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LEANER THAN THOU

Linking Lean Production, DFMA and Production Region in the Automotive Sector

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ABSTRACT:

The Asian (Japanese) Lean production methods won considerable acclaim with the advent of the book "*The Machine That Changed the World*" by Womack, Jones and Roos. Design for Manufacture and Assembly (DFMA) is a Lean tool aimed at reducing the parts usage and assembly time of the product. It is said that the two principles are connected, and that Asian automobile manufacturers are well versed in this tool. It should be possible to test this claim by comparing the service time and parts data of altogether twelve Asian, North American and European cars, on the basis of collision insurance data from 1990-1991.

This thesis will attempt to answer three questions: will Asian cars be Leaner in design than North American and European; will the cars' results be so close for different companies in the same region that something can be said about the region's expertise? And what cars will come out on top and bottom in the test? The analysis involves performing Chi squared tests on the significance of region in using "Lean" assemblies, and visual and qualitative evaluation of the test data.

The results are ambiguous. While the Asian producers show strength in reduced service times – significantly so – the parts count, on the other hand, is dominated by the North American producers. That analysis, however, shows low – if any – statistical significance. Regional cohesion is furthermore visible in service times, not in parts count. Finally, the comparison shows Hyundai Sonata and Ford Taurus heading the service time and parts evaluations, respectively, with Saab 900 and Honda Accord trailing at the other end of the spectrum. The significance of this is unclear: a broader data analysis seems necessary.

KEYWORDS: Lean production, Lean design, DFMA, Design for Manufacture and Assembly, Automotive industry

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ABSTRAKT:

Den asiatiska (japanska) produktionsmetodiken vann stor framgång i och med boken "*The Machine That Changed the World*" av Womack, Jones och Roos. *Design for Manufacture and Assembly* (DFMA) är ett verktyg inom *Lean* (avskalad) produktion som strävar till att reducera en produkts komponentanvändning och monteringstid. Det sägs att de två produktionsfilosofierna är förenade på många punkter, och att de asiatiska bilproducenterna är kunniga i användningen av också detta verktyg. Det borde vara möjligt att pröva detta påstående genom att jämföra data över reparationstider och komponentanvändning i allt som allt tolv asiatiska, nordamerikanska och europeiska bilar, på basen av kollisionsförsäkringsdata från 1990-1991.

Denna avhandlig kommer att försöka finna svaren till tre frågor: kommer de asiatiska bilarna att vara mera *Lean* i sin design än de nordamerikanska och de europeiska; kommer resultaten för olika företags bilar i samma region att var tillräckligt nära för att någonting ska kunna sägas om hela regionens kunnande? Och vilka bilar kommer att visa störst och minst användning av *Lean* -principer is sin design? Analysen består av Chi-kvadrattest på produktionsregionens signifikans för användningen av *Lean*, samt visuell och kvalitativ utvärdering av testdata.

Resultaten är mångtydiga. Medan de asiatiska producenterna visar sin styrka i reducerade reparationstider – till en statistiskt signifikant grad – domineras komponentanvändningsanalysen av de amerikanska företagen. Den analysen, å andra sidan, visar en låg grad av statistisk signifikans. Dessutom är den regionala sammanhållningen bara tydlig i reparationstidsanalysen, inte i komponentanvändningen. Slutligen visar jämförelsen att Hyundai Sonata och Ford Taurus leder respektive klass, med Saab 900 and Honda Accord i andra änden av skalan. Betydelsen av allt detta är oklar: en forstsatt, djupare analys tycks nödvändig.

NYCKELORD: *Lean* produktion, *Lean* design, DFMA, *Design for Manufacture and Assembly*, automobilindustri

1. INTRODUCTION

Ever since the days the industrial revolution, the slogan of the industrial world has been efficiency. Waste not, want not – the idea that has brought us historically unparalleled standards of living, and given rise to the computerised/industrialised society of today. Frederick Winslow Taylor with his well-known studies of production management, and Henry Ford with his mass production visions paved the road for the generations of efficient production management that would follow and build on the concept. The Western world bloomed under these ideas.

