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A comparison of American and Asian automakers' vehicles in quality, reliability, and safety

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A COMPARISON OF AMERICAN AND ASIAN AUTOMAKERS' VEHICLES IN

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ABSTRACT

Consumer Reports (CR) and J.D. Power and Associates (JDP) are two widely-known agencies that gather data on automobile quality and prepare reports on the data gathered that are related to various aspects of automobiles for different models for each manufacturer. This research has two overarching goals: The first is to determine if there are any clear differences in reliability, between the Japanese and U.S. auto-makers. The second is to determine if there is consistency between JDP and CR in the reliability ratings of vehicles. In order to attain these goals, this dissertation starts with the evaluation of these two major sources in terms of the kind of information they present, the way they collect their data, and what they measure. The result of the analysis provides a perspective on the magnitude and value of the information provided by these sources.

The first overarching goal of this research is to obtain comparable quantitative information about automobile reliability manufactured by the U.S. Big Three and their Japanese counterparts. The manufacturers surveyed include US-based companies, such as Ford Motors, GM, and Chrysler, and Japanese-based companies, such as Toyota and Honda. An approach to develop a realistic comparison of data related to a given metric for any given automobile type from the two reports is presented. Then the results from the analyses of the actual data for three American manufacturers and two Japanese manufacturers are shown. Finally, regression analysis was used to determine whether the reliability data of American and Japanese manufacturers showed statistically significant trends and gaps. The results of the regression analysis conclude the dissertation.

DEDICATION

To my parents, to whom I am deeply indebted for making this doctoral journey happen. There are no words to express my gratitude to my Mother, Aynur Senoz, for her self-sacrifice, support and assistance throughout the process of pursuing my Bachelor's, Master's, and now PhD degrees here at Missouri S&T. She has literally sacrificed her own life to be by my side through it all-especially during the rough times. Thank you Mom, and this dissertation would not have been possible at all without you!

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1. INTRODUCTION

The popular media is rich with advertisements claiming that U.S. manufacturers have closed the historical gap in quality, reliability, and safety with their Asian counterparts. However, it is difficult to separate facts from marketing license within the information available. A guiding quality principle of fact-based decision making suggests that a more comprehensive study of the comparative performance of U.S. and Asian automobile manufacturers is warranted. In this study two major sources of information on quality, reliability, and safety have been examined to determine their suitability for such comparisons.

In this dissertation, the focus is on the nature of the information that can be extracted from existing sources of information in order to compare American and Asian cars in a systematic manner. Studying these differences can be helpful in many different ways – both to consumers and to manufacturers. Further, this work seeks to determine if there are consistencies in the information provided by the two major sources of information.

Consumer Reports (CR) and *J.D. Power and Associates* (JDP) are the two widely-known agencies that we will use as our sources of information. They gather data on automobile quality and prepare reports on the data gathered. The reports they prepare usually contain a wealth of data related to various aspects of automobiles for different models for each manufacturer. The manufacturers they survey include US-based companies, such as Ford Motors, GM, and Chrysler, and Asian-based companies, such as Toyota, Honda, and Hyundai. Although there are similarities and differences between these two sources, in terms of how they collect their data, the information they present, and how they evaluate and score vehicles, both sources provide information that sheds light on the current state of quality, reliability, and safety of automobiles currently on the market in the U.S. The majority of data comes firsthand from the owners who used the vehicles concerned.

The overarching goals of this study are 1) To determine if there are any clear differences between American and Japanese vehicles in terms of reliability. (Senoz et al., ASEM Conference Proceeding Paper), and 2) To determine if there is agreement between the two popular systems, JDP and CR, in predicting reliability. The main reason for studying potential differences is to provide the customer, interested in buying a vehicle, with information regarding the overall perception of these cars amongst the consumer base. The reason for selecting JDP and CR as the sources of consumer reactions is that they are two of the most well-known and cited databases of consumer surveys. The second goal is aimed at determining if it is possible to replace one source by the other. The literature survey indicates that none of these issues have been studied in any detail in contemporary times.

In order to attain the two main goals, first the approaches and methodologies used by these two agencies are examined in terms of how they collect and analyze their data, along with the differences between them. Second, a methodology is developed to perform a realistic comparison of data available from the two reports. The reason for developing this scheme is to determine if the ratings (rankings) provided by the two agencies agree/match, and if they do what additional information can be extracted from comparing the reports from these two agencies.

2. REVIEW OF LITERATURE

2.1. IMPORTANCE OF CONSUMER SURVEYS

Consumer surveys have historically produced a significant impact on design and manufacturing of automobiles (Hauser and Clausing, 1988). Hence, it is no surprise that CR and JDP have acquired importance; they provide voluminous amounts of consumer survey data that manufacturers can use to improve their vehicles. Brand names often convey signals of product quality to the consumer (Rao and Rukert, 1994), and consumer surveys can perform reality checks for potential buyers, with some brand names performing poorly. As a result, consumer surveys have become very important instruments in marketing. Unfortunately, product quality is often unobservable (Kirmani and Rao, 2000), and therefore consumer surveys are valuable tools for potential buyers.

Luca (2011) from Harvard Business School investigated how consumer reviews affect restaurant demand. He found that online consumer reviews substitute for more traditional forms of reputation. Luca (2011) states: "I (then) test whether consumers use these reviews in a way that is consistent with standard learning models. I present two additional findings: (1) consumers do not use all available information and are more responsive to quality changes that are more visible and (2) consumers respond more strongly when a rating contains more information."

Luca further indicates that online consumer reviews are more likely to affect independent restaurants rather than chains due to the fact that chain affiliation reduces uncertainty about restaurant quality. One way Yelp may cause an overall shift in demand between chains and independent restaurants is that if it is providing more information about independent restaurants than chains. He also discovered that a one star improvement on the Yelp.com rating led to a 5-9% increase in revenue. The main message of his work is that online consumer review websites improve the information available about product quality. This information has larger impact on products which have relatively unknown quality information. He also believes that as this information flow improves, other forms of reputation such as chain affiliation should continue to become less influential.

Chen and Xie (2008) argue that as new word-of-mouth information continues to become more important, online consumer reviews are playing an increasingly important role in consumers' purchase decisions. Based on personal usage experience, online reviews can serve as a new element in the marketing communications mix and work as free “sales assistants” to help consumers identify the products that best match their idiosyncratic usage conditions.

An article by Gary Belsky (2012) in *Time* magazine discusses a recent study that was published in *Marketing Science*. The study was conducted by marketing professors Gerard Tellis of USC and University of Houston's Seshadri Tirunillai, and involved the analysis of nearly 350,000 consumer product reviews on three major sites (Amazon.com, Epinions.com and Yahoo Shopping) between June 2005 and January 2010, as well as their affect on the share prices of 15 publicly traded firms involved in six businesses. The important findings from the study were that the more negative chatter there is in the first few days after a product is released, the more likely the underlying stock price will drop soon after. However, positive reviews were unhelpful in predicting stock prices. The reasons they attribute to that finding are that: "... negative information is harder to come by in these forums—positive reviews were four times more common than critical ones—so investors may find gripes more useful. Second, investors are almost certainly lossaverse; humans in general tend to give more attention to risks than rewards. Finally, positive information may already have been absorbed into the stock price before the product actually came out, thanks to PR campaigns and other anticipatory buzz" (Belsky, 2012).

In summary, it is important to point out that consumer survey reports produced by JDP and CR are used extensively in the real world for decision-making and have also been employed in the academic literature (Shiv et al. (1997) and Rangaswamy and Van Bruggen (2005) to cite a subset of journal articles in the literature). While there are numerous works that use data from JDP and CR, there is no work that examines the relationship between the data provided by these sources. First and foremost, no systematic study exists that compares and contrasts the features of cars examined by these sources. Secondly, since these two sources report data on different scales, there is no way to perform a numerical comparison of the data for a given automobile type from the two sources. Thus, there is a need for a unified scale that can be used to perform a fair comparison between reports from the two sources. Finally, at least recently, there has been no attempt to compare cars from Japanese and American auto-makers, with or without a unified scale. This clearly indicates that there are significant gaps in the literature, and this dissertation seeks to fill these gaps.

2.2. BACKGROUND ON CONSUMER REPORTS AND JD POWER & ASSOCIATES

Consumer Reports (CR) and *J.D. Power and Associates* (JDP) have been providing information on automobile quality, reliability and safety since 1936 and 1968, respectively. Countless consumers have relied on these two sources of information to make buying decisions on both new and used cars. The extent and depth of their coverage has evolved over the years to address nearly every aspect of an automobile. CR is one of the top-ten-circulation magazines in the country and is published by the independent nonprofit organization, *Consumers Union* (CU). The mission of CU is to work for a fair, just, and safe marketplace for all consumers. In addition, CU does not accept outside advertising to maintain its independence and impartiality. JDP is a global marketing information firm that conducts surveys of customer satisfaction, product quality, and buyer behavior. JDP states that its rankings reflect the opinions of consumers only. Like CR, in order to stay impartial and deliver unbiased results, JDP funds all of its own syndicated research (Senoz et al., 2012).

CR reliability ratings attempt to show how well vehicles have held up compared with other models and how likely it is that an owner will face problems and repairs. The data come from annual surveys of approximately 7 million magazine and web-based subscribers. Similarly, JDP provides the information it collects from surveys in what is called the *Power Circle Ratings* (Website 2, 2012). All Power Circle Ratings are based on the opinions of a sample of consumers who have used or owned the product or service being rated. As stated by JDP on its website: “As a result, J.D. Power and Associates ratings are based entirely on consumer opinions and perceptions…..For example, Power Circle Ratings related to the *J.D. Power and Associates Initial Quality Study*^{SM} measure consumer perceptions of automotive new-vehicle quality after 90 days of ownership” (Website 3, 2012).

The surveying approaches of the two organizations are significantly different. The Consumer Reports National Research Center sends out *The Annual Auto Surveys* (Website 3, 2012) to a random sample of the several million readers who subscribe to

Consumer Reports or to *consumerreports.org.* These surveys are not commissioned or financed by industry. They offer detailed information on approximately 300 models each year by asking the respondents about any serious problems they have had with their vehicles in the preceding 12 months in 17 trouble areas. Based on the information gathered from the surveys, a reliability history is created for each model for the last 10 years. *Consumer Reports* makes forecasts about the upcoming year's model based on that reliability data. The surveys also ask owners how satisfied they were with their vehicle and whether they would buy that vehicle again.

Korsch (2007) questions the geographical profile of the CR readership and states that it appears dense on the two U.S. coasts and less dense in the heartland and the Deep South. He also has suspicions about basing the ratings on self-selected responses such as CR's ownership satisfaction polls. An article in *The New York Times* by Noah (1999) draws attention to the different incentives of these two entities when it comes to the rankings they publish. He says JDP is gaining in visibility, because unlike JDP, CR does not allow its ratings to be publicized by advertisers. Also, CR itself does not advertise its findings. JDP on the other hand uses advertisements to raise its own profile with the public, which in turn helps it attract more corporate clients who potentially buy copies of its syndicated studies, commission it to do proprietary studies, or both. Further, Noah states that this symbiotic relationship inhibits JDP in some ways as compared to CR**.** JDP has mostly stopped releasing unfavorable rankings to the public – except to the corporate buyers of the syndicated surveys. This was due to the adverse reactions provided to the "poorly-performing" manufacturers by the press, which was perhaps emphasizing bad news. Hence, JDP instituted a policy where only above-average rankings in syndicated studies were made public. Companies that rank below average are listed alphabetically in press releases. As a result, consumers get information about what JDP likes, but not about what it does not like.

CR buys and tests about 80 vehicles per year at their independent automobile testing center. Each vehicle is driven for thousands of miles and goes through more than 50 individual tests. Some of these tests are objective, which yield empirical results; yet some are subjective evaluations done by the engineering staff. Murray (2007) states that Consumer Reports' automotive test facility has become recognized as the best in the world at automotive evaluation and has “extraordinary influence over the car-buying public.” At the testing site, the small engineering staff does what no one else in the car evaluation business even tries. It runs vehicles through a battery of 50 performance tests, then matches those results up against data from 1.3 million car owners, in order to determine whether a vehicle's initial performance matches up against its long-term reliability. Also, wherever possible, subjectivity is removed from performance tests. This is done by objective, instrumented track tests, using state-of-the-art electronic equipment that yields empirical findings. Still, some are subjective evaluations – jury tests done by the experienced engineering staff (Website 7, 2012). Acceleration tests are an example of objective testing. The test car is rigged with an optical road-scanning device hooked to a data-logging computer. This equipment creates precise records of time, speed, and distance for sprints from 0 to 30 mph, 60 mph, and for quarter-mile runs. For braking tests, the test car is rigged with a pavement-scanning optical device which records precise stopping times and distances. In a similar manner, fuel economy is tested by using a precise fuel-flow measuring device spliced into the fuel line. Finally, noise and trunk and cargo space are evaluated using measurement devices. Noise is measured by precision microphones mounted in the cabin that make digital recordings of sound pressure, while the car is driven over various pavements, including a specially built coarse pavement at the track, and at different speeds. For cars with an enclosed trunk, the usable volume is measured with a set of typical-sized suitcases and duffle bags. For cargo-oriented vehicles such as hatchbacks, station wagons, and SUVs, an expandable rectangular pipe-frame "box" is used. That box is enlarged enough to just fit through the rear opening and to extend into the cargo bay as far as possible without preventing the hatch from closing; cargo capacity is the volume enclosed by that box (Website 7, 2012).

JDP, however, does not perform these types of tests on vehicles. It collects survey responses through 5 different studies: Initial Quality Study (IQS), Vehicle Dependability Study (VDS), Automotive Performance, Execution and Layout Study (APEAL), Customer Service Index (CSI), and Sales Satisfaction Index (SSI). For the IQS, survey respondents provide feedback on quality of their new vehicles during the first 90 days of ownership. They are asked about mechanical quality indicators such as defects and malfunctions; and design quality indicators such as how well a particular feature works.. The study examines 217 vehicle attributes. For the APEAL study, JDP surveys thousands of new vehicle owners by asking them about their purchase experience, their vehicle’s quality, service experience at the dealer, and what they like and dislike about the new vehicle after 90 days of ownership. For the VDS, JDP also surveys owners of 3-year-old vehicles that were purchased new and asks them to identify problems that have arisen in the previous 12 months in any of 200 areas. Newman (2004) indicated that virtually all automakers today buy some of JDP data. However, they complain that the rankings oversimplify the quality issue. For example, in the new car quality survey, a car's basic attributes, gas mileage, and the placement of cup holders are lumped in with problems like rattles, buzzes, and broken equipment. Carmakers believe the survey should measure only defects. Newman points out that some auto executives argue that outlets such as *Consumers Union*, which exhaustively test and evaluate cars, provide better information than opinion surveys. He adds, however, that the discomfort JDP causes the industry clearly indicates a degree of success. According to Whitney (2001), in the world of automotive industry research, nothing makes for more entertaining reading than the reports of U.S.-based business sector analyst JDP. He continues by stating that JDP's ratings of automobiles are awaited by manufacturers with a mixture of fear and hope and many a board of directors has been pruned following a poor showing in these prestigious reports. Noah (1999) of *The New York Times*, however, discusses how survey research is not infallible and adds that JDP's minimum sample size for automotive surveys – 250 responses per car model – allows for a margin of error approximating 6 percent. He even questions whether JDP's surveys accurately reflect public opinion, and how much emphasis ought to be placed on what responders say some of which could be casual. He writes: "Alternatively, it may be that the sort of people who do fill out questionnaires the same folks who go through life sending their steak back because they wanted it medium well, not medium – skew JDP's survey not toward intelligent criticism, but toward querulous complaints. People who care too much about being satisfied customers don't necessarily have a tighter grip on reality than people who care too little, like me".

2.3. EVALUATIONS AND SCORING

2.3.1. CR Reliability Evaluations. The data that CR collects includes surveys on several hundred makes and models of cars, minivans, pickups, and SUVs, spanning 10 model years. The Reliability History Chart shows whether a particular model has had more or fewer problems than the average model of that year in each of 17 trouble spots.

The so-called "used car verdict" is the summary of the 17 trouble spots for the model each year going back 10 years. It also includes the comparison of that model to the average of all vehicles in the same model year. The 17 trouble spots that are rated by CR (Website 1, 2012) in their own words are as follows:

"TROUBLE SPOTS:

1. ENGINE MAJOR: Engine rebuild or replacement, cylinder head, head gasket, turbocharger or supercharger and timing chain or belt.
2. ENGINE MINOR: Oil leaks, accessory and pulleys, engine mounts, engine knock or ping.
3. ENGINE COOLING: Radiator, cooling fan, water pump, thermostat, antifreeze leaks, overheating.
4. TRANSMISSION (AND CLUTCH)-MAJOR: Transmission rebuild or replacement, torque converter, premature clutch replacement.
5. TRANSMISSION (AND CLUTCH)-MINOR: Gear selector and linkage, coolers and lines, transmission computer, transmission sensor or solenoid, clutch adjustment, hydraulics [clutch master or slave cylinder]; rough shifting, slipping transmission.
6. DRIVE SYSTEM: Driveshaft or axle, CV joint, differential, transfer case, four-wheel-drive/all-wheel-drive components, driveline vibration, electrical failure.
7. FUEL SYSTEM: Check-engine light, sensors (O2 or oxygen sensor), emission-control devices (includes EGR), fuel-injection system, engine computer, fuel cap, fuel gauge/sender, fuel pump, fuel leaks, stalling or hesitation.
8. ENGINE ELECTRICAL: Starter, alternator, hybrid battery and related system, regular battery, battery cables, engine harness, coil, ignition switch, electronic

ignition, distributor or rotor failure, spark plugs and wires failure.

9. CLIMATE SYSTEM: A/C compressor, blower (fan) motor, condenser, evaporator, heating system, automatic climate system, electrical failure, refrigerant leakage.
10. SUSPENSION: Shocks or struts, ball joints, tie rods, wheel bearings, alignment, steering linkage [includes rack and pinion], power steering (pumps and hoses, leaks), wheel balance, springs or torsion bars, bushings, electronic or air suspension.
11. BRAKES: Antilock system (ABS), parking brake, master cylinder, calipers, rotors, pulsation or vibration, squeaking, premature wear, failure.
12. EXHAUST: Exhaust manifold, muffler, catalytic converter, pipes, leaks.
13. PAINT/TRIM/RUST: Paint (fading, chalking, peeling or cracking), loose exterior trim or moldings, rust.
14. BODY INTEGRITY (Squeaks or rattles): Seals, and/or weather stripping, loose interior trim and moldings, air and water leaks, wind noise.
15. BODY HARDWARE (Power or manual): Windows, locks and latches, doors or sliding doors, tailgate, trunk or hatch, mirrors, seat controls (movement and temperature), seat belts, sunroof, convertible top, glass defects.
16. POWER EQUIPMENT AND ACCESSORIES: Cruise control, clock, warning lights, body control module, keyless entry, wiper motor or washer, tire pressure monitor, interior or exterior lights, horn, gauges, 12V power plug, alarm or security system, remote engine start.

