/a
	Max	30000	21049	26249	26300						
Toyota Avalon	Min	25100	22058	26365	25600	N/a	N/a	N/a	Large	$20000-$30000	N/a
	Max	31900	25195	30005	34000						
USA											
Buick Century	Min	20162	17936	19725	19840	N/a	N/a	N/a	Family	$16000-$20000	N/a
	Max	22297	19602	21860	25396						
Buick LeSabre	Min	23845	21260	23235	24107	27500	N/a	N/a	Family	$20000-$30000	N/a
	Max	27995	23235	27525	32476						
Buick Regal	Min	22780	20331	22670	22845	23495	N/a	N/a	Family	$20000-$30000	N/a
	Max	25625	22220	27395	27510						
Chevrolet Impala	Min	19265	17115	18790	18999	N/a	N/a	N/a	Family	$16000-$20000	N/a
	Max	23025	18705	22590	26700						
Chevrolet Lumina	Min	18895	15878	18790	19490	N/a	N/a	N/a	Family	$16000-$20000	N/a
	Max	22500	18790		20500						
Chevrolet Malibu	Min	16995	15061	16445	17020	N/a	N/a	N/a	Family	$16000-$20000	N/a
	Max	20500	16460	19215	20000						
Chrysler 300M	Min	29685	26661	29085	28500	29150	N/a	N/a	Large	$20000-$30000	N/a
	Max	33500	29085		32500						
Chrysler Concorde	Min	22550	20146	22145	22000	N/a	N/a	N/a	Large	$20000-$30000	N/a
	Max	26000	21990	26070	26500						
Chrysler LHS	Min	28685	25775	28090	28500	N/a	N/a	N/a	Large	$20000-$30000	N/a
	Max	33500	28090		33500						
Dodge Intrepid	Min	20900	18677	20545	20500	25250	N/a	N/a	Large	$20000-$30000	N/a
	Max	25000	20390	24435	28000						
Ford Taurus	Min	18795	16306	17790	18500	23040	N/a	N/a	Family	$16000-$20000	N/a
	Max	21995	17695	20990	25600						
Mercury Sable	Min	19395	17177	18940	19185	N/a	N/a	N/a	Family	$16000-$20000	N/a
	Max	26500	18845	21340	22500						
Oldsmobile Intrigue	Min	24283	20212	22210	22395	27400	N/a	N/a	Family	$20000-$30000	N/a
	Max	26280	22090	25840	29000						
Pontiac Bonneville	Min	24295	21667	23695	25075	24595	N/a	N/a	Large	$20000-$30000	N/a
	Max	32245	23680	31650	34090						
Pontiac Grand Prix	Min	20385	18131	19935	20300	N/a	N/a	N/a	Family	$20000-$30000	N/a
	Max	24870	19815	24280	27345						
EUROPE											
Audi A4	Min	24000	25580	23990	24540	N/a	N/a	N/a	Upscale C	$20000-$30000	N/a
	Max	42000	28790	37900	28900						

2000 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Infiniti Q45	Min	49000	43255	48895	48895	52600	N/a	N/a	Luxury	$40000- $50000	N/a
	Max	52000	48200	50595	50595						
Lexus GS 300	Min	37500	32663	37805	38138	50347	N/a	N/a	Luxury	$30000- $40000	N/a
	Max	53200	37605	46305	54439						
Lexus LS400	Min	53800	45648	54005	55045	60869	N/a	N/a	Luxury	$50000 & up	N/a
	Max	68500	53805		61105						
USA											
Cadillac Catera	Min	32000	31772	30860	31305	36661	N/a	N/a	Upscale	$30000- $40000	N/a
	Max	36000	34180	32860	35783						
Lincoln LS series	Min	32250	31624	31215	31665	N/a	N/a	N/a	Upscale	$30000- $40000	N/a
	Max	41000	34690	34990	42800						
Lincoln Town Car	Min	39300	35186	38630	39145	N/a	N/a	N/a	Luxury	$30000- $40000	N/a
	Max	44900	38630	43130	47400						
EUROPE											
BMW 540iA	Min	38900	46150	38900	35000	55458	N/a	N/a	Luxury	$30000- $40000	N/a
	Max	71561	51100	69400	73000						
BMW 750iL	Min	62400	N/a	62400	62900	70850	N/a	N/a	Luxury	$50000 & up	N/a
	Max	127000		92100	124400						
Jaguar S-type	Min	48000	37128	42500	43655	N/a	N/a	N/a	Luxury	$40000- $50000	N/a
	Max	57000	42500	48000	49355						
Jaguar XJ8	Min	58000	N/a	55650	56355	N/a	N/a	N/a	Luxury	$50000 & up	N/a
	Max	71000		68550	83355						
Mercedes Benz C280	Min	31668	33434	31750	31750	N/a	N/a	N/a	Upscale	$30000- $40000	N/a
	Max	57885	35950	35950	47335						
Mercedes-Benz E430	Min	46900	48779	47100	47100	47500	N/a	N/a	Luxury	$40000- $50000	N/a
	Max	72635	52450	69800	75220	72000					