But only the Western world? No, the same ideas were eventually adopted by the East, where, with an absolute grasp of effectiveness, even the theory of efficiency was made more efficient. The history of production development does a geographical jump at this time, with the rise of such groundbreaking concepts as the Toyota Production System and Just-in-Time production – and the advent of Lean production thinking.

Lean production – today a broad concept that encompasses thousands of different ways to reach the goal of effective, non-waste production. Lean thinking is not static, nor is it the same thing as the Toyota Production System; it is a way of thinking that has grown and absorbed new theories and tools to stay up-to-date, and as such kept its importance in production management undiminished for many decades.

Toyota and the other Asian car manufacturers are still very good at thinking Lean though. In *The Machine That Changed the World* – the international best-seller production management book – authors James Womack, Daniel Jones, and Daniel Roos showed that Toyota and the Asian car manaufacturers produce cars more efficiently than their North American and European counterparts, and the reason: their all-encompassing way of making their company think and act Lean. Whether or not this is true is debatable, but the the Asian production figures speak for themselves (and have been doing so for a long time). This work is a part of that debate – checking the link between Asian car manufacturers' Lean thinking and the concept of Lean design, and Design for Manufacture and Assembly.

Design for Manufacture and Assembly (or Design for Manufacture *and* Design for Assembly) are concepts that lie at the base of Lean design. Making a product using fewer and simpler parts (Design for Manufacture) and making a product that requires fewer assembly operations (Design for Assembly) is a basic step in eliminating process and material waste; a Lean production tool. So basic that it should be standard practise in every truly Lean company, right?

That is the question. The aim of this work will be to study the Lean-ness of car design: based on objective service time and parts data that insurance companies use to estimate collision damage costs, it should be possible to see whether some cars are more sparing in their use of parts, and less time-consuming to service (a proxy for assembly time efficiency).

While this will almost certainly the be case, the point of interest in this data will rather be this: will Asian cars be Leaner in design, considering their expertise in the field of Lean production? Will the cars' results be so close for different companies in the same region that something can be said about the region's expertise? And what cars will in fact come out on top and bottom in the test? The answers to these questions will hopefully be provided by comparison and suitable analysis of the data.

The structure of the work will be simple – chapter two will give more background to Lean production: history, key points and development over time. Also the theory around Design for Manufacture and Design for Assembly will be elaborated upon, and finally some thoughts around the Asian success in Lean production will be discussed. Chapter three, in turn, will contain the data collection and analysis, detailing what methods were used to perform the data and analysis tool selection. The final chapter will cap off the work with discussion on the accuracy and validity of the results, and state any conclusions that can be made from the analysis.

2. THE LEAN CONCEPT AND CAR

In this section we acquaint ourselves with the theory behind the research: the origins of Lean Production, through the Toyota Production System to the eventual internationalisation and spread of the Lean concept. After this, a brief summary of the design tool Design for Manufacture and Assembly (DFMA), and its relevancy to Lean design, capped off by a more in-depth look at the regional aspects of Lean success. The aim of this section is to provide the basis for the assumptions we make before starting the data analysis; that the Asian car manufacturers show mastery of Lean production and that Lean production excellence is closely linked with proficiency in DFMA.

2.1. The history and development of Lean thinking

The beginning

The first steps on the path to Lean production were taken with the advent of mass production in the automotive sector: Ford Motor Company under the leadership of Henry Ford. The 1908 model T-Ford was the result of several ground-breaking innovations. Womack, Jones and Roos (1990: 26-38) start their own illustration of the history of Lean by pinpointing that the most major strength of the mass production system was not the famous assembly line itself (even though that certainly made a huge difference from former tradition) but rather the complete inter-changeability of the parts themselves, and the easy way they could be assembled. This meant a clear step away from the crafts-based production methods prevalent at the time, where almost all car components had to be machined and fitted individually; making each car more or less unique.