17. AUDIO SYSTEM [excluding aftermarket systems]: radio, speakers, antenna; cassette, CD, or DVD player; video screen, iPod & MP3 interface; SYNC, OnStar, Bluetooth; navigation system (GPS), backup camera/sensors.”

Each of the 17 problem areas in the survey covers an array of possible breakdowns. For instance, "Power Equipment" includes keyless entry, dashboard warning lights, tire-pressure monitor, and other things. "Body integrity" includes squeaks and rattles, seals and weather stripping, and air or water leaks, among other things. "Major Engine" problems include cylinder head and timing belt besides replacing the engine itself, while "Minor Engine" includes oil leaks, accessory belts and engine mounts. In addition, problems with the engine-major, cooling system, transmission-major, and driveline are weighed more heavily in CR’s calculations of Used Car Verdicts and Predicted Reliability because those areas are more expensive to repair than others. CR’s Predicted Reliability rating for new cars is a measure of how well a new model is likely to hold up based on the model’s recent history, provided the model hasn’t been significantly redesigned for the current model year. To calculate this rating, *Consumer Reports* averages a model’s Used Car Verdict for the newest three years. Predicted Reliability is shown in the Reliability History Charts as the New Car Prediction.

2.3.2. J.D. Power And Associates Reliability Evaluations. To obtain its Reliability Ratings, JDP uses the Vehicle Dependability Study (VDS). For example, in conducting the 2010 VDS, original vehicle owners were asked to report the type and number of problems they experienced during the preceding 12 months with their 3-year-old vehicle. Predicted Reliability information is derived from the Initial Quality and Vehicle Dependability Studies and is a forecast of how reliable a newer vehicle might be over time. The areas that are included by JDP can be described in their own words (taken directly from Website 2, 2012) as follows:

“Vehicle Dependability Study:

1. OVERALL DEPENDABILITY: Taken from the Vehicle Dependability Study (VDS), which looks at owner-reported problems in the first 3 years of new-vehicle ownership, this score is based on problems that have caused a complete breakdown or malfunction of any component, feature, or item, i.e., components that stop working or trim pieces that break or come loose.

2. POWERTRAIN DEPENDABILITY: Taken from the Vehicle Dependability Study (VDS), which looks at owner-reported problems in the first 3 years of new-vehicle ownership, this score is based on problems with the engine or transmission as well as problems that affect the driving experience, i.e., vehicle/brakes pull, abnormal noises or vibrations only.

3. BODY AND INTERIOR DEPENDABILITY: Taken from the Vehicle Dependability Study (VDS), which looks at owner-reported problems in the first 3 years of new-vehicle ownership, this score is based on problems with wind noise, water leaks, poor interior fit/finish, paint imperfection, and squeaks/rattles.

4. FEATURE AND ACCESSORY DEPENDABILITY: Taken from the Vehicle Dependability Study (VDS), which looks at owner-reported problems in the first 3 years of new-vehicle ownership, this score is based on problems with the seats, windshield wipers, navigation system, rear-seat entertainment system, heater, air conditioner, stereo system, sunroof and trip computer.”

As can be seen, the CR information is much more detailed than that from JDP. For example, instead of one rating for "powertrain dependability," CR lists and rates five areas that are related to powertrain: engine, transmission, brakes, drive system, and suspension. For "body and interior dependability" rating, CR provides ratings for body integrity and paint/trim/rust. Finally, for the "feature and accessory dependability" area, CR has the ratings for the climate system, power system and accessories, body hardware, and audio system.

2.3.3. Quality Evaluations. The significant difference between the two sources is that CR makes its own initial new car quality evaluations through road tests and other calculations; whereas JDP surveys new vehicle owners within the first 90 days of ownership to gather quality information. CR comments on the JDP system briefly at consumerreports.com, and states that JDP covers only the first three months of ownership, a period in which relatively little goes wrong. It also asks owners about many subjective impressions of their vehicles, not just serious problems they've had (Website 1, 2012). Automotive News senior writer Snyder (2009) comments on JDP's IQS methodology by saying that over the years, critics have griped about J.D. Power's methodology -- not a random sample and too-small samples on less popular models -- and policies, such as placing equal numerical weight on blown engines as on vibrating ash trays. His reply to these critics is: "I say, so what?" He continues: "For all its flaws, the data are the best available. And the IQS has driven continuous improvement in vehicle quality for years, acting as both carrot and stick. Automakers grumble, but they work very hard to improve their scores. And they pay J.D. Power for the right to use its name and endorsement on their advertising".

CR provides summary information on quality through its Model Summary including a note of Recommended Vehicles. In order to earn a CR Recommendation, a model needs to meet three criteria: The model needs to do well in their road tests, the model must have at least average Predicted Reliability, and if the model was crash-tested by the National Highway Traffic Safety Administration (NHTSA) or the Insurance Institute for Highway Safety (IIHS), it must perform at least adequately. In addition, pickups and SUVs must not have tipped up in the government's rollover test or, if not tested, must be available with electronic stability control (ESC).

The last rating is also based on crash test results performed by the U.S. Government and the insurance industry. Vehicles are rated by category with an overall score for comparative purposes. The overall score for a tested model is based on CR's results from more than 50 tests and evaluations. On the other hand, JDP quality ratings come from its Initial Quality Study (IQS), which surveys owners of new vehicles in the first 90 days to obtain information on 217 vehicle attributes. This study divides consumer-reported problems into two main categories: Malfunctions/Defects, and Design issues. The JDP summary information includes an Overall IQS Score based on problems that have caused a complete breakdown or malfunction and quality scores based on specific problems in mechanical, power-train, interior areas, accessories, and design features. CR does not conduct surveys to determine initial quality. It buys and tests about 80 cars per year and drives each for thousands of miles. The evaluation regimen consists of more than 50 tests and includes both subjective and empirical findings.

2.3.4. Performance Evaluations. The information comes from the Consumer Reports test data for the vehicle (taken directly from Website 1, 2012) and any related versions tested and provides evaluation of:

“PERFORMANCE FACTORS:

ACCELERATION: Acceleration runs are made from a standstill with engine idling.

TRANSMISSION: Transmission performance is determined by shifting smoothness, response, shifter action, and clutch actuation for manual transmissions.

ROUTINE HANDLING: This judgment reflects how agile the vehicle is on the road by the amount of body lean and steering response. It also reflects the turning circle.

EMERGENCY HANDLING: This judgment reflects how the vehicle performed when pushed to its limits on the track and in the CR emergency-avoidance maneuver.

BRAKING: The braking judgment is a composite of wet and dry stopping distances, resistance to fade, as well as pedal feel and directional stability.

RIDE: The ride judgment is determined by how well the suspension isolates and absorbs road imperfections and how steady it keeps the body on various road surfaces.

NOISE: This judgment is a composite of several instrumented measurements as well as subjective evaluation in normal driving.

DRIVING POSITION: Driving position shows how well drivers of various heights are situated in relation to the controls and their visibility.

FRONT, REAR, AND THIRD SEAT COMFORT: These are determined by a jury evaluation of various sized testers.

FRONT, REAR, AND THIRD ACCESS: Measure of how easy it is to enter and exit the cabin.

CONTROLS AND DISPLAY: Measure of clarity and intuitiveness.

INTERIOR FIT AND FINISH: An evaluation of the interior quality and craftsmanship.

TRUNK/CARGO AREA: Judged by the amount of luggage they can accommodate.”

Climate system and Fuel economy data are also provided. Korsch (2007) believes that Consumer Reports is thinner on specifications and performance data than it was 40 years ago. He contends it never published a car's top speed, which is legitimate data.

The JDP Automotive Performance, Execution and Layout Study (APEAL) provides data about new vehicles after 90 days of ownership. It is based on eight categories of vehicle performance and design: engine/transmission; ride, handling and braking; comfort/convenience; seats; cockpit/instrument panel; heating, ventilation and cooling; sound system; and styling/exterior. However, the scores are grouped under these categories: Overall performance and design, performance, comfort, features and instrument panel, style. The Appeal Study as described on Website 6 (2011) taken directly from this website) states the following:

"PERFORMANCE FACTORS:

1. PERFORMANCE is based on owner satisfaction with the vehicle's powertrain and suspension systems. These include acceleration, fuel economy, handling stability, braking performance, and shift quality.
2. COMFORT is based on owner satisfaction with the vehicle's comfort and convenience features and seats.
3. FEATURES AND INSTRUMENT PANEL component is based on owner satisfaction with the vehicle's stereo system, instruments, and climate system.
4. STYLE is based on owner satisfaction with the vehicle's interior and exterior styling, uniqueness of styling, exterior and interior colors."

According to a PRNewswire report (Website 5, 2011), the APEAL Study is significant as it measures the passion owners have for their cars, including their delight with the design, content, layout and overall driving performance of their new vehicles. Another article at PRNewswire (Website 6, 2011) says the closely watched APEAL Study survey measures customer satisfaction in design, content, and vehicle performance. Customers rate their level of "gratification" on a variety of vehicle attributes, including safety, fuel economy, cargo space, roominess and exterior styling. The article also quotes Ford's group vice president, Bennie Fowler, who said it was a significant accomplishment to do so well in APEAL on the heels of receiving high marks from JDP on initial quality (Website 6, 2011).

CR provides more detailed ratings in the performance category. For instance, under performance evaluation, where JDP gives one rating, CR divides that into acceleration, routine handling, emergency handling, braking, transmission, and ride. In the comfort category, CR rates various properties related to comfort: Driving position, front/rear/third seat comfort, driving position, and noise. For the 'features and instrument panel' category, CR also has one scoring grouped under 'controls and display'. Finally, instead of a single 'style' rating, CR has separate ratings for interior fit and finish, and trunk/cargo area.

2.3.5. Safety Evaluations. CR gives data on availability of Antilock brakes, traction control, stability control, daytime running lights, tire pressure monitor, safety belts, and air bags for every model. In particular, crash and rollover tests results are provided from two independent crash tests. One of them is the National Highway Traffic Safety Administration (NHTSA), which is a branch of the U.S. Transportation Department (Website 4, 2006). The other is the Insurance Institute for Highway Safety; a safety-research group sponsored by the insurance industry (Website 4, 2006). These two organizations conduct front and side-impact crash tests using their own methodologies.

NHTSA also tests for rollover propensity and the IIHS evaluates rear-crash protection. NHTSA scores its tests using a scale of one to five stars; more stars mean safer cars. The IIHS uses a four-level scale: Poor, Marginal, Acceptable, and Good. In contrast, JDP gives safety ratings (i.e., the two government crash test results) for only the vehicles that were chosen for Power Steering Reviews. For a vehicle to make the Power Steering Reviews, it has to rank among the top 3 vehicles in its class in one of the ratings studies, has to have done well in the gov't crash tests, and finally has to rank top in the fuel economy ratings by the EPA.

2.4. SUMMARY

The two major sources of information, *Consumer Reports* and J.D. Power and Associates, on vehicle reliability, quality, and safety in the U.S. both have the same purpose of conveying information about the above factors. However, there are differences in how they collect their data, the amount of such data, and how the data are categorized. There are disagreements over the validity and value of the data as discussed above. Overall, it is seems that CR has much more detailed information and categorization about the vehicles it studies than JDP. Table 2.1 provides a summary of the major rating categories for both sources and how they differ from each other.

Flint (2005) believes CR is “unjustly dismissed” and explains why people should not do that. He states that Detroit engineers and executives do “not spend enough time in Hondas and Toyotas; they really don't understand how good they are.” They always think “the criticisms of their products are prejudiced.” Detroiters insist their vehicles are constantly improving but nobody recognizes the changes. Flint (2005) adds; “CR doesn't create the trends, but it does make them understandable. The CR center tests four to six vehicles each issue, 11 issues a year. The 12th issue is devoted to automobiles. CR spends $2 million a year buying new vehicles for testing and gets $1.4 million back selling them afterwards. It's time to start paying attention to what CR is saying. Before it's too late" (Flint, 2005). On the contrary, Dodge (2007) thinks when it comes to American vehicles, Consumer Report's ratings border on cruelty. While he agrees that CR is the gold standard of auto ratings, he also believes that American and German vehicles are not that far behind their Japanese rivals. He then questions how CR comes up with those ratings. He talks about Murray's (2007) visit to CR's testing center and what he reported. To better understand the 50 performance tests vehicles undergo, Murray rode with the Testing Director and recorded his experiences. After that experience he claims to understand why CR, whose independence from the automakers is legendary, gets so much respect. Murray presents information on how Consumer Report's eight-person engineering team is attracting the top brass of the auto industry to its Connecticut-based facility. According to a Big Three insider, the importance of *Consumer Reports* is recognized most strongly at the highest levels of the automotive industry. He adds that they are no doubt the best in the business. *Consumer Report* evaluations distinguish themselves from the others by their use of reliability data in conjunction with the performance tests. Some vehicles which perform very well on the track might fall flat when data from the survey respondents come in.

2.5. CONSUMER REPORTS VS. JD POWER & ASSOCIATES

As seen in Table 2.1., both CR and JDP provide significant amounts of information on automobile quality, performance, and safety. Overall, this information is illuminating, but given some of the criticisms leveled at both sources, there is a viable concern about how much value should be placed on it. However, the consistency of the methodology used by both entities provides a foundation for a study of improvement in the factors of reliability, quality, and safety for vehicles.

Table 2.1. Comparison of Consumer Reports' and JD Power & Associates' Vehicle Evaluations

	Consumer Reports	***J.D. Powers and Associates***
Survey Methodology	-About 1 Million responses on 300 models -Asks about problems in the past 12 months in 17 trouble areas -History is compiled for 10 years -Buys and tests 80 cars per year	- Tens of thousands of responses from 5 different studies -Asks about problems in the first 90 days for IQS; after 90 days for APEAL study; and 3-year-old vehicles for the past 12 months for VDS -Do not test cars
Reliability Evaluations	-Reliability history chart showing problem rates for a model spanning 10 years -Covers and rates 17 trouble spots -Predicted reliability rating for new cars	-VDS collects data in nearly 200 problem areas but rating are grouped into 3 categories -Predicted reliability rating for new cars
Quality Evaluations	-Conducts own tests and evaluations -Road tests, in-house empirical and subjective evaluations -Opinions in the 'model summary' section	-Ratings come from the IQS survey responses asking about problems within the first 90 days of new vehicle ownership -Problems are divided into Malfunctions and Design issues
Performance Evaluations	-Information comes from the road test data on: acceleration, transmission, routine handling, emergency handling, braking, ride, noise, driving position, front/rear/ third seat comfort and access, controls and display, fit and finish, trunk area, climate system, and fuel economy.	-Information comes from the APEAL study data on: performance, comfort, features and instrument panel, and style.
Safety Evaluations	-Data on availability of Antilock brakes, traction control, stability control, daytime running lights, tire pressure monitor, safety belts, and air bags -Results from the two major crash tests: NHTSA and IIHS.	-Gives safety ratings as crash test results and for only the vehicles that are chosen for Power Steering Reviews.

To help clarify the value of the information, this study compares the vehicles' scores from the two sources simultaneously in several dimensions of quality and reliability. Information derived from all of these dimensions shed light on the current state of that vehicle's overall quality. The dimensions which are scored and evaluated as critical contributors to quality are: Performance, comfort and convenience features, predicted reliability, safety (results of crash tests), dependability history (powertrain, body and interior, feature and accessory, and overall dependability), overall performance and design, and initial quality evaluation.

The combined data from CR and JDP will provide a good foundation for a meaningful comparison of the U.S. and Japanese automobile manufacturers. As shown in this work, both sources provide current and historical data that can be utilized for direct comparisons and trend analysis. This analysis will ultimately address the need for fact-based understanding of how the U.S. and Japanese automobile makers are performing in reliability, and may pave the way for inclusion of other aspects not currently studied in future reports but considered important by consumers and manufacturers. The following sections will discuss whether there are any correlations between the results found from these sources, what the trends exist in the three categories over time, and whether U.S. automakers are closing the gap with their Japanese counterparts.

3. METHODOLOGY

3.1. INTRODUCTION

The goals in this research, as noted above, are twofold. The first is to determine if there are any clear differences in reliability between Japanese and U.S. auto-makers. The second is to determine if there is consistency in the two agencies' ratings of vehicles. Such comparisons are not new, and Hauser and Clausing (1988) is one of the earliest of such comparisons, where a systematic approach to compare certain attributes of different makers was introduced. In their paper, Hauser and Clausing illustrated how voice of the customer can be translated into measurable objectives that automobile makers can use to produce cars that carried those desirable attributes. One specific comparison between U.S. and Japanese automakers pertains to the number of design changes for the Japanese manufacturer using Quality Function Deployment, and for the American manufacturer not using that. The Japanese design stayed the same before the first car came off the assembly line, while the U.S. company was still revamping months later. However, what is interesting to test is if significant differences still exist in the perceived quality of U.S. and Japanese car-makers and if these differences have changed over time. A discussion on the methodology used is provided in Figure 3.1. below.

The general framework of how this research was conducted is depicted as a sequence of steps in the above figure. Initially, the goals of the research were set. Then, relevant data were collected followed by quantifying and unifying that data to a common scale. Regression analysis comparing the scores of CR and JDP was conducted. Based on those analysis results, trend analysis was done. Findings, based on yet another regression analysis, emerged and goals set at the beginning of the research were achieved.