2005 Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Honda Civic	Min	13160	13680	13260	13000	19500	N/a	Under $15000	Small	N/a	N/a
	Max	20650	16615	19900	19500						
Hyundai Accent	Min	9999	10499	9999	10000	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	10499	11299	10799	12000						
Hundai Elantra	Min	13299	13299	13299	N/a	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	14849	15649	14849							
Kia Optima	Min	15750	15900	15900	15200	N/a	N/a	Under $25000	Small	N/a	N/a
	Max	19895	19895	19900	19200						
Kia Spectra	Min	12620	12620	12700	11200	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	15250	15970	15150	14200						
Kia Rio	Min	9835	9740	9995	9700	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	11480	10615	11500	11300						
Mazda 3	Min	13680	13680	13680	13500	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	17105	16615	18685	18500						
Mitsubishi Lancer	Min	14374	13999	14299	14000	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	32500	19099	34699	29000						
Nissan Sentra	Min	12500	12600	12700	12000	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	17600	17700	17800	17300						
Suzuki Aerio	Min	13749	13449	13499	12999	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	15749	17449	17249	16799						
Suzuki Forenza	Min	13449	13449	13449	12000	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	16949	17449	17449	15000						
Toyota Corolla	Min	14195	13680	13780	13570	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	17970	17455	17555	15580						
Toyota ECHO	Min	10870	10885	10445	10245	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	11400	11685	10985	11575						
USA											
Chevrolet Aveo	Min	9995	9455	9455	9999	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	13055	12570	12865	11500						
Chevrolet Cobalt	Min	13625	13625	13625	N/a	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	21430	18195	21430							
Dodge Neon	Min	14160	13615	13700	12700	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	21195	16750	20650	20100						
Ford Focus	Min	13550	13830	13315	13200	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	18450	17930	18215	19500						
Saturn ION	Min	11430	11995	23770	11430	N/a	N/a	Under $15000	Small	N/a	N/a
	Max	20885	17370	29855	20000						
EUROPE											
Volkswagen Jetta	Min	17680	17680	17900	17300	N/a	N/a	Under $25000	Small	N/a	N/a
	Max	24070	25045	21385	23500						

2005 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura TSX	Min	26490	N/a	27190	26490	N/a	N/a	Under $35000	Upscale	N/a	N/a
	Max				28490						
Honda Accord	Min	16195	16195	16195	16000	N/a	N/a	Under $25000	Family	N/a	N/a
	Max	30000	28700	28700	28000						
Hyundai Sonata	Min	15999	15999	18000	15500	N/a	N/a	Under $25000	Family	N/a	N/a
	Max	19799	19799	22000	19000						
Mazda6	Min	18995	18995	18995	18800	N/a	N/a	Under $25000	Family	N/a	N/a
	Max	22895	26125	27995	21300						
Nissan Altima	Min	19050	17250	17350	16750	N/a	N/a	Under $25000	Family	N/a	N/a
	Max	29200	29200	29300	24000						
Toyota Camry	Min	18560	18045	18195	19045	N/a	N/a	Under $25000	Family	N/a	N/a
	Max	25920	25405	25555	25405						
EUROPE											
Saab 9-3	Min	26850	26850	26850	25995	38615	N/a	Under $35000	Upscale	N/a	N/a
	Max	32850	32850	42600	39995						
Volkswagen Passat	Min	23360	22070	22070	22000	N/a	N/a	Under $25000	Family	N/a	N/a
	Max	30865	32615	33615	41000						
Volvo S40	Min	23260	23260	23560	24450	N/a	N/a	Under $25000	Family	N/a	N/a
	Max	28910	27710	29385	29545						