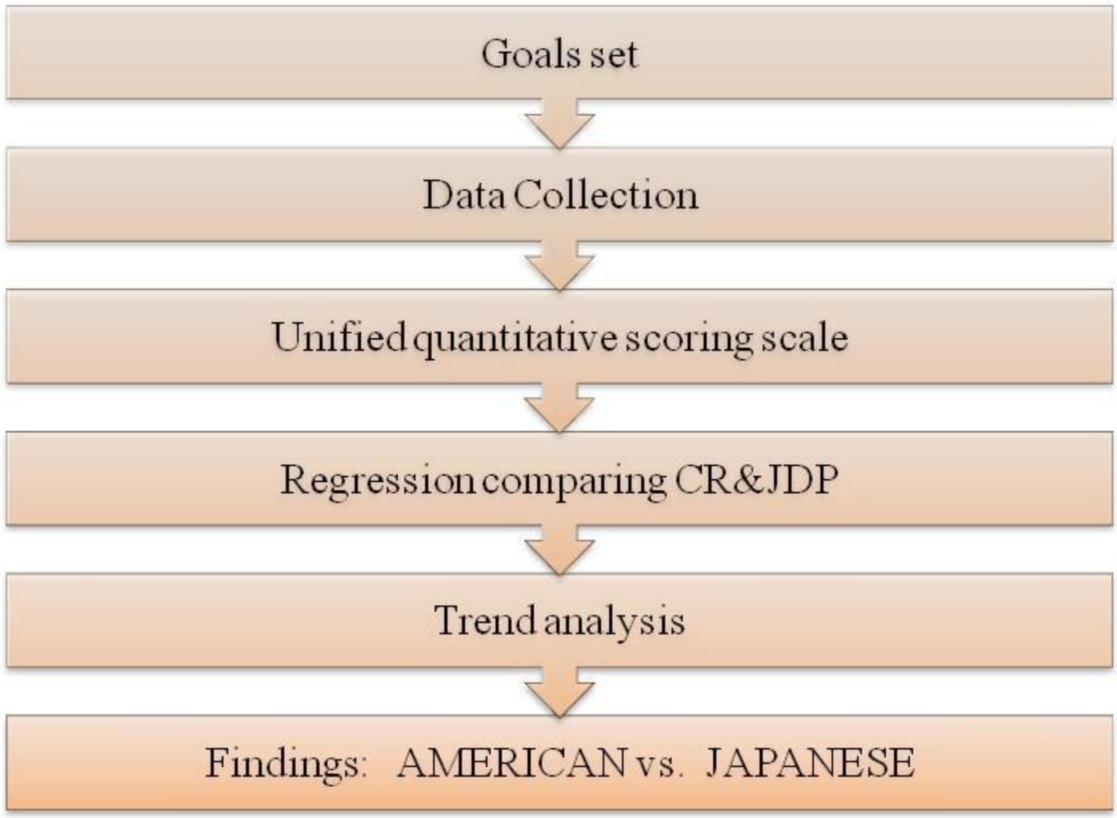

Figure 3.1. Flowchart of the Research Methodology

3.2. VEHICLE SELECTION

As stated above, one of the goals of this research is to see if there are any clear differences between the ratings/rankings of U.S. automobiles and their Japanese counterparts in the data available the past 10 years. In order to make a meaningful comparison between the vehicles, representative models were selected from vehicle categories where comparative models could be found in both the U.S. and Japanese manufacturers. Five categories of vehicles were selected where each automaker had a representative model for comparison.

In order to make the most useful comparisons, four representative attributes have been selected for our overall study. These are: Powertrain dependability, Body and

Interior dependability, Feature and Accessory dependability, and Overall dependability. Models that had the most amounts of comparable data over the last 10 years were included in the analysis. The intent was to determine whether the CR and JDP were providing similar numerical values for all the models, or only for some specific models, and whether the results varied from year to year.

3.3. SCORING: QUALITATIVE TO QUANTITATIVE

In this section, how the quantification of the original qualitative scoring by the two sources, CR and JDP, was accomplished is presented. Assigning numerical values to each rating on the scales was an obvious choice. However, the two sources used different scales; hence a conversion to a consistent numerical scale for each vehicle for every year from each source had to be conducted – in order to obtain readings that could be compared.

3.3.1. Consumer Reports Ratings. CR has a rating system that is represented by symbols, which correspond to a different evaluation level by the consumer. With "excellent" being the best rating, the score range continues with "very good", "good", "fair", and "poor". In order to have quantifiable and comparable rating scales, each of these qualitative values were assigned numbers from 1 to 5, "1" representing "poor", and "5" representing "excellent" (Figure 3.2.).

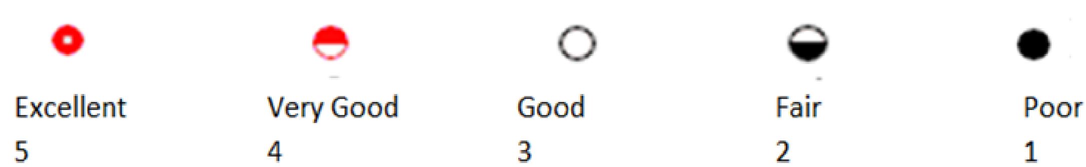

Figure 3.2. CR Rating Scale

3.3.2. JDP & Associates Ratings. Using the same method that was used for CR, JDP's ratings were converted to a numerical scale by assigning numbers to qualitative symbols and values. Their rating scale was represented by assigning values ranging from "among the best" being the highest score, to "the rest" being the lowest score. The other values from top to bottom continued as follows: "better than most", and "about average". Unlike CR, JDP has 4 evaluation values, so the numbers assigned to JDP scales range from 1 to 4 (Figure 3.3.).

Figure 3.3. JDP Rating Scale

3.4. NORMALIZATION OF RATING SCALES

As can be seen from looking at information provided by the two agencies, many of the metrics needed for quality and reliability measurement are common to both agencies, but the scales on which they are measured are not equivalent. The next critical step in the methodology was to bring the results from the two systems to a common scale. In this section, the techniques that were used to develop a scale that works for both JDP and CR and is at the same time consistent is described.

CR has a 5-point scoring scale, whereas JDP has one that uses 4-points (Figure 3.4.). In order to obtain a unified scale, linear interpolation was used to bring the two systems into alignment:

- X_{CR}: actual reading for CR
- X_{JDP}: actual reading on JDP
- Z_{JDP}: converted reading on JDP
- Z_{CR}: converted reading on CR

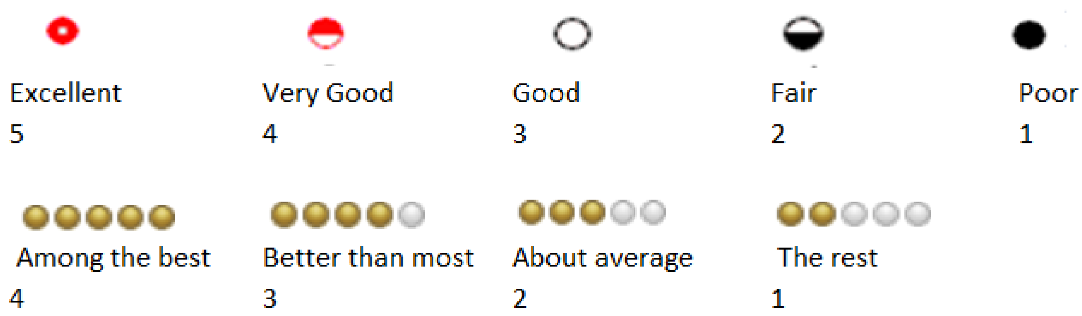

Figure 3.4. CR and JDP Rating Scales

CR assumes values from 1 to 5, and JDP assumes values from 1 to 4. All readings are to be placed on a scale from 1 to 4. To this end, the ratings are normalized to a new scale, Z.

Z is the reading on the transformed scale where,

$$Z_{JDP} = X_{JDP}$$

$$Z_{CR} = X_{CR} - 1, \text{ when } X_{CR} >= 2,$$

$$Z_{CR} = 1 \text{ otherwise}$$

With this conversion, the ratings from the two sources can be compared using a unified scale. Without such a unified scale, it will be difficult to use results from two sources within the *same* statistical experiment. Henceforth, all the results used will employ the scale proposed above, i.e., the Z-values.

4. COMPARING THE TWO SYSTEMS

4.1. INTRODUCTION

In this section, the two systems and their results for vehicle ratings are examined. Both the vehicle scores in their corresponding class and the scores of the two systems are compared to each other. The first part of the analysis section discusses results from the comparative analysis of the two sources to determine whether their ratings match. The results of this analysis determine the method used to construct trend charts and analyze the trend data.

4.2. EMPIRICAL RESULTS

To determine whether CR and JDP produce the same results in a statistical sense for all or a subset of the makes or models, and how the results varied from year to year, a statistical model was constructed. SAS was used to perform the computations.

Assuming the data was normal, regression analysis was performed in an attempt to predict JDP based on CR. This would potentially determine if they were related. A general linear model based on vehicle classes (i.e., Family Sedans, Large Sedans, Sports, Small SUV, and Midsize SUV) for every year between 2001 and 2010 was constructed. The model was defined as:

$$Z_{JDP} = Z_{CR} + t + Z_{CR}*t + \epsilon,$$

where t is the YEAR and ϵ is the error term. An analysis of variance (ANOVA) was run using a general linear model. The response variable was JDP scores, from which its relationship with CR scores and YEAR (t) for the given type of vehicles was explored.

The model examined has the main effects of CR scores and YEAR (t), as well as their interaction.

From the analysis, it can be concluded that the correlation of vehicle ratings between CR and JDP is positive. However it is very weak, i.e., R-square value is less than 0.5; the actual values are presented in Table 4.1. Further, this correlation did not change from year to year; this was found to be true of a 10 year span.

Table 4.2. shows the P-values for the ANOVA. It can be concluded from the result that the independent variable YEAR has no significance. It has a p-value of 0.7386, which is greater than the 0.05 significance level. If the p-value is greater than the significance level (α), then the test statistic, in this case YEAR, is not statistically significant. The only significant factor was found to be Z_{CR}. As noted above, the R^2 values are quite weak, and hence although they show correlation, it is not strong enough to allow replacement of one set of values by the other. Further, the R^2 values were different for every class, which implies that these two sources cannot be treated as giving the same results.

Table 4.1. R-Squares from General Linear Model including YEAR as an Independent Variable

VEHICLE CLASS	**R-SQUARE**
ALL CLASSES	0.300312
Family Sedans	0.489956
Large Sedans	0.140323
Sports	0.245093
Small SUV	0.428750
Midsize SUV	0.491109

Table 4.2. P-values and a Significance Level of 0.05 (p-value is significant if it is <0.05)

	All classes &Makers	**Family sedans**	**Large Sedans**	**Sports**	**Small SUV**	**Midsize SUV**
CR	<.0001	<.0001	0.0070	0.0136	<.0001	<.0001
YEAR	0.2688	0.6197	0.6061	0.6961	0.6095	0.7386
CR*YEAR	0.6905	0.5944	0.6693	0.9436	0.7102	0.8143

Since the year-to-year changes did not have an effect, further regression analyses were performed to determine if the correlation between the two agencies would change when the year was excluded from the analysis. Hence, the same regression analysis was performed again lumping data from all the vehicle classes and makers, after excluding the year from the analysis as a variable. A second study was conducted to perform the regression one class at a time combining all makers for a particular class. A third study followed, where the regression analysis took one maker at a time combining the data from all the classes for that maker. Finally, a fourth study was conducted in which regression analysis was performed selecting one maker-class combination at a time (e.g. Toyota-Family Sedans, Toyota-Sports etc.). However, none of the four studies showed in a statistical sense that the two systems provide the same mean for the scores. The results of the first study are presented in the first row of Table 4.3, while the remaining rows of this table present the results from the second study. The results of the third study are discussed in the first row of Table 4.4, while the remaining rows of this table present the results from the fourth study. Taken together, these analyses do not indicate a statistically significant degree of correlation between the two.

Table 4.3. R-Squares from Regression Analysis Without YEAR as an Independent Variable Across Classes

VEHICLE CLASS	**R-SQUARE**
ALL CLASSES	0.2751
Family Sedans	0.4480
Large Sedans	0.0472
Sports	0.0701
Small SUV	0.3744
Midsize SUV	0.4508

Table 4.4. R-Squares from Regression Analysis Without YEAR as an Independent Variable Across Makers and Classes

	GM	**FORD**	**CHRYSLER**	**TOYOTA**	**HONDA**
All Classes	0.0287	0.0492	0.0617	0.3147	0.1554
Family Sedans	0.0020	N/A	0.0159	0.2105	0.2297
Large Sedans	0.0006	0.0684	0.0050	0.3790	0.0815
Sports	0.0384	N/A	N/A	0.3995	0.0228
Small SUV	0.2916	0.0005	0.1653	0.2927	0.2071
Midsize SUV	N/A*	0.0878	0.0172	0.2034	0.2580

*Comparable data not available for that class

5. ANALYSIS

This section presents some of the preliminary work performed with the data followed by an aggregation scheme that sought to extract useful information from the data. In Section 5.1, the preliminary analysis performed is discussed. In Section 5.2, the aggregation scheme and its results are discussed. The main findings of this dissertation are reported in the next section.

5.1. PRELIMINARY ANALYSIS

One of the important goals of this research is to identify the changes that have occurred in the past ten years in reliability of American and Japanese vehicles, and to see whether there is any consistent increase or decrease in reliability over time. If there is a change, then, what is the degree of this change?

The best way to find answers to those questions would be to plot the values against time to see the trends of the scores. To make it easier to interpret the data, it was determined that fitting the data points to a regression line would give a clearer picture. It was also assumed that there could be a consistent score increase from year-to-year, and thus linear fitting would be appropriate. Separating the data by "maker" and "class" unfortunately made the data much more difficult to interpret and to draw any useful conclusions. See Figure 5.1. as an illustration of this phenomenon. As is clear from this figure, the shape of the polynomial fit for some models is the reverse of that for some of the other models implying that there is no uniform trend. Table 5.1. shows the R-Square values for linear and polynomial trend lines (Polynomial R-Squares are much higher than the linear ones, which indicates a better fit. Therefore, polynomial trendiness were used in the graph). Hence it was determined that another potential approach for analysis would be to aggregate *all* models for a single automaker in order to determine if a uniform trend becomes visible.

The equations for the polynomial trend lines in Figure 5.1. are as follows:

- $Score=0.0685(year)^2+0.7649(year)+0.4911$ (FORD ESCAPE)
- $Score=0.0714(year)^2+0.7857(year)+3.7143$ (JEEP LIBERTY)
- $Score= -0.1042(year)^2+1.0506(year)+0.7411$ (TOYOTA RAV4)
- $Score=0.0446(year)^2-0.2887(year)+3.3482$ (HONDA CR-V)

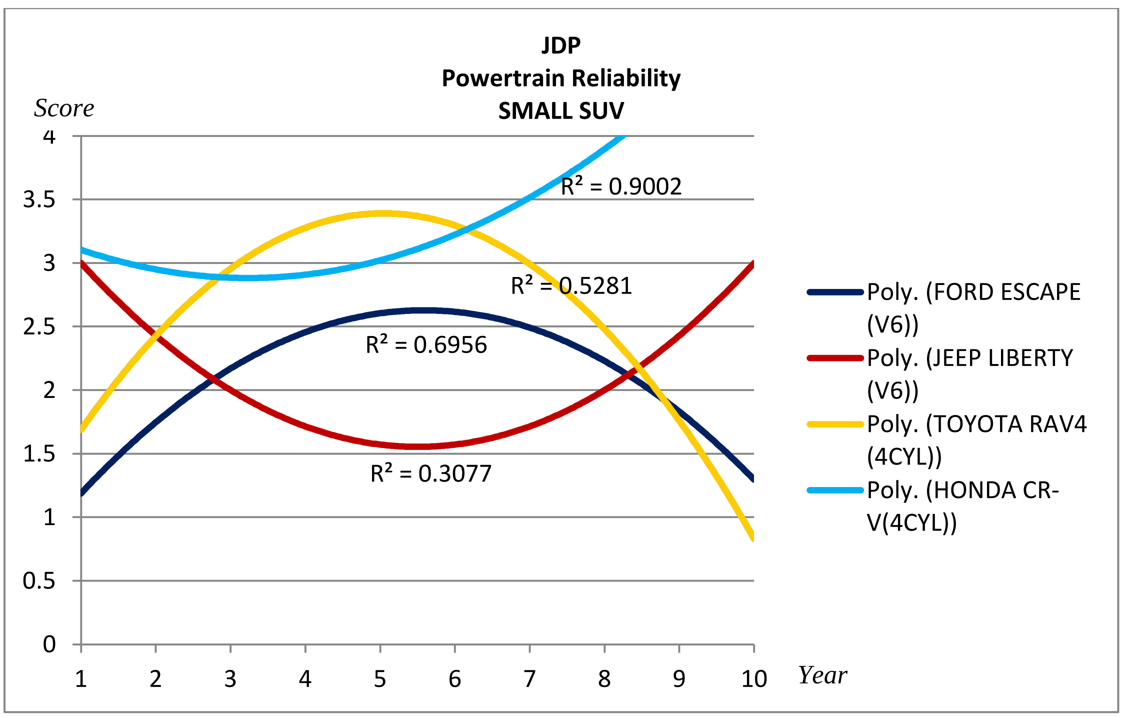

Figure 5.1. Polynomial Trend Lines For JDP Powertrain Reliability

Table 5.1. R-Square Values For Linear and Polynomial Trend Lines

JDP-Powertrain-Small SUV										
	R-sq.-linear	R-Sq. polyn.	2001	2002	2003	2004	2005	2006	2007	2008
ESCAPE	0.376	0.6956	1.50	1.50	2.00	2.00	3.00	3.00	2.50	2.00
LIBERTY	0.076	0.3077	N/A	2.50	1.50	2.50	1.50	1.00	2.00	2.00
RAV4	0.120	0.5281	1.50	2.00	4.00	3.50	3.00	3.00	2.50	3.00
CR-V	0.554	0.9002	3.00	3.00	3.00	3.00	3.00	3.00	3.50	4.00

5.2. TREND-AGGREGATING BY MAKER

In order to make meaningful comparisons, other than bringing the scoring to the same scale for the two systems, the grouping of the attributes that were scored had to be brought to the same scale as well. Both CR and JDP took into account similar items for dependability; however, how they grouped those items for scoring was different. JDP has four dependability categories that it has ratings on: Powertrain, Body-Interior, Feature-Accessory, and Overall dependability. Unlike JDP**,** CR's reliability ratings are grouped under 17 problem areas. For example, instead of one rating for "powertrain dependability," CR lists and rates five areas that are related to powertrain: engine, transmission, brakes, drive system, and suspension. For "body and interior dependability" rating, CR provides ratings for body integrity and paint/trim/rust. Finally, for the "feature and accessory dependability" area, CR has the ratings for the climate system, power system and accessories, body hardware, and audio system. JDP also includes most of those areas that CR does, however, it does not have a separate scoring system for each. Under Powertrain for example, it demands only a single score for engine, transmission, brakes, drive system, and suspension. Consumers do not have the option of rating each item separately. But in CR's ratings they do have that choice. This difference in grouping may be one of the major reasons why CR's graphs are different than JDP's. For the purposes of this research, in order to make a fair comparison, CR's attributes that were scored separately by the consumers were bundled into one group so that it would match the corresponding JDP category. In order to do that, the average of the attributes was determined and a single score obtained. These results were then compared to their equivalent categories in the JDP results. Table 5.2. below illustrates a scheme used to bring some kind of equivalency in the rating systems of the two sources.