2005 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura TL	Min	32650	32900	33100	33000	N/a	N/a	Under	Upscale	N/a	N/a
	Max		35100		34000			$35000			
Hyundai XG350	Min	24600	24399	24899	23999	N/a	N/a	Under	Family	N/a	N/a
	Max	26000	25999	26499	25599			$25000			
Kia Amanti	Min	25245	25200	25500	22500	N/a	N/a	Under	Large	N/a	N/a
	Max				24500			$25000			
Lexus ES 330	Min	31975	31975	32175	32000	N/a	N/a	Under	Upscale	N/a	N/a
	Max							$35000			
Nissan Maxima	Min	27100	27100	27350	26950	N/a	N/a	Under	Family	N/a	N/a
	Max	29350	29350	29600	28900			$35000			
USA											
Buick Century	Min	22605	22040	N/a	21520	N/a	N/a	Under	N/a	N/a	N/a
	Max		26030					$25000			
Buick LaCrosse	Min	24000	22835	22835	N/a	N/a	N/a	Under	Large	N/a	N/a
	Max	29000	28335	28335				$25000			
Buick LeSabre	Min	27150	26545	26725	25745	N/a	N/a	Under	Large	N/a	N/a
	Max	32810	32205	32385	31520			$35000			
Chevrolet Impala	Min	22780	22220	22350	21240	21990	N/a	Under	Family	N/a	N/a
	Max	28985	26030	28555	27335	27790		$25000			
Chevrolet Malibu	Min	19620	19085	19200	17000	N/a	N/a	Under	Family	N/a	N/a
	Max	24480	23945	24610	21000			$25000			
Chrysler 300	Min	23920	23295	23370	29180	N/a	N/a	Under	Large	N/a	N/a
	Max	34820	34195	39370	32615			$25000			
Chrysler Sebring	Min	19975	19350	19460	19850	N/a	N/a	Under	Family	N/a	N/a
	Max	31645	22360	31130	30325			$25000			
Dodge Stratus	Min	19770	20145	19255	18195	N/a	N/a	Under	Family	N/a	N/a
	Max	22250	21625	23235	22370			$25000			
Ford Five Hundred	Min	22795	22145	22145	24000	N/a	N/a	Under	Large	N/a	N/a
	Max	26795	27845	28070	30000			$25000			
Ford Taurus	Min	20685	20685	20935	19500	N/a	N/a	Under	Family	N/a	N/a
	Max	22595	22595	23690	24000			$25000			
Mercury Montego	Min	24995	24345	24345	25000	N/a	N/a	Under	Large	N/a	N/a
	Max	28895	28245	28570	31000			$25000			
Pontiac G6	Min	21300	20675	20675	N/a	N/a	N/a	Under	Family	N/a	N/a
	Max	23925	23300	23300				$25000			
Pontiac Grand Prix	Min	23460	22900	23060	21760	N/a	N/a	Under	Family	N/a	N/a
	Max	27095	26560	29335	25860			$25000			
EUROPE											
Audi A4	Min	26500	25800	25800	26000	N/a	N/a	Under	Upscale	N/a	N/a
	Max	35250	47050	47050	45500			$35000			

2005 Class 4: High-Price - Rear Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Infiniti Q45	Min	55900	55900	56200	52000	N/a	N/a	Under	Luxury	N/a	N/a
	Max				62000			$45000			
Lexus GS 430	Min	47975	38875	42900	38725	N/a	N/a	Over	Luxury	N/a	N/a
	Max		47975	51125	47825			$45000			
Lexus LS 430	Min	55675	55675	56225	55125	N/a	N/a	Under	Luxury	N/a	N/a
	Max							$45000			
USA											
Cadillac CTS-V	Min	29995	30000	30190	30140	N/a	N/a	Under	Sporty	N/a	N/a
	Max	49995	32250	49490	45000			$35000			
Cadillac STS	Min	40995	40300	40525	45000	N/a	N/a	Under	Luxury	N/a	N/a
	Max	47945	61815	70000	52000			$45000			
Lincolm LS	Min	32330	32475	32620	31860	N/a	N/a	Under	Luxury	N/a	N/a
	Max	43330	43452	43570	42860			$35000			
Lincoln Town Car Signat	Min	41675	41875	42035	41020	N/a	N/a	Under	Luxury	N/a	N/a
	Max	50120	50245	50505	49675			$45000			
EUROPE											
BMW 545i	Min	41995	41300	38000	41300	N/a	N/a	Under	Luxury	N/a	N/a
	Max	56495	55800	78000	75000			$45000			
BMW 745i	Min	70595	69900	69900	68500	N/a	N/a	Over	Luxury	N/a	N/a
	Max	117995	117300	117300	115800			$45000			
Jaguar S-Type	Min	51995	44230	44230	43230	N/a	N/a	Under	Luxury	N/a	N/a
	Max		51330	58330	62445			$45000			
Jaguar XJ8	Min	61495	60830	60830	59330	N/a	N/a	Under	Luxury	N/a	N/a
	Max	89995	89330	89330	74330			$45000			
Mercedes-Benz E500	Min	49220	48500	50050	48000	N/a	N/a	Over	Luxury	N/a	N/a
	Max	80220	59400	82600	77500			$45000			
Mercedes-Benz S430	Min	76060	75300	64900	74500	N/a	N/a	Over	Luxury	N/a	N/a
	Max	125470	124750	169000	123000			$45000			

2010

Class 1: Low-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Honda Civic	Min	15655	15655	15455	16075	16363	N/a	$15000-$25000	Small	N/a	Under $18000
	Max	23800	27000	27000	27420	26050					
Hyundai Accent	Min	9970	13645	9970	11765	14365	N/a	Under $15000	N/a	N/a	Under $18000
	Max	15070	14645	16995	16565						
Hyundai Elantra	Min	14120	14145	14145	14500	14865	N/a	Under $15000	Small	N/a	Under $18000
	Max	20795	17845	19795	17000	18565					
Kia Forte	Min	13695	13695	13695	N/a	14390	N/a	Under $15000	Small	N/a	Under $18000
	Max	18695	18495	18695		17890					
Kia Rio	Min	11495	11695	11495	11700	12145	N/a	Under $15000	N/a	N/a	Under $18000
	Max	14025	15795	15125	14500	14675					
Mazda 3	Min	15295	15345	15295	14700	15795	N/a	Under $15000	Small	N/a	Under $18000
	Max	23195	22445	23195	24900	22250					
Mitsubishi Lancer	Min	14790	14790	14790	14665	15510	N/a	Under $15000	Small	N/a	Under $18000
	Max	27590	27190	27590	38900	41710					
Nissan Sentra	Min	15420	15420	15420	17100	16140	N/a	$15000-$25000	N/a	N/a	Under $18000
	Max	20080	20080	20080	21500	20800					
Nissan Versa	Min	10000	9990	9990	13650	10620	N/a	Under $15000	N/a	N/a	Under $18000
	Max	16500	16780	16530	16870	16820					
Suzuki SX4	Min	13500	13359	13359	15600	13994	N/a	Under $15000	Small	N/a	Under $18000
	Max	16500	18899	19949	17000	16434					
Toyota Corolla	Min	15350	15450	15350	15910	16100	N/a	$15000-$25000	Small	N/a	Under $18000
	Max	20050	20150	20050	19420	19610					
Toyota Yaris	Min	12355	13365	12355	12400	13865	N/a	N/a	N/a	N/a	Under $18000
	Max	13915	14165	13915	14800						
USA											
Chevrolet Aveo	Min	11965	11965	11965	12120	12685	N/a	$15000-$25000	N/a	N/a	Under $18000
	Max	15365	15365	15365	15520	14820					
Chevrolet Cobalt	Min	14990	14990	14990	15670	15710	N/a	Under $15000	Small	N/a	Under $18000
	Max	24535	16470	24535	31410	17190					
Ford Focus	Min	15995	16290	15995	15690	16690	N/a	$15000-$25000	Small	N/a	Under $18000
	Max	19300	18780	18485	16875	19180					