Table 5.2. Scheme Used to Bring CR and JDP Rating Systems to Equivalency

RELIABILITY	**DEPENDABILITY**
Engine major Engine minor Engine cooling Transmission major Transmission minor Drive system Suspension Brakes	POWERTRAIN DEPENDABILITY
Paint/Trim Squeaks & Rattles	BODY AND INTERIOR DEPENDABILITY
Climate System Body Hardware Power equipment Audio system	FEATURE AND ACCESSORY DEPENDABILITY
USED CAR VERDICT	**OVERALL DEPENDABILITY**

The quantified scores from CR and JDP for each maker, model, and year were used to construct the graphs below. First, the graphs for each maker across the 10-year span are presented. The series represent the Powertrain (PT), Body Interior (BI), Feature Accessory (FA), and Overall Dependability categories.

The scores from these three categories (PT, BI, and FA) were averaged across the five vehicle classes (Family Sedans, Large Sedans, Sports, Small SUVs, and Midsize SUVs) to come up with the "powertrain average", "body-interior average", and "feature-accessory average" for one maker. First the raw data is presented in a table and it is followed by a figure that represents the same data graphically. In what follows, the data for a variety of classes and models for different automakers is presented via figures and tables. For instance, Table 5.x will represent the data, while Figure 5.x will represent the time-series graph/plot.

The graphs and the tables (Tables 5.3. through 5.16. and Figures 5.2. through 5.15.) show five parameters:

- The powertrain average (PT average),
- The body interior average (BI average)
- The feature accessory average (FA average)
- Average of the PT, BI, and FA averages
- The average provided by the agency

The three lines in the graph represent the PT average, the BI average, and FA average, respectively. One of the heavier lines in the graphs represents the averaging of the three averages discussed above (denoted by the three thin lines) and is denoted by "Avg.-PT, BI, FA." The other heavier line labeled "Avg.-Overall" represents the average presented by the sources (i.e., CR and JDP) themselves. In other words, the "Avg-PT, BI, FA" is obtained by averaging data from PT, BI, and FA. The overall average they present

("Avg-Overall") does not always equal our "Avg-PT,BI,FA". The details and weights of the calculations performed to obtain "Avg-Overall" are not disclosed by the sources. Therefore, any difference between the calculated averages and theirs could be attributed to calculation and assumption differences.

The data table and corresponding trend charts are shown in the next two sections (Section 5.2.1 and 5.2.2) for CR and JDP, respectively.

5.2.1. CR Data Tables and Graphs. Data points on the graphs below are tabulated and represented in the accompanying tables. Table 5.3. contains averaged scores from all vehicle classes for GM for each year. Figure 5.2. is a time-series plot of these scores.

Table 5.3. GM-CR: The Data Represent Values of Z_{CR}

GM-CR	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	2.88	3.63	2.25	2.79	2.28	3.00	3.09	3.41	3.56	4.00
BODY-INTERIOR-AVERAGE	3.50	3.00	2.25	2.17	2.13	1.88	2.38	2.13	2.38	3.50
FEATURE-ACCESSORY-AVERAGE	2.00	1.50	1.75	2.08	1.75	2.19	2.56	2.25	2.31	2.58
AVG(PT,BI,FA)	**2.79**	**2.71**	**2.08**	**2.35**	**2.05**	**2.35**	**2.68**	**2.59**	**2.75**	**3.36**
OVERALL-AVERAGE	**2.00**	**3.00**	**1.50**	**2.67**	**1.25**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**

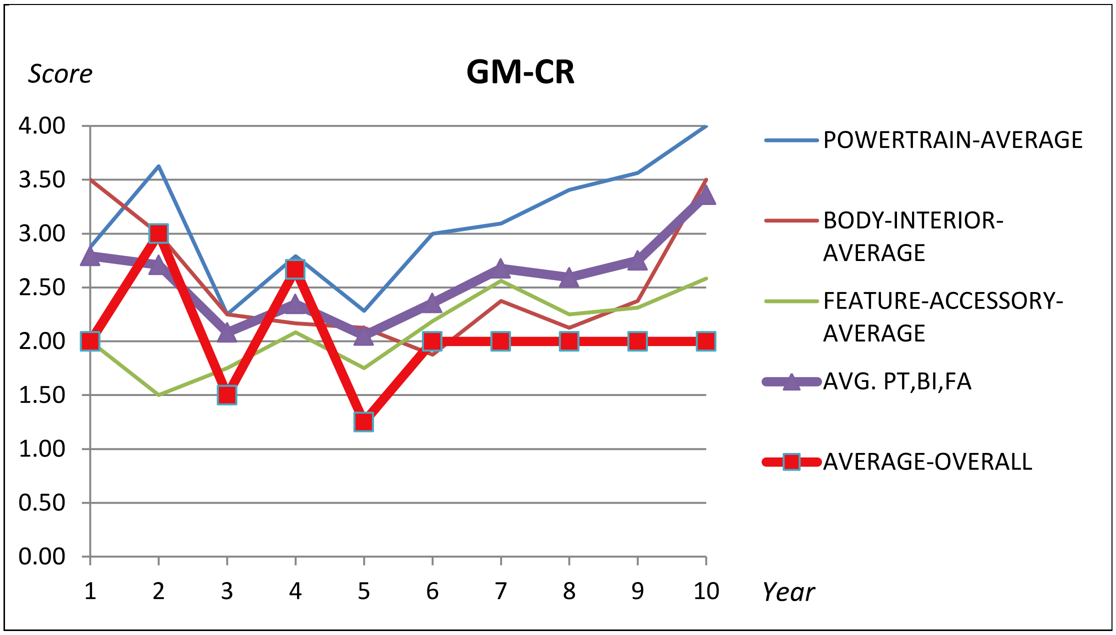

Figure 5.2. GM-CR

Table 5.4. contains averaged scores from all vehicle classes for CHRYSLER for each year. Figure 5.3. is a plot of these scores.

Table 5.4. CHRYSLER-CR: The Data Represent Values of Z_{CR}

CHRYSLER-CR	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	1.31	1.58	1.75	1.96	2.38	2.54	2.50	3.08	3.69	3.50
BODY-INTERIOR-AVERAGE	1.75	2.17	1.83	1.83	2.17	1.83	1.83	2.00	3.00	2.50
FEATURE-ACCESSORY-AVERAGE	1.38	1.75	1.75	1.83	1.92	2.00	1.75	1.50	1.88	2.25
AVG(PT,BI,FA)	**1.48**	**1.83**	**1.78**	**1.88**	**2.15**	**2.13**	**2.03**	**2.19**	**2.85**	**2.75**
OVERALL-AVERAGE	**1.00**	**1.33**	**1.33**	**1.33**	**1.33**	**1.33**	**1.00**	**1.33**	**1.50**	**1.00**

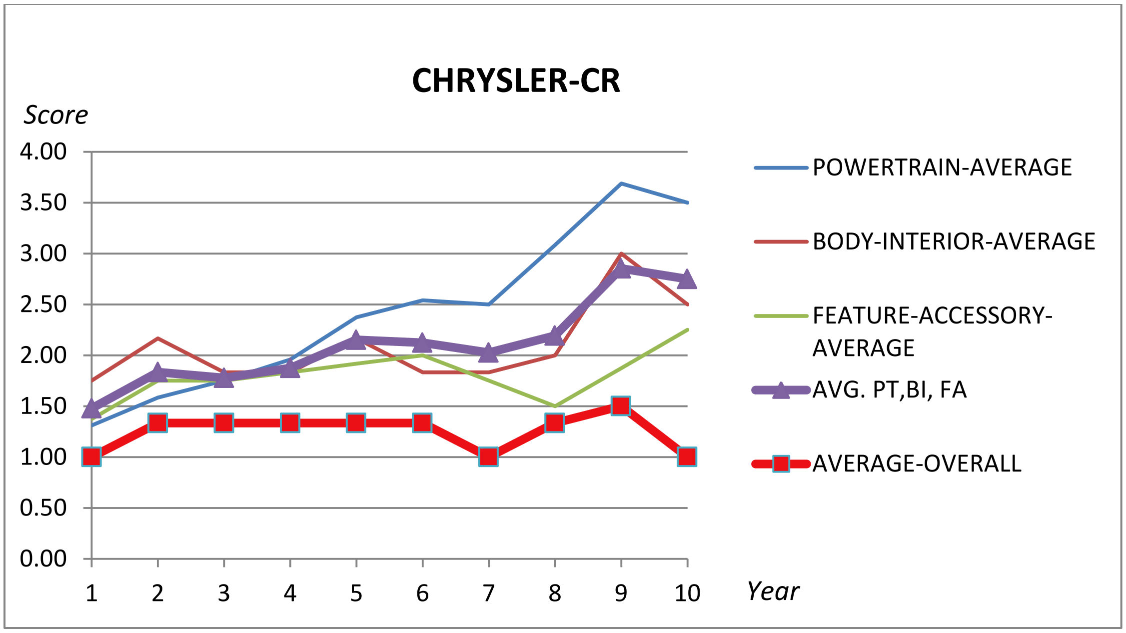

Figure 5.3. CHRYSLER-CR

Table 5.5. contains averaged scores from all vehicle classes for FORD for each year. Figure 5.4. is a plot of these scores.

Table 5.5. FORD-CR: The Data Represent Values of Z_{CR}

FORD-CR	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	2.34	1.84	2.41	2.63	2.72	2.69	2.91	2.97	3.38	3.88
BODY-INTERIOR-AVERAGE	2.00	1.88	1.75	1.75	2.00	2.00	2.50	2.00	3.13	3.38
FEATURE-ACCESSORY-AVERAGE	2.31	2.19	2.38	2.44	2.56	2.88	2.50	2.56	3.00	2.81
AVG.(PT,BI,FA)	**2.22**	**1.97**	**2.18**	**2.27**	**2.43**	**2.52**	**2.64**	**2.51**	**3.17**	**3.35**
OVERALL-AVERAGE	**2.33**	**1.67**	**2.33**	**2.00**	**2.25**	**2.00**	**2.25**	**2.00**	**2.50**	**2.00**

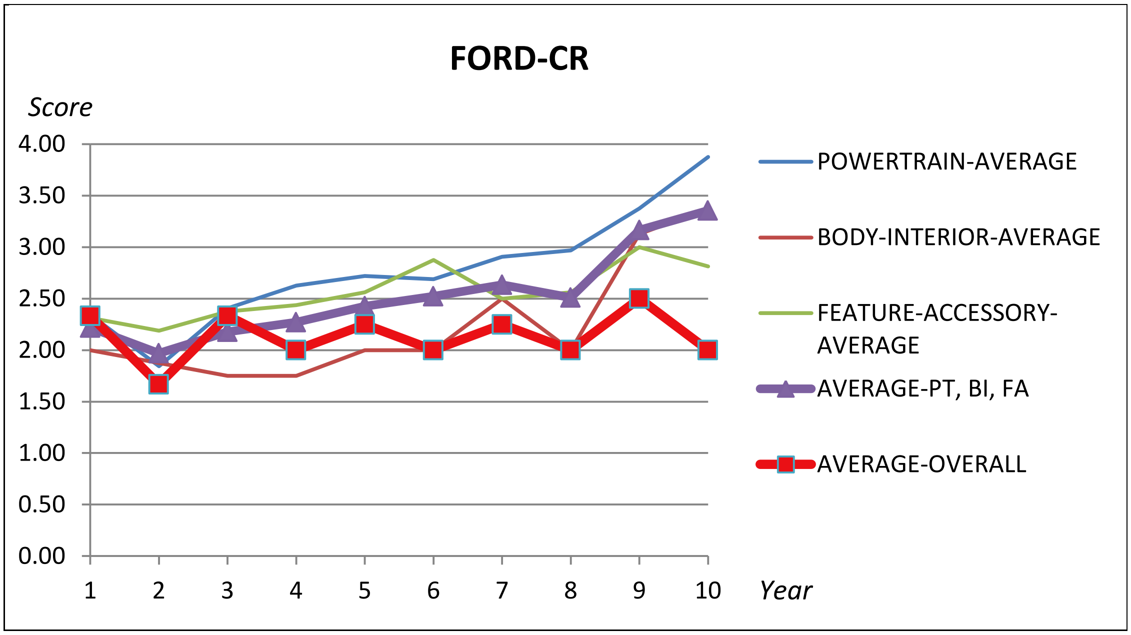

Figure 5.4. FORD-CR

Table 5.6. contains averaged scores from all vehicle classes for TOYOTA for each year. Figure 5.5. is a plot of these scores.

Table 5.6. TOYOTA-CR: The Data Represent Values of Z_{CR}

TOYOTA-CR	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	3.44	3.41	3.50	3.59	3.50	3.48	3.73	3.78	3.90	4.00
BODY-INTERIOR-AVERAGE	3.25	3.00	3.13	3.13	2.60	2.50	2.30	2.50	2.90	3.38
FEATURE-ACCESSORY-AVERAGE	3.50	3.50	3.44	3.38	3.10	3.25	3.10	3.05	3.05	2.69
AVG.(PT,BI,FA)	**3.40**	**3.30**	**3.35**	**3.36**	**3.07**	**3.08**	**3.04**	**3.11**	**3.28**	**3.35**
OVERALL-AVERAGE	**4.00**	**3.75**	**4.00**	**4.00**	**3.60**	**3.40**	**3.20**	**3.60**	**3.40**	**2.50**

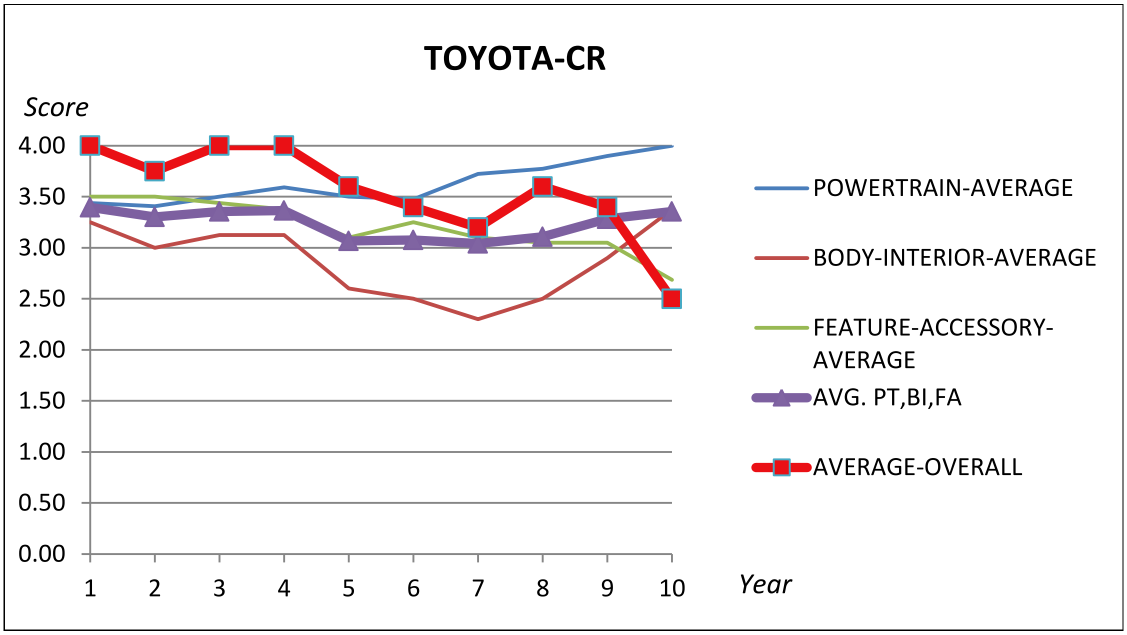

Figure 5.5. TOYOTA-CR

Table 5.7. contains averaged scores from all vehicle classes for HONDA for each year. Figure 5.6. is a plot of these scores.

Table 5.7. HONDA-CR: The data represent values of Z_{CR}

HONDA-CR	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	3.00	3.16	3.20	3.55	3.58	3.73	3.83	3.75	3.88	3.97
BODY-INTERIOR-AVERAGE	2.88	3.13	3.20	3.00	3.00	3.20	2.90	3.00	3.00	3.50
FEATURE-ACCESSORY-AVERAGE	3.31	3.13	2.70	3.00	3.25	3.40	3.40	3.31	3.19	3.06
AVG(PT,BI,FA)	**3.06**	**3.14**	**3.03**	**3.18**	**3.28**	**3.44**	**3.38**	**3.35**	**3.35**	**3.51**
OVERALL-AVERAGE	**3.50**	**3.50**	**3.40**	**3.80**	**3.80**	**3.80**	**3.80**	**3.50**	**3.50**	**3.50**

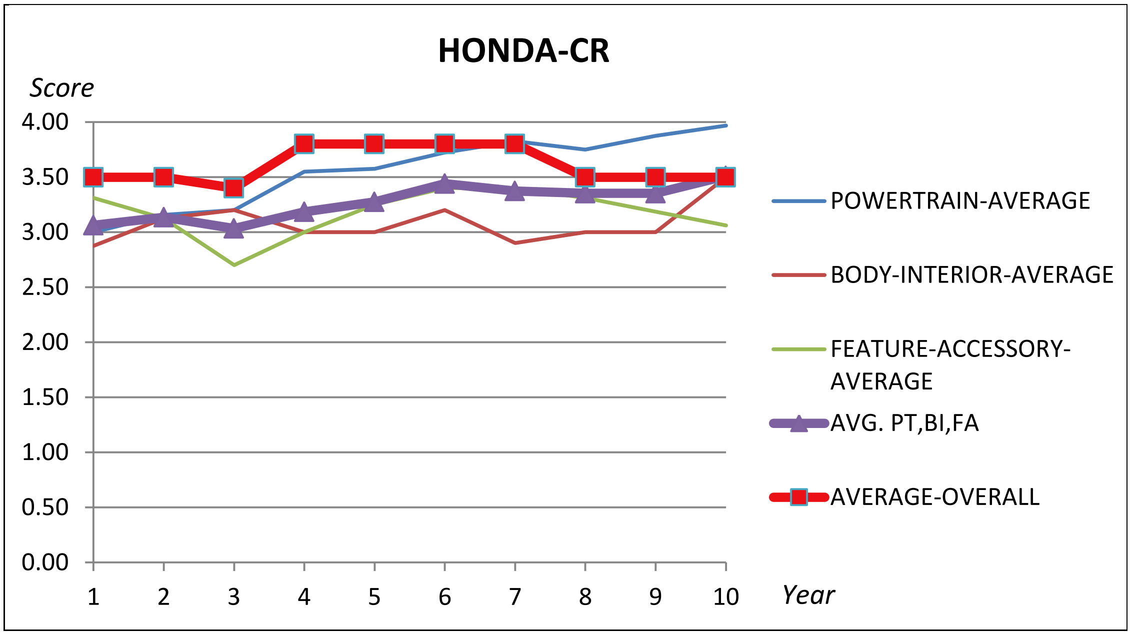

Figure 5.6. HONDA-CR

Table 5.8. contains averaged scores from all American makers for each year. Figure 5.7. is a plot of these scores.