2010 Class 2: Mid-Price - Front Wheel Drive - Inline (straight) engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Honda Accord	Min	21055	21055	21055	21425	21765	N/a	$15000-	Entry-	N/a	$18000-
	Max	31305	31105	31305	29475	29475		$25000	Family		$25000
Hyundai Sonata	Min	18995	18700	18700	18795	19420	N/a	$15000-	Entry-	N/a	$18000-
	Max	26545	26550	26550	26345	27270		$25000	Family		$25000
Kia Optima	Min	17495	17995	17995	17200	18170	N/a	$15000-	Entry-	N/a	$18000-
	Max	22145	22795	22795	21400	22820		$25000	Family		$25000
Mazda 6	Min	18450	18600	18450	19220	19200	N/a	$15000-	Entry-	N/a	$18000-
	Max	28390	28540	28390	24800	29140		$25000	Family		$25000
Mitsubishi Galant	Min	21599	21599	21599	21774	23319	N/a	$15000-	Entry-	N/a	$18000-
	Max	23999	23999	23999	27974	24719		$25000	Family		$25000
Nissan Altima	Min	20100	19900	19900	20595	20620	N/a	$15000-	Entry-	N/a	$18000-
	Max	2985	24520	29600	30075	25220		$25000	Family		$25000
Suzuki Kizashi	Min	21000	18999	20000	27500	19374	N/a	$15000-	N/a	N/a	$18000-
	Max	28000	26899	27000	29500	27484		$25000			$25000
Toyota Camry	Min	19395	19395	19395	19580	20145	N/a	$15000-	Entry-	N/a	$18000-
	Max	29045	29045	29045	26130	29795		$25000	Family		$25000
USA											
Chevrolet Malibu	Min	21825	21825	21825	21395	22545	N/a	$15000-	Entry-	N/a	$18000-
	Max	25925	26995	26605	26670	27325		$25000	Family		$25000
Chrysler Sebring	Min	20120	20120	20120	19800	22855	N/a	$15000-	Entry-	N/a	$18000-
	Max	34705	22115	34705	33345	25105		$25000	Family		$25000
Dodge Avenger	Min	20230	20230	20230	18895	20970	N/a	$15000-	Family	N/a	$18000-
	Max	21730	21730	21730	25545	22470		$25000			$25000
Ford Fusion	Min	19270	19695	19620	19345	20345	N/a	$15000-	Entry-	N/a	$18000-
	Max	27270	28355	28030	25915	28755		$25000	Family		$25000
Mercury Milan	Min	21180	21860	21535	20035	22260	N/a	$15000-	Entry-	N/a	$18000-
	Max	27800	28480	28155	27010	28880		$25000	Family		$25000
EUROPE											
Volkswagen Jetta	Min	17500	17735	17605	17990	18305	N/a	$15000-	Entry-	N/a	$18000-
	Max	26000	26090	25410	25240	25000		$25000	Family		$25000
Volkswagen Passat	Min	28000	27195	26995	28380	27745	N/a	$25000-	Family	N/a	$25000-
	Max	30000	27195	28395	30990			$35000			$40000
Volvo S40	Min	26200	26200	26200	29345	27050	N/a	$25000-	Compact-	N/a	$25000-
	Max	33050	31350	31350	36295	32200		$35000	Sports		$40000

2010 Class 3: Mid-High-Price - Front Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura TL	Min	35105	35105	35105	37500	35915	N/a	$35000-	Upscale	N/a	$25000-
	Max	43385	43385	43385	39500	39465		$45000			$40000
Acura TSX	Min	29310	29310	29310	29720	30120	N/a	$25000-	Compact-	N/a	$25000-
	Max	43385	37950	37950		35660		$35000	Sports		$40000
Hyundai Azera	Min	25745	24970	24970	25295	24800	N/a	$15000-	Upscale	N/a	$25000-
	Max	30345	29570	29570	29245	28750		$25000			$40000
Lexus ES 350	Min	35000	35175	34470	35100	34800	N/a	$35000-	Upscale	N/a	$25000-
	Max							$45000			$40000
Nissan Maxima	Min	30460	30690	30460	29950	31180	N/a	$25000-	Upscale	N/a	$25000-
	Max	33180	33410	33180	32700	33900		$35000			$40000
Toyota Avalon	Min	27945	27945	27945	28565	28695	N/a	$25000-	Upscale	N/a	$25000-
	Max	35285	35285	35285	35905	36035		$35000			$40000
USA											
Buick Lacrosse	Min	27085	26245	27085	25590	27835	N/a	$25000-	Upscale	N/a	$25000-
	Max	33015	33015	33015	33755	33765		$35000			$40000
Buick Lucerne	Min	29265	29230	29230	29180	29995	N/a	$25000-	Upscale	N/a	$25000-
	Max	40205	42515	39230	40080	39995		$35000			$40000
Chevrolet Impala	Min	23890	24290	23890	24715	23795	N/a	$15000-	Family	N/a	$25000-
	Max	29630	29930	29630	30455	31140		$25000			$40000
Ford Taurus	Min	25995	25170	25170	25000	25995	N/a	$25000-	Upscale	N/a	$25000-
	Max	37995	37770	37170	30000	37995		$35000			$40000
Lincoln MKZ	Min	34115	34225	34115	32950	34965	N/a	$35000-	Upscale	N/a	$25000-
	Max	36005	36115	36005	34840	36855		$45000			$40000

2010 Class 4: High-Price - All Wheel Drive - V-engine - Sedans

		Prices					Classifications				
		Road & Track, $US	Edmund's, $US	Consumer Report, $US	Motor Trend, $US	Car & Driver, $US	Road&Track's Class.	Edmund's Class.	Consumer Report's Class.	Motor Trend's Class.	Car & Driver's Class.
ASIA											
Acura RL	Min	46820	46830	46830	47040	47640	N/a	$45000-	Compact-	N/a	Over
	Max	54250	54250	54250	54460			$55000	Sports		$40000
Infiniti G37	Min	33500	33250	33250	34000	34500	N/a	$35000-	Compact-	N/a	$25000-
	Max	44000	43550	43900	41000	37000		$45000	Sports		$40000
Infiniti M35	Min	45800	45800	45800	45500	46665	N/a	$45000-	Luxury	N/a	Over
	Max	54650	47950	54650	55500	56815		$55000			$40000
Lexus GS 350	Min	45000	45600	45000	45800	45000	N/a	$45000-	Luxury	N/a	Over
	Max	55000	47550	56550	57200	53470		$55000			$40000
Lexus IS 350	Min	32000	37595	31845	32100	32720	N/a	$35000-	Compact-	N/a	$25000-
	Max	57000		57760	57300	58635		$45000	Sports		$40000
USA											
Cadillac CTS	Min	36730	35165	36730	37555	35555	N/a	$35000-	Compact-	N/a	$25000-
	Max	60720	48765	60720	62845	62775		$45000	Sports		$40000
Cadillac STS	Min	46845	46846	46845	47640	45290	N/a	$45000-	Luxury	N/a	Over
	Max	68785	68785	70335	71160	89940		$55000			$40000
Lincoln MKS	Min	40870	41270	40870	38465	41695	N/a	$45000-	Upscale	N/a	Over
	Max	47760	48160	47760	40355	48585		$55000			$40000
EUROPE											
Audi A6	Min	45200	45200	45200	46025	44155	N/a	$45000-	Luxury	N/a	Over
	Max	76100	59150	76100	78225	73845		$55000			$40000
Audi A8	Min	74550	74550	74550	74875	75375	N/a	$55000-	Luxury	N/a	Over
	Max	78400	78400	78400	97025	79225		$85000			$40000
Audi S4	Min	31450	45900	31450	33525	32275	N/a	$45000-	Compact-	N/a	$25000-
	Max	47900	47300	53400	41575	46275		$55000	Sports		$40000
BMW M3	Min	34425	35150	32850	33200	33675	N/a	$35000-	Compact-	N/a	$25000-
	Max	66500	43950	66500	60000	55675		$45000	Sports		$40000
BMW M5	Min	45800	45950	45800	46625	45075	N/a	$45000-	Luxury	N/a	Over
	Max	85500	60600	85500	89325	86675		$55000			$40000
Mercedes-Benz C350	Min	34475	33600	33600	32500	34475	N/a	$35000-	Compact S	N/a	$25000-
	Max	58225	57350	57350	57500	60325		$45000			$40000
Mercedes-Benz E350	Min	49475	48600	48000	52500	49475	N/a	$45000-	Luxury	N/a	Over
	Max	89375	85750	85750	89500	88075		$55000			$40000
Saab 9-5	Min	38000	N/a	38000	38500	N/a	N/a	N/a	N/a	N/a	N/a
	Max	42000		45000	40800						
Volvo S80	Min	39200	39200	39200	33695	40050	N/a	$35000-	Luxury	N/a	Over
	Max	50950	50950	50950	52645	52350		$45000			$40000