Table 5.8. AMERICAN-CR: The Data Represent Values of Z_{CR}

AMERICAN-CR	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	2.18	2.35	2.14	2.46	2.46	2.74	2.83	3.15	3.54	3.79
BODY-INTERIOR-AVERAGE	2.42	2.35	1.94	1.92	2.10	1.90	2.24	2.04	2.83	3.13
FEATURE-ACCESSORY-AVERAGE	1.90	1.81	1.96	2.12	2.08	2.35	2.27	2.10	2.40	2.55
AVG.(PT,BI,FA)	**2.16**	**2.17**	**2.01**	**2.16**	**2.21**	**2.33**	**2.45**	**2.43**	**2.92**	**3.16**
OVERALL-AVERAGE	**1.78**	**2.00**	**1.72**	**2.00**	**1.61**	**1.78**	**1.75**	**1.78**	**2.00**	**1.67**

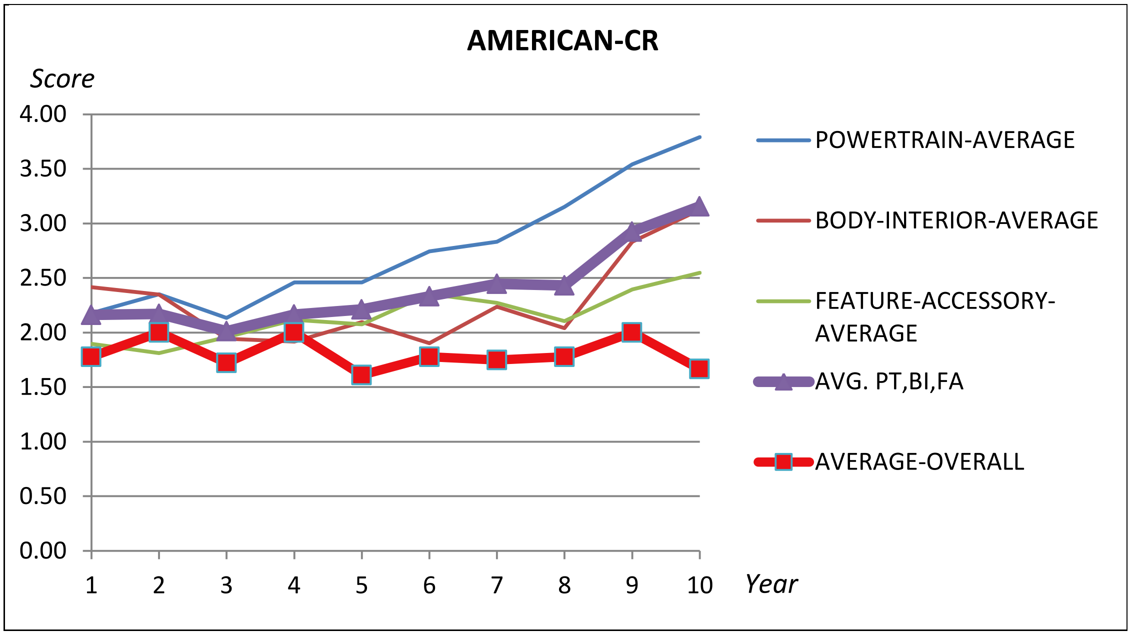

Figure 5.7. AMERICAN-CR

Table 5.9. contains averaged scores from all Japanese makers for each year. Figure 5.8. is a plot of these scores.

Table 5.9. JAPANESE-CR: The Data Represent Values of Z_{CR}

JAPANESE-CR	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
POWERTRAIN-AVERAGE	3.22	3.28	3.35	3.57	3.54	3.60	3.78	3.76	3.89	3.98
BODY-INTERIOR-AVERAGE	3.06	3.06	3.16	3.06	2.80	2.85	2.60	2.75	2.95	3.44
FEATURE-ACCESSORY-AVERAGE	3.41	3.31	3.07	3.19	3.18	3.33	3.25	3.18	3.12	2.88
AVG.(PT,BI,FA)	**3.23**	**3.22**	**3.19**	**3.27**	**3.17**	**3.26**	**3.21**	**3.23**	**3.32**	**3.43**
OVERALL-AVERAGE	**3.75**	**3.63**	**3.70**	**3.90**	**3.70**	**3.60**	**3.50**	**3.55**	**3.45**	**3.00**

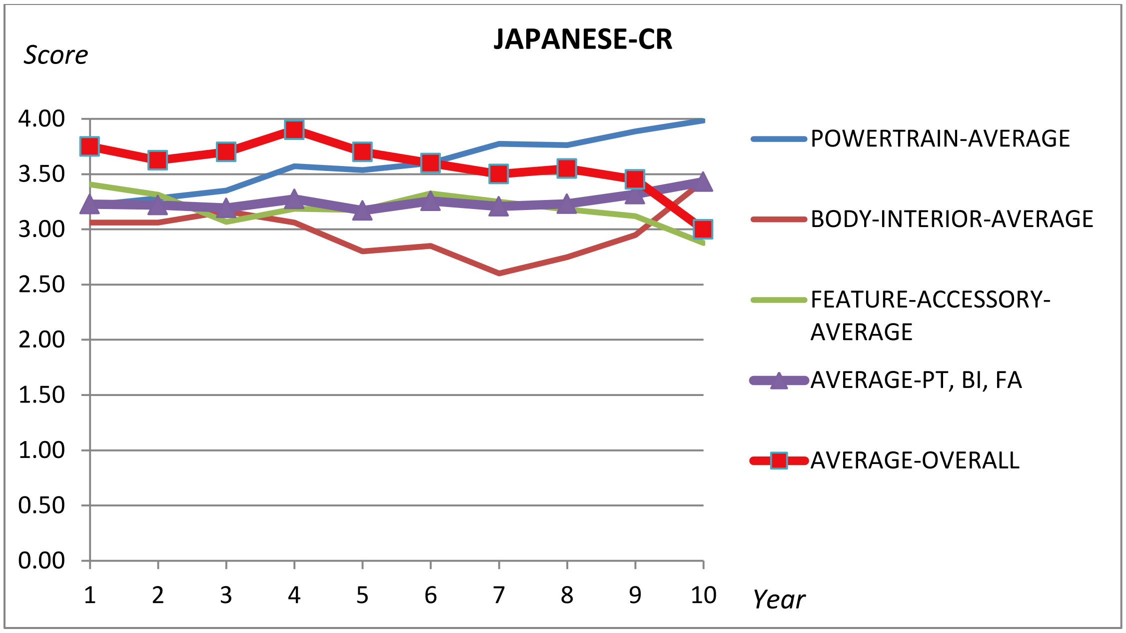

Figure 5.8. JAPANESE-CR

5.2.2. JDP and Associates Data Tables and Graphs. JDP did not have the last two years' data for reliability; therefore the values for year 2009 and 2010 were left empty. Table 5.10. contains averaged scores from all vehicle classes for GM for each year. Figure 5.9. is a plot of these scores.

Table 5.10. GM-JDP: The Data Represent Values of Z_{JDP}

GM-JDP	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	3.00	3.00	3.17	2.83	2.17	2.00	2.17	2.50		
BODY-INTERIOR-AVERAGE	1.75	2.00	2.83	2.67	3.00	2.33	2.83	2.50		
FEATURE-ACCESSORY-AVERAGE	2.50	3.25	3.33	3.50	3.00	3.00	3.50	3.75		
AVG.(PT,BI,FA)	**2.42**	**2.75**	**3.11**	**3.00**	**2.72**	**2.44**	**2.83**	**2.92**		
OVERALL-AVERAGE	**2.75**	**3.00**	**3.33**	**3.33**	**2.83**	**2.33**	**2.83**	**3.25**		

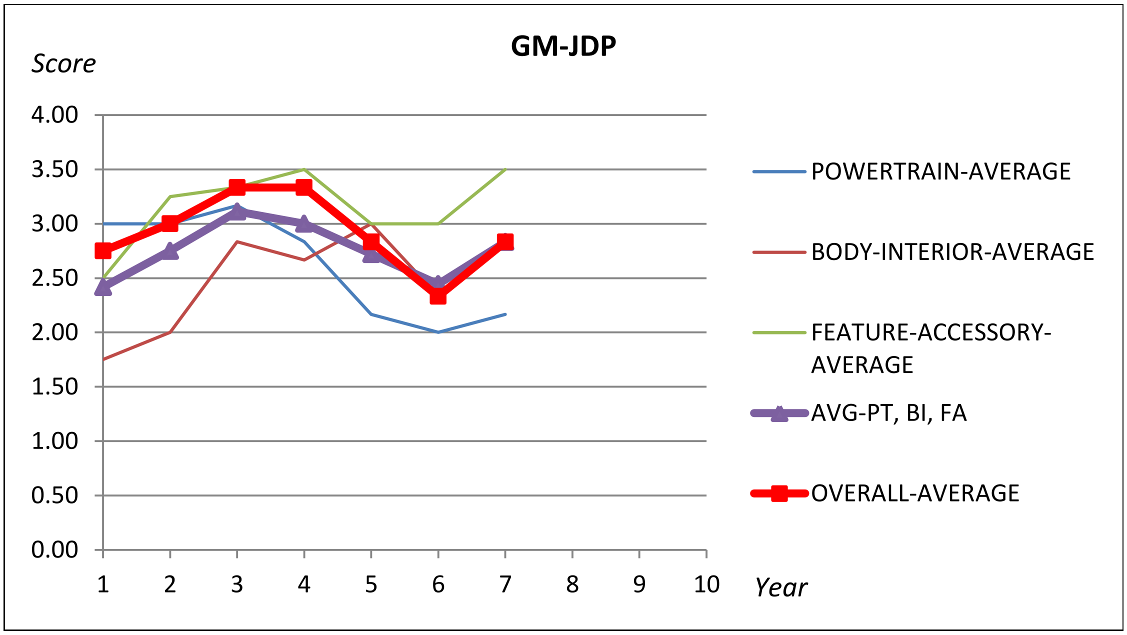

Figure 5.9. GM-JDP

Table 5.11. contains averaged scores from all vehicle classes for CHRYSLER for each year. Figure 5.10. is a plot of these scores.

Table 5.11. CHRYSLER-JDP: The Data Represent Values of Z_{JDP}

CHRYSLER-JDP	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	1.50	1.67	1.67	1.83	1.50	1.33	1.50	2.25		
BODY-INTERIOR-AVERAGE	3.50	2.67	2.67	2.67	2.00	2.33	2.00	2.00		
FEATURE-ACCESSORY-AVERAGE	2.00	1.83	1.67	2.50	2.17	2.00	1.67	1.00		
AVG.(PT,BI,FA)	**2.33**	**2.06**	**2.00**	**2.33**	**1.89**	**1.89**	**1.72**	**1.75**		
OVERALL-AVERAGE	**1.50**	**1.67**	**1.83**	**2.17**	**1.83**	**1.67**	**1.67**	**1.50**		

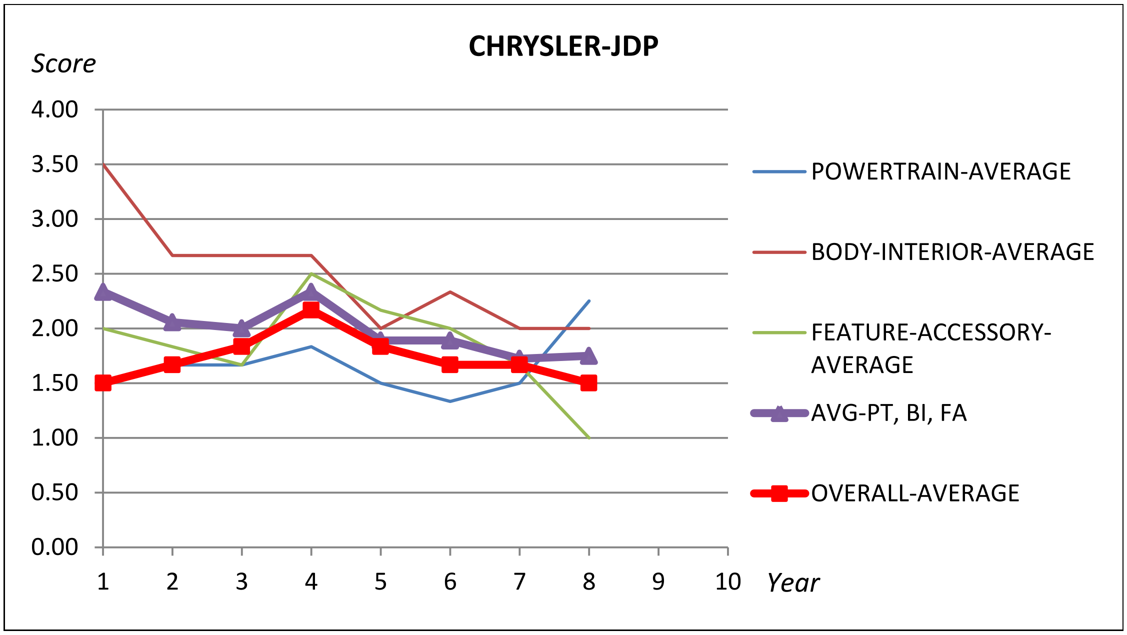

Figure 5.10. CHRYSLER-JDP

Table 5.12. contains averaged scores from all vehicle classes for FORD for each year. Figure 5.11. is a plot of these scores.

Table 5.12. FORD-JDP: The Data Represent Values of Z_{JDP}

FORD-JDP	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	1.75	1.88	2.25	2.38	2.75	2.33	2.33	2.50		
BODY-INTERIOR-AVERAGE	2.13	2.38	2.50	2.50	2.38	2.33	2.83	2.63		
FEATURE-ACCESSORY-AVERAGE	2.13	2.25	2.63	2.38	2.75	2.00	2.83	3.50		
AVG.(PT,BI,FA)	**2.00**	**2.17**	**2.46**	**2.42**	**2.63**	**2.22**	**2.67**	**2.88**		
OVERALL-AVERAGE	**2.00**	**2.00**	**2.50**	**2.38**	**2.75**	**1.67**	**2.83**	**3.00**		

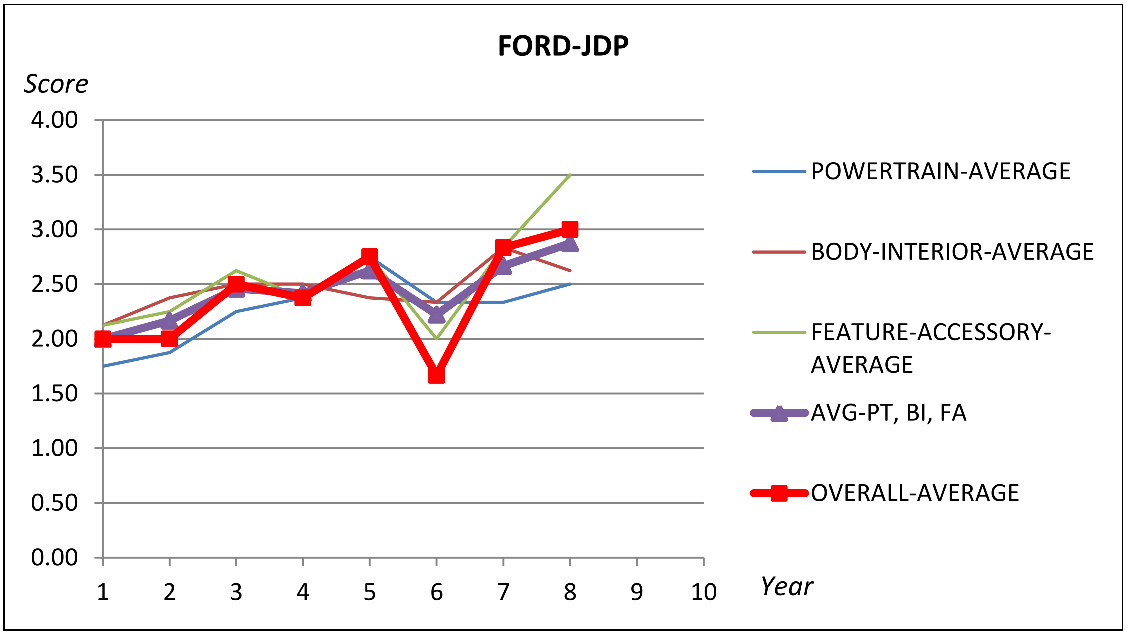

Figure 5.11. FORD-JDP

Table 5.13.contains averaged scores from all vehicle classes for TOYOTA for each year. Figure 5.12. is a plot of these scores.

Table 5.13. TOYOTA-JDP: The Data Represent Values of Z_{JDP}

TOYOTA-JDP	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	3.25	3.38	3.75	3.38	3.50	3.75	3.25	3.33		
BODY-INTERIOR-AVERAGE	2.38	2.13	3.13	2.50	3.13	3.00	3.25	3.17		
FEATURE-ACCESSORY-AVERAGE	3.75	3.25	3.38	3.25	3.50	3.25	2.75	2.50		
AVG.(PT,BI,FA)	**3.13**	**2.92**	**3.42**	**3.04**	**3.38**	**3.33**	**3.08**	**3.00**		
OVERALL-AVERAGE	**3.38**	**3.25**	**3.63**	**3.50**	**3.75**	**3.50**	**3.25**	**3.33**		

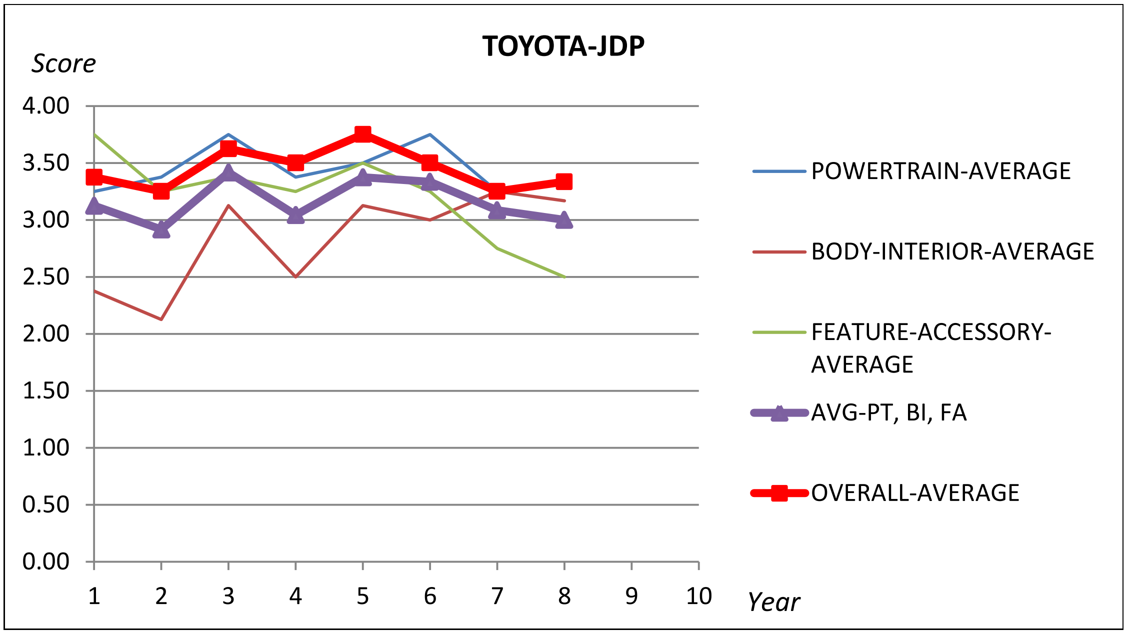

Figure 5.12. TOYOTA-JDP

Table 5.14. contains averaged scores from all vehicle classes for HONDA for each year. Figure 5.13. is a plot of these scores.

Table 5.14. HONDA-JDP: The Data Represent Values of Z_{JDP}

HONDA-JDP	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	2.88	2.88	3.30	3.30	3.50	3.25	3.38	3.67		
BODY-INTERIOR-AVERAGE	3.13	2.88	3.00	2.60	2.80	2.25	2.88	3.33		
FEATURE-ACCESSORY-AVERAGE	3.00	3.00	3.00	3.40	3.10	2.75	2.88	3.00		
AVG.(PT,BI,FA)	**3.00**	**2.92**	**3.10**	**3.10**	**3.13**	**2.75**	**3.04**	**3.33**		
OVERALL-AVERAGE	**3.50**	**3.38**	**3.10**	**3.20**	**3.40**	**3.25**	**3.13**	**3.67**		

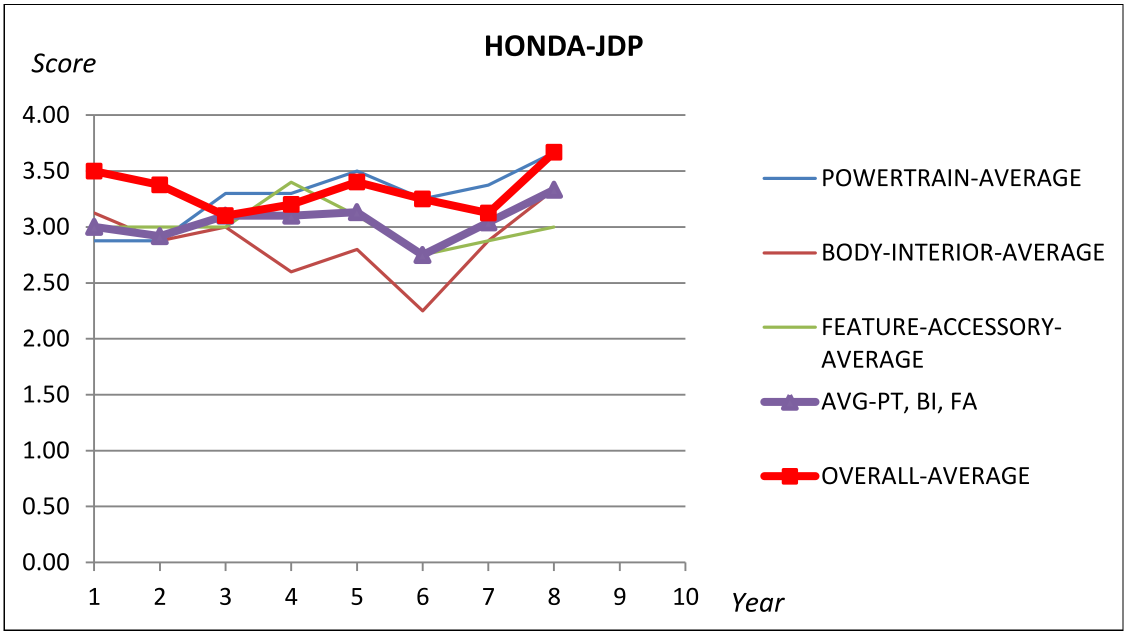

Figure 5.13. HONDA-JDP

Table 5.15. contains averaged scores from all American makers for each year. Figure 5.14. is a plot of these scores.

Table 5.15. AMERICAN-JDP: The Data Represent Values of Z_{JDP}

AMERICAN -JDP	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	2.08	2.18	2.36	2.35	2.14	1.89	2.00	2.38		
BODY-INTERIOR-AVERAGE	2.46	2.35	2.67	2.61	2.46	2.33	2.56	2.31		
FEATURE-ACCESSORY-AVERAGE	2.21	2.44	2.54	2.79	2.64	2.33	2.67	2.25		
AVG.(PT,BI,FA)	**2.25**	**2.32**	**2.52**	**2.58**	**2.41**	**2.19**	**2.41**	**2.31**		
OVERALL-AVERAGE	**2.08**	**2.22**	**2.56**	**2.63**	**2.47**	**1.89**	**2.44**	**2.25**		

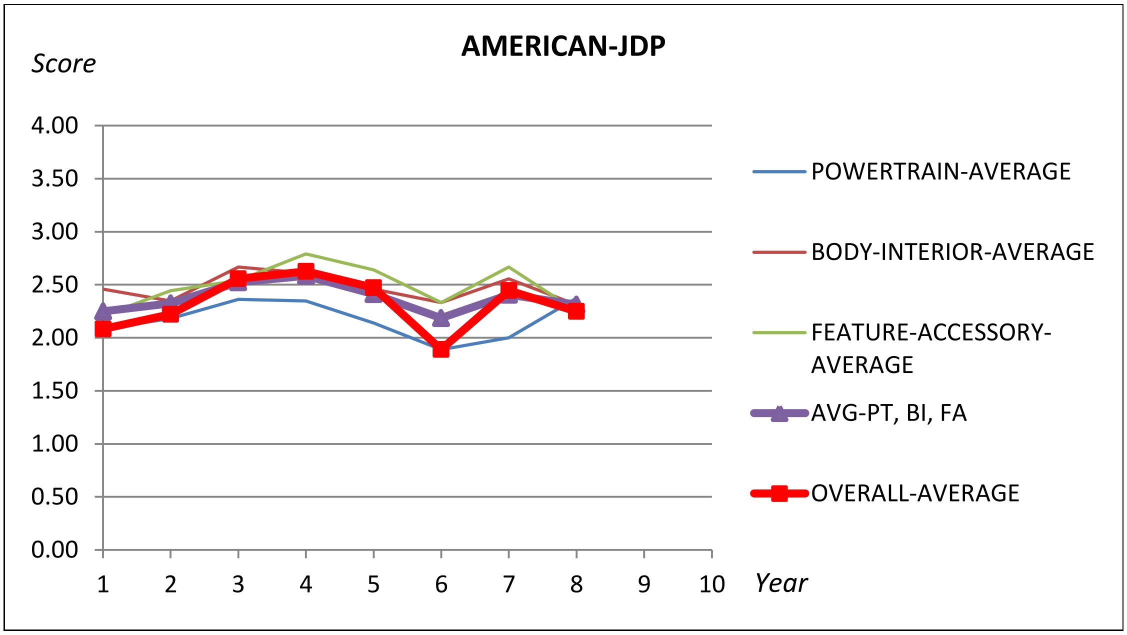

Figure 5.14. AMERICAN-JDP

Table 5.16. contains averaged scores from all Japanese makers for each year. Figure 5.15. is a plot of these scores.

Table 5.16. JAPANESE-JDP: The Data Represent Values of Z_{JDP}

JAPANESE -JDP	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
POWERTRAIN-AVERAGE	3.06	3.13	3.53	3.34	3.50	3.50	3.31	3.50		
BODY-INTERIOR-AVERAGE	2.75	2.50	3.06	2.55	2.96	2.63	3.06	3.25		
FEATURE-ACCESSORY-AVERAGE	3.38	3.13	3.19	3.33	3.30	3.00	2.81	2.75		
AVG.(PT,BI,FA)	**3.06**	**2.92**	**3.26**	**3.07**	**3.25**	**3.04**	**3.06**	**3.17**		
OVERALL-AVERAGE	**3.44**	**3.31**	**3.36**	**3.35**	**3.58**	**3.38**	**3.19**	**3.50**		

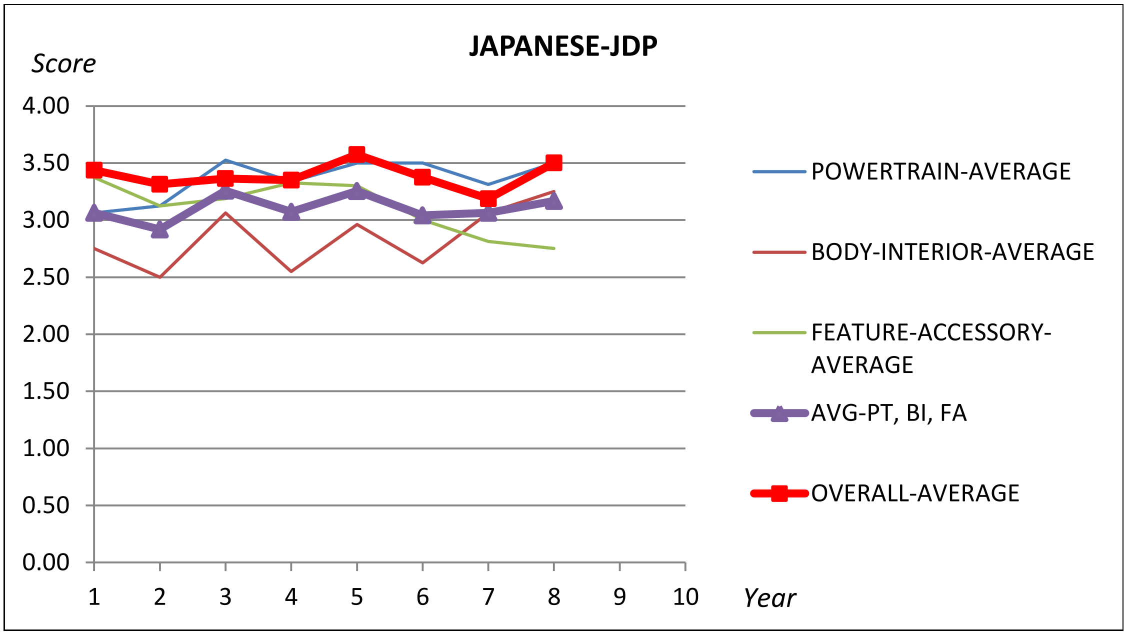

Figure 5.15. JAPANESE-JDP

5.2.3. Some Observations. All models of every single maker were pooled together, and the corresponding ratings for the four dependability categories were recorded. Next, year by year, mean values for these dependability categories were obtained. The overall dependability category was treated as a separate item and was not included in calculations of the mean because the sources have already obtained these overall ratings by taking averages of the other categories according to their own criteria.

The study's average shows a higher score range and a constant increasing trend, whereas CR's average shows a lower score range, flatter trend overall, and even a declining trend in the end. The reason for this is thought to be stemming from the fact that CR's 17 problem areas that were evaluated were lumped into fewer categories to match JDP's problem areas so that a fair comparison could be made.

CR calculates "used car verdict" by taking into account the scores for all 17 areas for a given model in a single year. This value is used as an "overall score" in this research. CR does not disclose how they arrive at the final used verdict score, but they mention that problems with the engine-major, the cooling system, the transmission-major, and the driveline are weighed more heavily in CR's calculations. That may be one of the other major reasons that the averages of PT, BI, and FA do not match up with their given "overall" scores. JDP has a different approach to obtaining their "overall" score as well which is via asking consumers to rate it as a separate category, called the overall dependability category. There, consumers are asked to rate the vehicle overall, not categorizing it by engine, or body-interior. This might further explain why differing trends in the various graphs are observed.

6. FINDINGS

In this section, the main findings of this research are presented. In Section 6.1, the qualitative aspects of the main findings are provided, while the quantitative aspects are discussed in Section 6.2.

6.1. QUALITATIVE ANALYSIS

While both CR and JDP serve the main purpose of providing automobile ratings in terms of reliability, quality, and safety, there are methodological differences in the way they evaluate vehicles and collect data. Nevertheless, both make substantial contributions in terms of the amount of data they provide to help consumers make more informed choices.

CR places heavy emphasis on reliability issues and ratings related to that. It provides individual ratings on 17 well-known trouble spots that vehicles may face. JDP, on the other hand, clusters these areas (trouble spots) into fewer groups of ratings. JDP provides ratings on two major categories: mechanical issues and design issues. It is important to note that CR has no survey ratings in terms of quality; however, it provides results and opinions based on their own road tests and evaluations.

One of the goals of this research was to test whether both CR and JDP provided consistent results on a large number of vehicle categories and how much value should be attached to their annual reports. That test was done by running a statistical analysis to calculate the correlation between the two systems' ratings.

6.2. QUANTITATIVE ANALYSIS

6.2.1. CR vs. JDP Correlation. To answer the question whether there was a correlation between CR's and JDP's ratings, their reported scores for each model of vehicle were compared. The goal was to determine whether the CR and JDP were producing the same results for all models, or for a particular model, and whether the results varied from year-to-year. Regression analysis was used. According to the test results, discussed in section 4, CR and JDP are positively co-related, but not strong enough to conclude that we can substitute one by the other. Therefore, for the research, CR and JDP were treated as separate entities having their own ratings.

6.2.2. Results: American vs. Japanese. To obtain results that have additional predictive power ratings by each maker were aggregated for their individual models. Then, all Japanese and all American models were averaged further for each year to come up with a single score the American cars a single score for the Japanese score. Further, ratings for Powertrain, Body-Interior, and Feature-Accessory dependability were averaged to obtain an Overall average. This value was then compared with the Overall average scores provided by the sources.

CR calculates the average of the above three dependability areas by assigning different weights to different attributes. Therefore, any differences between averages determined in this study and their average can be attributable to calculation methods. JDP, on the other hand, gets its overall scores by asking the consumers to evaluate a vehicle in terms of overall dependability without evaluating specific attributes. They are also asked to evaluate the vehicle as a whole; including on categories: complete malfunctions and breakdowns. So, any differences between the averages calculated in this research and JDP's overall dependability scores can be attributed to that.

Figure 6.1. shows CR data of how American and Japanese manufacturers are performing in terms of our calculated PT, BI, and FA average. It can be seen from Figure 6.1. that Japanese cars are consistently performing better than the American cars in terms of the scores.

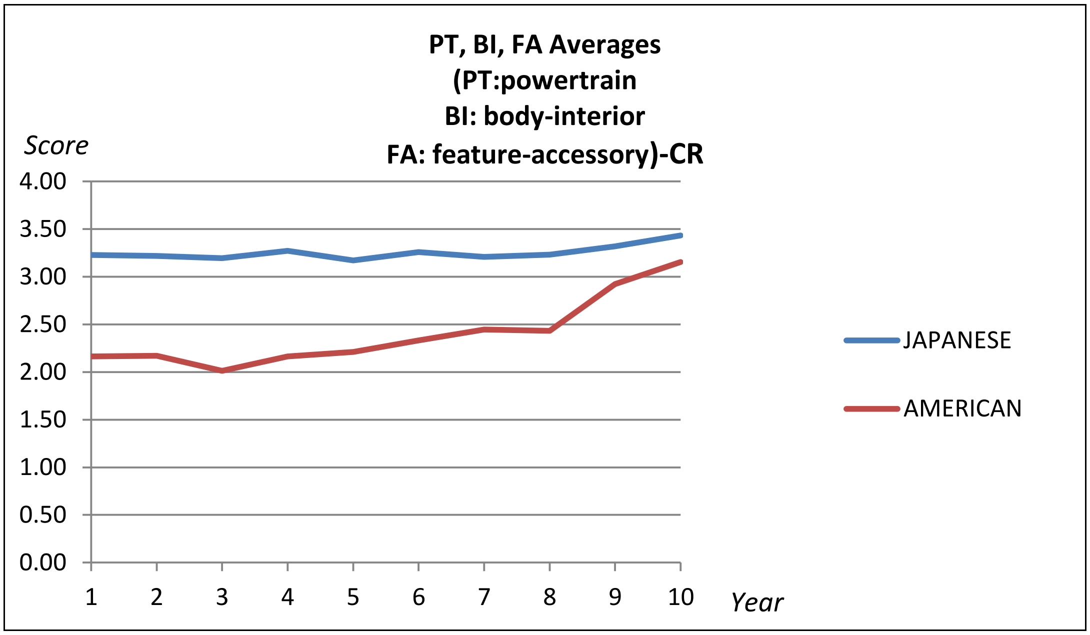

Figure 6.1. American vs. Japanese (PT, BI, FA) Raw Plot-CR

The trend is somewhat steady, showing a slight increase towards years 9 and 10 for Japanese cars. American brands, on the other hand, perform poorly compared to Japanese in early years, but appear to close the gap steadily towards the end of the decade. For year 10, the scores for Japanese and American are quite close.

In order to draw statistically sound conclusions, regression analysis was employed by analyzing the slopes of the data by country. This would show the trends and the amount of gap over time between Japanese and American manufacturers. The regression model used for the analysis can be shown by the equations below:

$$Y = \beta_0 + \beta_1 X + \beta_2 C + \beta_3 XC \quad (1)$$

where, *C=0* for American;

C=1 for Japanese;

X = Year;

Y=R1 or R2;

R1=Dependent variable representing the PT, BI, FA AVERAGE;

R2=Dependent variable representing the OVERALL AVERAGE.

For American, $Y = \beta_0 + \beta_1 X$ *where* *C=0* (2)

For Japanese, $Y = (\beta_0 + \beta_2) + (\beta_1 + \beta_3) X$ *where* *C=1* (3)

The statistical results based on the above model, for the PT, BI, and FA AVERAGE scores from CR over the ten-year span show that: (i) the quality rating has a statistically significant increasing trend over the years for both American and Japanese cars, and (ii) there was a quality gap favoring Japanese cars at the beginning but this gap is decreasing. The related ANOVA output and parameter estimates are shown in Tables 6.1. to 6.4. Figure 6.2. shows the scatter plot and the fitted regression line along with the equations.

Table 6.1. Analysis of Variance, CR-R1*

Source of Variation	**D.F.**	**Sum of Squares**	**Mean Squares**	**F ratio**	**p-value (α=0.05)****
Model	3	4.56983	1.52328	73.45	<.0001
Error	16	0.33183	0.02074		
Total	19	4.90165			

*R1: Dependent variable representing the PT, BI, FA AVERAGE.
**α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.2. Parameter Estimates, CR-R1

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	1.82200	0.09838	18.52	<.0001
YEAR	1	0.10509	0.01586	6.63	<.0001
COUNTRY	1	1.34400	0.13913	9.66	<.0001
YEARC	1	-0.08927	0.02242	-3.98	0.0011

*α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.3. Parameter Estimates, CR-R1-Japanese

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	3.16600	0.04209	75.22	<.0001
YEAR	1	0.01582	0.00678	2.33	0.0480

*α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.4. Parameter Estimates, CR-R1-American

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	1.82200	0.13261	13.74	<.0001
YEAR	1	0.10509	0.02137	4.92	0.0012

*α=significance level. If p-value is less than α, then the result is statistically significant.

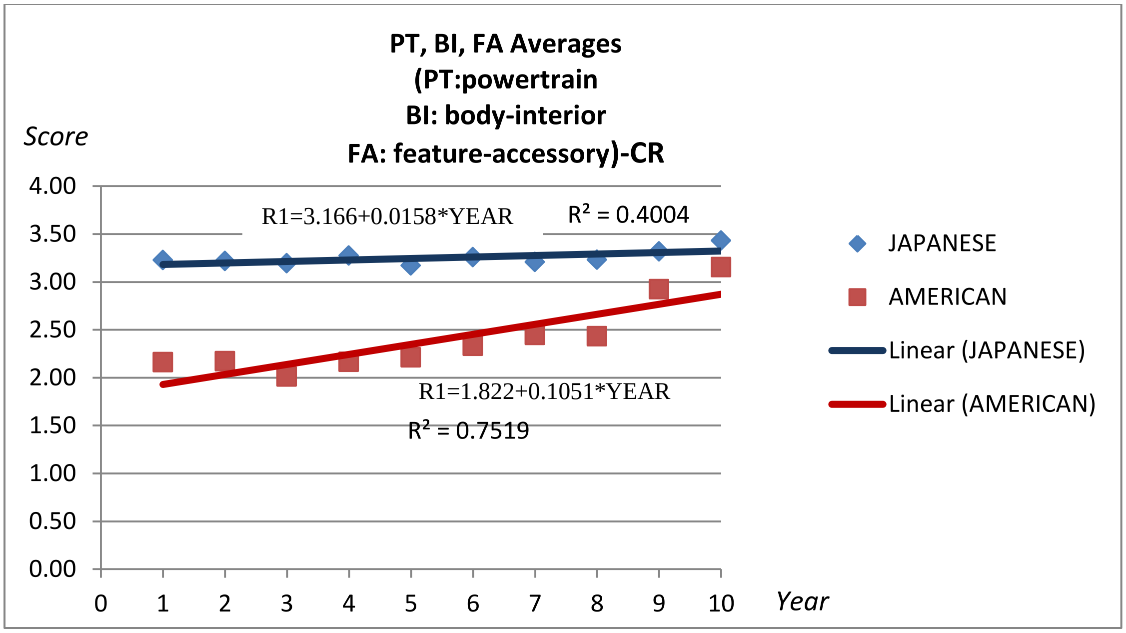

Figure 6.2. Scatter Plot & Fitted Regression Lines for CR-R1

Y=β_{0+} β_{1*}YEAR+ β_2*COUNTRY+ β_3*YEAR*COUNTRY (Regression Model)

Y=R1 (PT,BI,FA Averages),

β_0=3.166$_+$

β_1=0.10509

β_2=1.34400

β_3= -0.08927

COUNTRY=1 for Japanese,

COUNTRY=0 for American,

When these coefficients are inserted into the equation for the regression model:

R1(JAPANESE)= β_{0+} β_{1*}YEAR+ β_2*COUNTRY+ β_3*YEAR*COUNTRY

R1(JAPANESE)= 3.166 + 0.10509(YEAR) + 1.34400(1) - 0.08927(YEAR)(1) (4)

Solving the equation for YEAR provides:

R1(JAPANESE)=3.166+0.0158*YEAR (5)

R1(AMERICAN)= β_{0+} β_{1*}YEAR+ β_2*COUNTRY+ β_3*YEAR*COUNTRY

R1(AMERICAN)= 3.166 + 0.10509(YEAR) + 1.34400(0) - 0.08927(YEAR)(0) (6)

Solving the equation for YEAR provides:

R1(AMERICAN)=1.82200+0.10509*YEAR (7)

It can be statistically inferred from equation (4) that both countries have an increasing trend as shown by the corresponding coefficients. The third coefficient, β_3 reveals information about the gap between the two countries. In this case, it is negative, which means that the gap between Japanese and American makers are decreasing. Japanese have a higher β_0, so, they started at much a higher score range, but American ratings are catching up steadily.

Equations (5) and (7) are just other versions of equations (4) and (6) when the coefficients are inserted and the equations solved. These calculations show that according to the CR ratings, for the PT, BI, and FA Averages, Japanese makers had a substantial lead at the beginning, however, that is slowly disappearing towards the end of the decade.

Figure 6.3. as shown below, however, tells a different story. It is the plot of the overall scores calculated by CR using their own methods. In terms of the gap, it is wider between Japanese and American, and it is slightly narrowing as we go along the years. The Japanese are showing a decrease in performance, while Americans seem to be staying in the same range. Still, both show a decline in year 10. The reason why these two

graphs tell a different story in terms of the trends is that CR while calculating the averages for the three dependability categories assigns more weight to engine major and transmission major issues. Thus, it can be concluded that in those areas, both Japanese and American automobile manufacturers are having more problems since the slopes appear to be negative in the graphs.

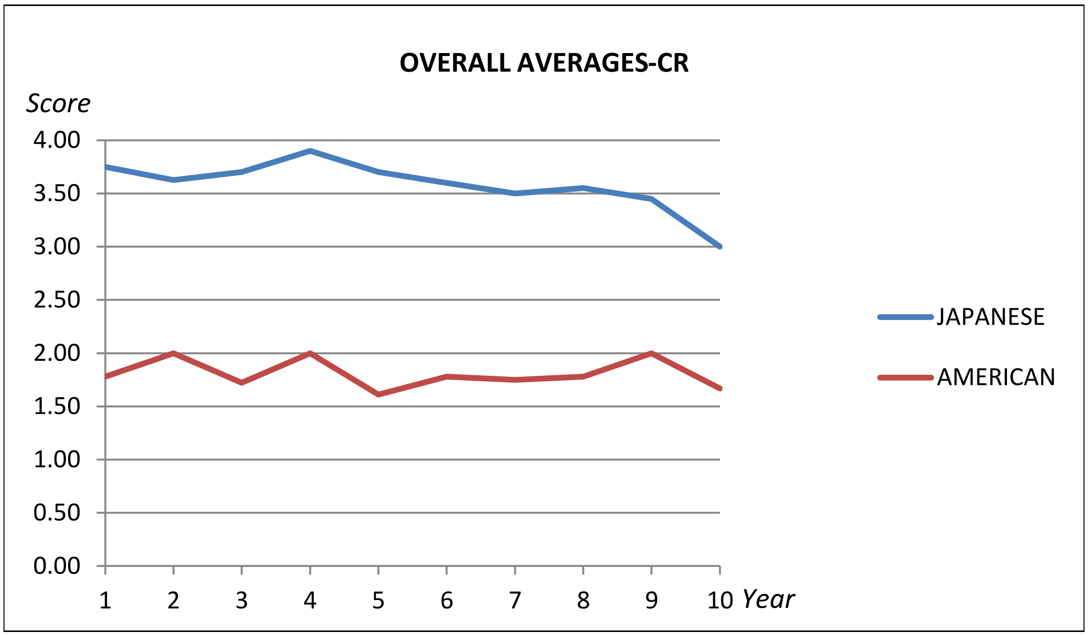

Figure 6.3. American vs. Japanese (OVERALL) Raw Plot-CR

In order to confirm these findings statistically, the results of the SAS regression analysis based on the model depicted in Equation (1) were interpreted for the OVERALL AVERAGE variable for CR. The findings indicate : (i) there is no statistically significant trend in quality for American cars, (ii) Japanese cars had better quality at the beginning of the study years, and (iii) there is a slight but statistically significant decrease in quality for

Japanese cars over the years (i.e., a negative trend). The corresponding ANOVA table and parameter estimates are shown in Tables 6.5. to 6.8. Figure 6.4. shows the scatter plot and fitted regression lines along with their equations for this model.

Table 6.5. Analysis of Variance, CR-R2*

Source of Variation	D.F.	Sum of Squares	Mean Squares	F ratio	p-value (α=0.05)**
Model	3	15.95837	5.31946	215.86	<.0001
Error	16	0.39428	0.02464		
Total	19	16.35265			

*R2: Dependent variable representing the OVERALL AVERAGE.
**α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.6. Parameter Estimates, CR-R2

Variable	DF	Parameter Estimate	Standard Error	t Value	p-value (α=0.05)*
Intercept	1	1.85133	0.10724	17.26	<.0001
YEAR	1	-0.00770	0.01728	-0.45	0.6620
COUNTRY	1	2.06200	0.15166	13.60	<.0001
YEARC	1	-0.05327	0.02444	-2.18	0.0446

*α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.7. Parameter Estimates, CR-R2-Japanese

Variable	DF	Parameter Estimate	Standard Error	t Value	p-value (α=0.05)*
Intercept	1	3.91333	0.11248	34.79	<.0001
YEAR	1	-0.06097	0.01813	-3.36	0.0099

*α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.8. Parameter Estimates, CR-R2-American

Variable	Df	Parameter Estimate	Standard Error	T Value	P-Value (A=0.05)*
Intercept	1	1.85133	0.1073	18.20	<.0001
YEAR	1	-0.00770	0.01639	-0.47	0.6513

*α=significance level. If p-value is less than α, then the result is statistically significant.

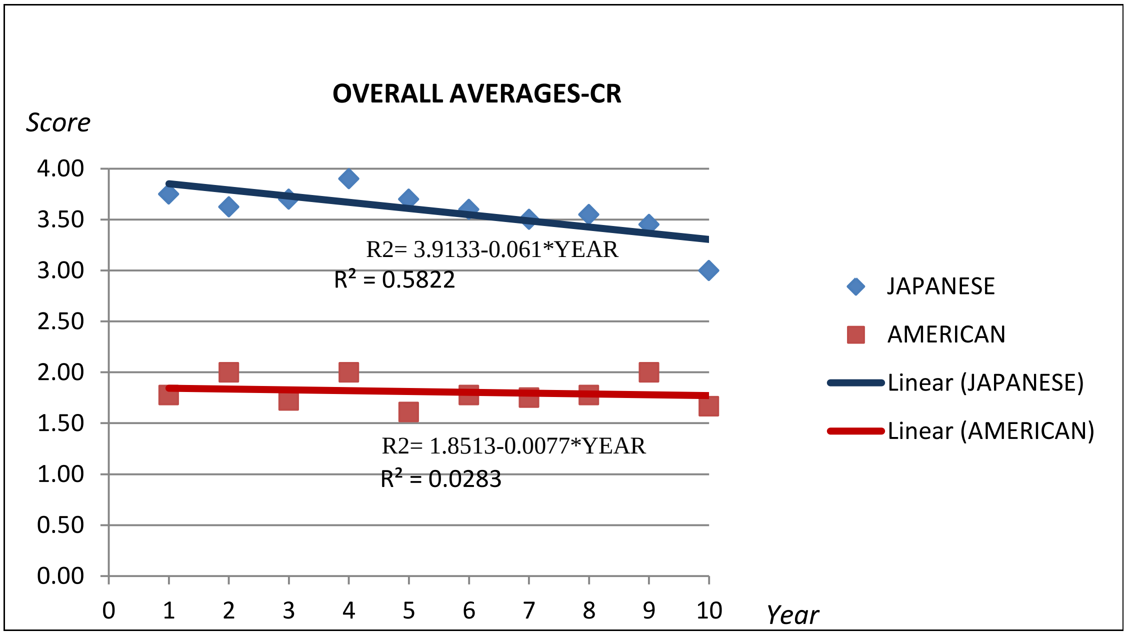

Figure 6.4. Scatter Plot & Fitted Regression Lines for CR-R2

When Equations (5) and (7) are substituted for R2 variable (Overall Averages) with R1, and the corresponding coefficients are inserted, the resulting equations are the ones shown in Figure 6.4. upon solving for YEAR. These equations show that Overall Average scores provided by CR are showing a decreasing trend for both Japanese and American vehicles, although Japanese are decreasing at a steeper rate as shown by the higher coefficient. This is also supported by the coefficient of YEAR*COUNTRY

(YEARC), which is β_3. It is negative 0.0533 (Table 6.6.), which is indicative of a decreasing gap.

Figure 6.5. shows JDP data of how American and Japanese manufacturers perform in terms of our calculated PT, BI, and FA average. These include the same make and model of cars as the CR ratings; yet, they tell a slightly different story than CR. Both agree in the score range; the Japanese are doing better. But they disagree on trends. The Japanese trends are quite close; however, American trends look fairly steady as opposed to the gradual increase seen in CR's graph. The gap between Japanese and American also remains fairly constant with the exception of a slight increase at the end, compared to the beginning due to Japanese scores' subtle increase.

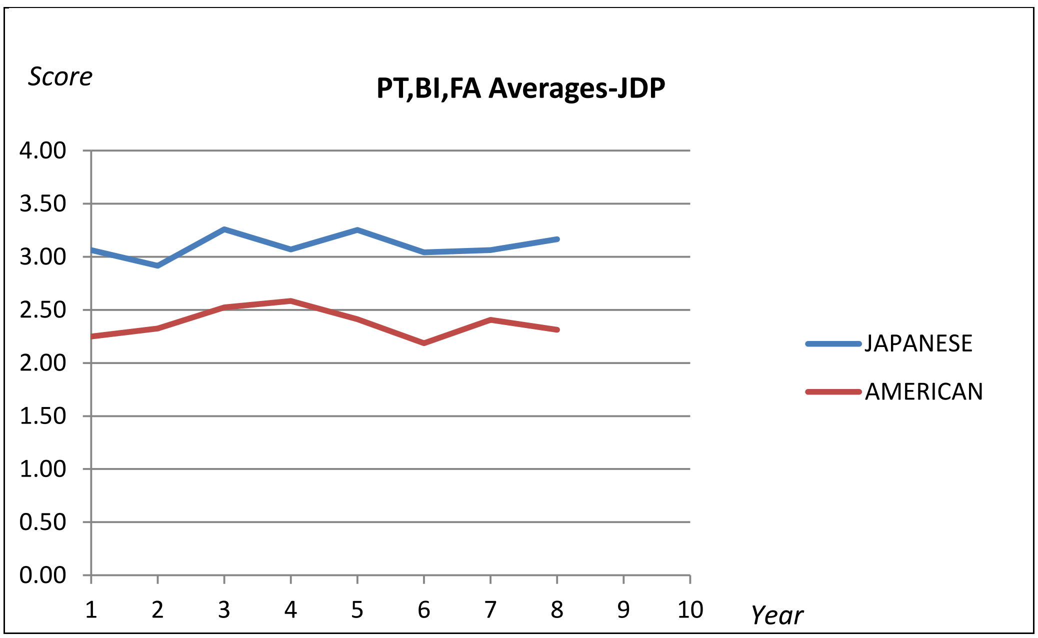

Figure 6.5. American vs. Japanese (PT, BI, FA) Raw Plot-JDP

These differences may be attributable to the methodological and systematic differences between them as discussed in previous sections. Survey demographics, evaluation criteria, and lumping of attributes together for scoring may all be important deciding factors in how these scores come out. The same regression analysis that was done for CR was conducted for JDP also based on the model represented by Equation 1. The results of the regression analysis for Figure 6.5. data (PT, BI, FA AVERAGE) reveal that: (i) There is no statistically significant trend in quality when cars of both countries were taken together, (ii) Japanese cars had better quality at the beginning of the study years, and this gap stayed the same over the years. The ANOVA table and parameter estimates are shown in Tables 6.9. to 6.12. The scatter plots and fitted regression lines along with their equations are shown in Figure 6.6. below.

Table 6.9. Analysis of Variance, JDP-R1*

Source of Variation	**D.F.**	**Sum of Squares**	**Mean Squares**	**F ratio**	**p-value (α=0.05)***
Model	3	2.13793	0.71264	40.87	<.0001
Error	12	0.20924	0.01744		
Total	15	2.34718			

*R1: Dependent variable representing the PT, BI, FA AVERAGE.
**α=significance level. If p-value is less than α, then the result is statistically significant.

Following in the same manner as CR-R1 and CR-R2, we can conclude that JDP's ratings for Japanese and American vehicles for R1(PT,BI,FA Averages) are not showing significant trends (low R^2 and p-values > α). The gap parameter YEAR*C is not significant either, so we can conclude there is no trend.

Table 6.10. Parameter Estimates, JDP-R1

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	2.38929	0.10289	23.22	<.0001
YEAR	1	-0.00345	0.02038	-0.17	0.8683
COUNTRY	1	0.66143	0.14551	4.55	0.0007
YEARC	1	0.01524	0.02882	0.53	0.6066

*α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.11. Parameter Estimates, JDP-R1-Japanese

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	3.05071	0.09391	32.49	<.0001
YEAR	1	0.01179	0.01860	0.63	0.5496

*α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.12. Parameter Estimates, JDP-R1-American

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	2.38929	0.11115	21.50	<.0001
YEAR	1	-0.00345	0.02201	-0.16	0.8805

*α=significance level. If p-value is less than α, then the result is statistically significant.

Figure 6.7. (shown below) is in fair agreement with 6.6. The only difference is slightly sharper changes for Figure 6.7. for the American scores. The trends look the same; however, they move more significantly in Figure 6.7.

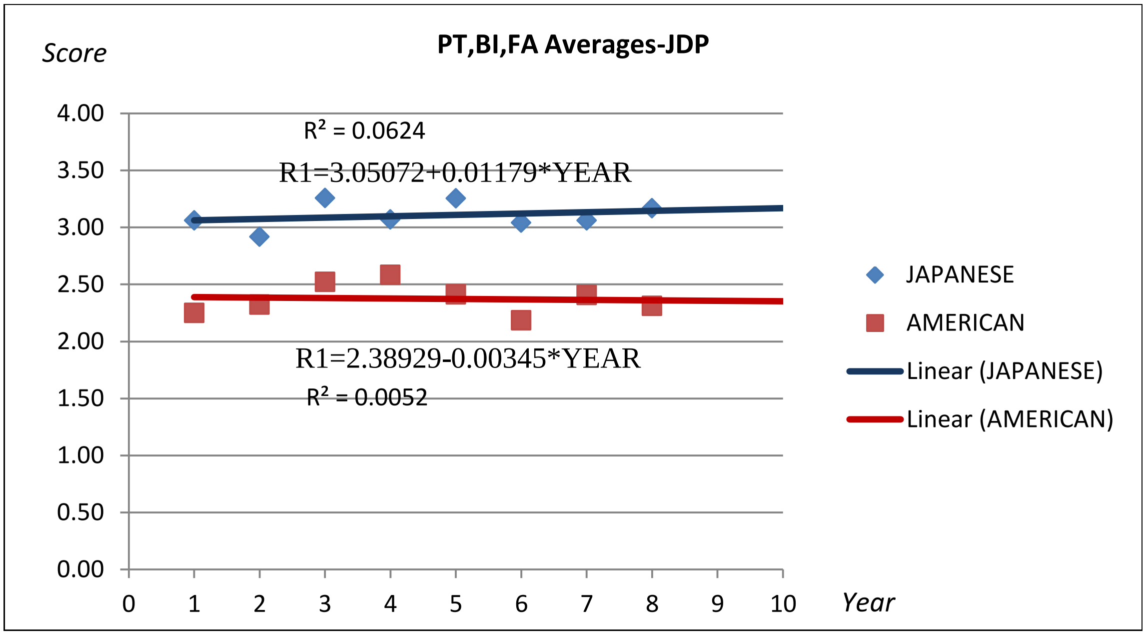

Figure 6.6. Scatter Plot & Fitted Regression Lines for JDP-R1

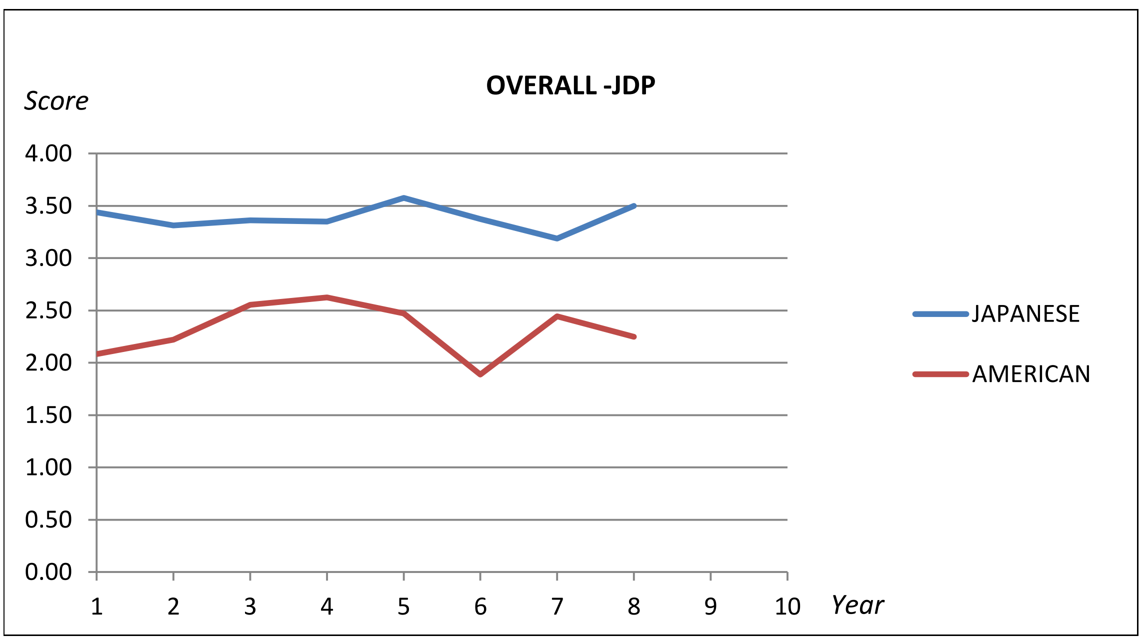

Figure 6.7. American vs. Japanese (OVERALL) Raw Plot-JDP

The lack of consistency for JDP for the two graphs and not for CR might be attributable to the fact that CR ratings had to be brought to the same scale as JDP to make meaningful comparisons. That is, since JDP combined its reliability ratings into fewer groups, and CR has more individual ratings for those groups, CR's corresponding ratings were averaged to come up with a single score that matched JDP's attribute grouping. The regression analysis based on Equation (1) for the data in Figure 6.7. (OVERALL AVERAGE) reveals the following: (i) there is no statistically significant trend in quality when cars of both countries were taken together, and (ii) Japanese cars had better quality at the beginning of the study years and this difference remain statistically the same at the end of the study period. The ANOVA table and parameter estimates are shown in Tables 6.13. to 6.16. Figure 6.8. plots the fitted regression lines along with the equations for the OVERALL data.

Table 6.13. Analysis of Variance, JDP-R2*

Source of Variation	**D.F.**	**Sum of Squares**	**Mean Squares**	**F ratio**	**p-value (α=0.05)****
Model	3	4.59046	1.53015	33.54	<.0001
Error	12	0.54748	0.04562		
Total	15	5.13794			

*R2: Dependent variable representing the OVERALL AVERAGE.
**α=significance level. If p-value is less than α, then the result is statistically significant.

The regression model in this case shows that trends for both Japanese and American makers are not significant. The gap coefficient is negative, however it is very small and not significant.

Table 6.14. Parameter Estimates, JDP-R2

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	2.31107	0.16643	13.89	<.0001
YEAR	1	0.00143	0.03296	0.04	0.9661
COUNTRY	1	1.07179	0.23537	4.55	0.0007
YEARC	1	-0.00011905	0.04661	-0.00	0.9980

*α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.15. Parameter Estimates, JDP-R2-Japanese

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	3.38286	0.10040	33.69	<.0001
YEAR	1	0.00131	0.01988	0.07	0.9496

*α=significance level. If p-value is less than α, then the result is statistically significant.

Table 6.16. Parameter Estimates, JDP-R2-American

Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**p-value (α=0.05)***
Intercept	1	2.31107	0.21288	10.86	<.0001
YEAR	1	0.00143	0.04216	0.03	0.9741

*α=significance level. If p-value is less than α, then the result is statistically significant.

Tables 6.17. and 6.18. provide a summary of the information derived from the trend graphs discussed above. First columns indicate whether the maker is Japanese or American, second columns indicate the trend information coming from CR, third columns indicate whether the results were significant, and finally fourth and fifth columns provide the same information for JDP, respectively.

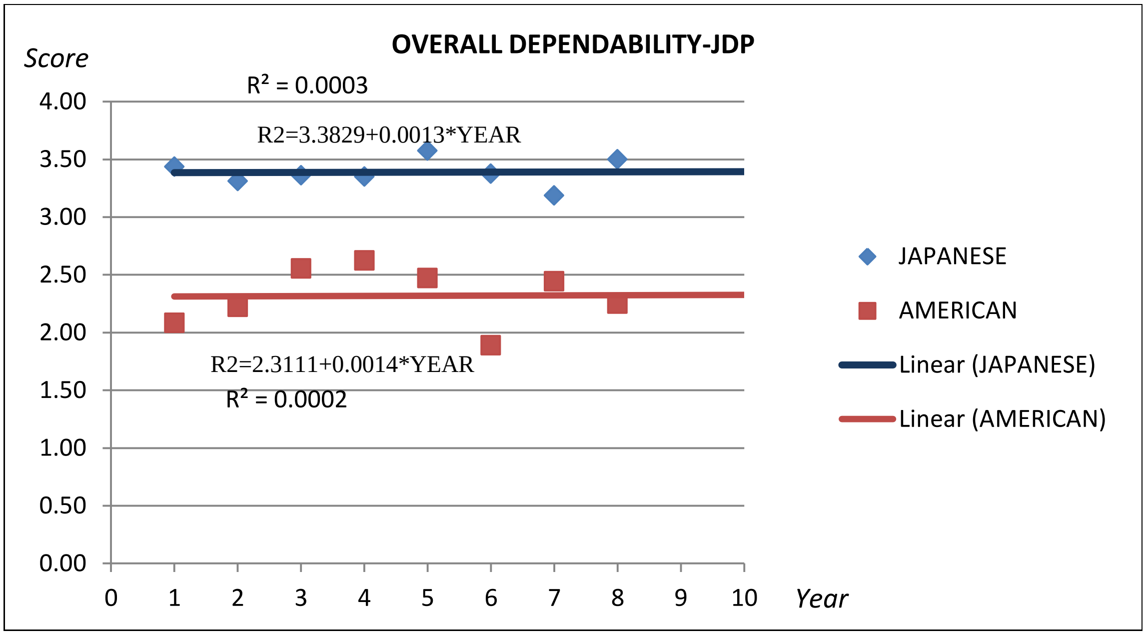

Figure 6.8. Scatter Plot & Fitted Regression Lines for JDP-R2

Table 6.17. Trend Directions for R1 (PT, BI, FA Averages)

	Significance & Direction	
	CR-R1	**JDP-R1**
JAPANESE	Y (+)	N
AMERICAN	Y (+)	N
GAP	Y (-)	N

"+": increasing trend, "-": decreasing trend, statistical significance: "Y": yes, "N": no

CR: The quality rating has a statistically significant increasing trend over the years for both American and Japanese cars. There was a quality gap favoring Japanese cars at the beginning but this gap is decreasing.

JDP: There is no statistically significant trend in quality when cars of both countries were taken together. Japanese cars had better quality at the beginning of the study years and the gap stayed the same.

Table 6.18. Trend Directions for R2 (OVERALL Averages)

	Significance & Direction	
	CR-R2	**JDP-R2**
JAPANESE	Y (-)	N
AMERICAN	N	N
GAP	Y (-)	N

"+": increasing trend, "-": decreasing trend, statistical significance: "Y": yes, "N": no

CR: There is no statistically significant trend in quality for American cars. Japanese cars had better quality at the beginning of the study years. There is a slight but statistically significant decrease in quality for Japanese cars over the years (i.e., a negative trend).

JDP: There is no statistically significant trend in quality when cars of both countries were taken together. Japanese cars had better quality at the beginning of the study years and this difference remains statistically the same at the end of the study period.

7. CONCLUSIONS

7.1. SUMMARY

The overarching goals of this study at the onset were twofold: (1) to determine the relative standing of U.S. automobile manufacturers against their Japanese counterparts in terms of reliability, and (2) to determine if there is consistency between JDP and CR in the reliability ratings of vehicles

At the end of the research and analyses, the results obtained illustrate that the overarching goals of the study were achieved. The first goal was accomplished and comparable information for reliability/dependability emerged for the U.S. Big Three automobile manufacturers and their Japanese counterparts. Korean manufacturers were left out of the study due to the fact that there was not enough rating/score data for those models in order to make meaningful comparisons. However, the results obtained from this research are very illuminating and valuable in terms of showing where the U.S. manufacturers stand against their Japanese counterparts in terms of reliability over a ten-year span. In that regard, this study accomplished its goals in comparing U.S. Big Three and the Japanese manufacturers.

The second goal of the research, to determine if the reliability ratings of the two agencies were consistent, was accomplished. Early on in the study, statistical analyses were conducted to see whether these two agencies' scores matched exactly. This way, it would be possible to use one agency's rating and treat the two of them as one rating source. However, analysis results showed that these two sources could definitely not be substituted for each other in terms of the scores they provided. They were positively correlated, but the correlation was very weak. The graphical final results comparing the American and Japanese manufacturers in terms of PT, BI, FA Averages and OVERALL Averages demonstrate those statistical findings. CR and JDP show some consistency in terms of the score ranges for Japanese and American makers, but do not show the same consistency for trends for the same models selected for comparison. This could be due to many factors including data collection methodology, grouping of the data to be rated, classification of categories, demographics of the raters, and other factors that are not disclosed by the agencies. Overall, this research has accomplished its objectives of comparing the U.S. auto manufacturers with their Asian counterparts; namely the Japanese, and was able to statistically confirm and demonstrate the trends and for the two rating agencies. Further, it was able to answer the question about whether CR and JDP's ratings were in agreement with each other.

This work adds an important intellectual contribution to the body of knowledge surrounding the merits, viability, credibility, and interpretation of systems analyzing consumer products. While answering specific questions about automotive reliability and the comparison of the two most popular systems for assessing that, this work also demonstrates how such approaches have to be carefully analyzed to fully appreciate the meaning of the published results. No previous study has made such an in-depth analysis of such systems that utilize a combination of consumer feedback and independent testing to arrive at conclusions about the products in question. This work clearly shows that drawing such conclusions based on multiple systems is a complicated undertaking and deserves careful consideration.

7.2. FUTURE WORK

It appears on the basis of this research that the two agencies cannot be treated as providing the same rating information; hence future research should focus on areas that were incomparable due to lack of corresponding data from either of these sources. Further, correlations within ratings categories can be explored for each source individually and independently. For example, JDP has a scoring system to determine initial quality. These initial quality scores could be compared with the ten-year reliability scores for the same models to determine whether initial quality scores are predictive of a vehicle's reliability over the long term. Individual attributes can be analyzed separately and thus, areas for improvement can be pinpointed more decisively. Sales figures could be incorporated and the correlation between sales, quality, and reliability information can be obtained. This correlation could provide information on how quality and reliability information provided by these two sources ideally affect sales.

Similar analyses can be done for CR as well. CR has no initial quality ratings, but it conducts its own road tests for new models and experts at their independent test facility evaluate vehicles' performance attributes and report those evaluations on their website. A future study could determine the relationship between a car's road test evaluation results and its ten-year reliability rating. Are road test results indicative of a vehicle's performance over the long term? What kind of relationship is there between these scores and sales figures? This relationship analysis can be extended to safety and crash ratings since CR provides detailed safety results. Do vehicles that rate high on safety rate high on road test and reliability scores as well? The data is already available to conduct these types of analyses and they could be quite illuminating and provide much more detailed information about the relative standing of U.S. automakers compared to their Asian counterparts.

Additional research along the lines discussed above could reveal valuable information that has prescriptive aspects, which in turn, might be useful to automobile manufacturers in terms of diagnosing their problem areas and develop targeted problem-solving strategies. In this research, although I have developed mathematical models for comparing Japanese and American cars, there are factors that cannot be incorporated into this analysis. Factors such as personal preferences and random experiences of customers, and the Warren-Buffet effect of the CEO, etc. are a few examples.

Finally, it should be noted that areas not explored so far are the effect of consumer perceptions of various automobile manufacturers and public announcements concerning recalls and vehicle problems, It would be informative to look for any changes in the consumer responses to the performance of their vehicles following significant announcements about a particular automaker's products. When the success of a company is to be studied or compared, the non-quantitative effects can play a major role.

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VITA

Ozge Senoz earned Bachelor of Science degree in Engineering Management from University of Missouri-Rolla in May 2001 with honors (Magna Cum Laude). She continued to pursue her Master of Science degree in Engineering Management at the same institution and graduated with 4.0 GPA in December 2002.

Various work experiences include assistant manager and strategic consultant duties at the family-owned business in Istanbul, Turkey involving manufacturing and repair of transformers. She then worked at a major Turkish brewery company in Istanbul, Turkey, in 2006-2007 as Supply Chain Planning Specialist.

Ozge Senoz started to work on her Ph.D. degree in Engineering Management and Systems Engineering Department at Missouri University of Science and Technology in 2008. She worked and contributed to a different research project prior to this dissertation research, which encompassed leading research study, entitled "Computationally Intelligent Team Facilitation," to codify circumstances that diminish group performance into a set of rules with interventions for each case to teach team skills to students. Ms. Senoz managed execution of project using a role-play simulation exercise with 400 students.

Research publications include two papers. First one is titled: “An evaluation of professional quality measurement systems for the automotive industry”, published in *International Journal of Engineering, Science and Technology*, vol 3(7), 2011; pp 101-108. Second one is titled: "A Comparative Analysis of Two Popular Quality Measurement Systems in the Automobile Industry", published for the International Annual Conference of the American Society for Engineering Management (2012). Ozge Senoz attended the ASEM 2012 Conference and presented the paper. She is also a member of the American Society for Engineering Management.