Ford's further improvements to the process – delivering all parts of a car to the assembly station in advance, making each worker responsible for a single task (the most time-saving change) and moving the car instead of the worker – were tangible advances that proved the basis for vast success, but everything builds on the interchangeable parts concept (Womack et al 1990: 27-28). Combined, these best practices of their time were enough to boost Ford Motor Company past anything the other automotive companies could achieve. In 1913 the Model T production began at Ford's famous Highland Park, Michigan, improving chassis assembly speed from 12 hours and eight minutes to one hour and 33 minutes (Ford 2008). In 1914, Ford produced 308,162 cars, more than all other automakers combined. And production would continue with only very minor modifications until the mid-twenties when production was halted in 1927. After having produced more than 15 million units, that is (Ford 2008).

The best production practises of Ford Motor Co. (and the best business organisation practises of General Motors under Alfred Sloan, see Womack at al (1990: 39-43)) were to become the blueprint for success in the automotive industry during the following decades. The production system was copied without greater alterations in Europe, before and after the Second World War. It is at this point in time that the Japanese paradigm change gets its first humble beginnings in Toyoda Automatic Loom Works, Ltd, under the owner Sakichi Toyoda’s son Kiichiro Toyoda. Kiichiro, who has visited the Ford Plants in 1929, was to become the first leader of the Automobile Department of Toyoda Automatic Loom Works (Toyota 2008). Kiichiro Toyoda had seen that automobile production was the way to go, but, had also seen that the mass production practises of Ford Motor Company and the other Western producers were not the way to go.

The Japanese business climate of the time and the financial situation of the company itself did not easily lend themselves to mass production – a small domestic market, a “proud” workforce unsuitable for tedious work and cyclical recruitment practises, no available “guest workers”, a lack of Japanese capital and an abundance of aggressive foreign firms ready to move in on the Japanese markets (Womack 1990: 49-50). Because of this, new solutions had to be found. Lean solutions, in fact.

The Toyota Production System

And this is where it all began at Toyota (renamed so in 1936)(Toyota 2008). During a depression in the late 1940:s Toyota faced economic hardships and labour strikes, a situation that did not resolve until Kiichiro Toyoda resigned in favour of his nephew Eiji Toyoda. (Womack et al 1980: 48-49) Eiji, together with his today famous production engineer Taiichi Ohno, concluded that to reach success in the automotive industry Toyota would have to do things in a significantly different way from its competitors; partially because of social and financial constraints, partially because there could be winnings to be made from new approaches (Holweg 2006: 422).

Taiichi Ohno correctly gauged the depth of the company's money coffers and concluded that they could not afford to buy hundreds of metal stamping machines to produce the components of the car's steel structure in the same way that Ford did. Instead Ohno decided to focus on a few different machines but make sure that the stamping dies (stamping templates) were easy to change. (Womack et al 1990: 52-53.) This to correct the two flaws he perceived in the Ford production system: a) by using big production batches large inventories build up, with a high number of defects and b) there is no room for product diversity (Holweg 2006: 422). The perfection of this small-batch system – eventually resulting in the Single-Minute-Exchange-of-Die program much later – led to the revolutionary discovery of a sort of reverse economies-of-scale, a Leaner production system.

On the shop-floor level, one of the first and most innovative changes implemented to the production norm, was the ability of any worker to halt the production line to avoid lapses in quality to propagate down the line, where correcting the mistake would be more costly and time-consuming (Womack et al 1990: 55-57). While this custom resulted in many stops in the beginning, the long run result was a smoother production line where initial problems had been closely pinpointed and eliminated. The workers were also introduced to the concept of quality control circles (QC circles), where they could and should discuss process development in a group, thus including the workers in the day-to-day decision-making of the production plant. This led to many gradual, small-scale improvement suggestions being brought forward and implemented, achieving what we know today as continuous improvement (or Kaizen), a hot tool within Lean production (Monden 1983: 126-130).

These few changes eventually established the base of Toyota's success, but the Toyota Production system spans much more. In figure 1, we can see a sketch of the different focus areas and production tools that make up the somewhat more modern Toyota Production System (Monden 1983: 3) These are numerous and each deserves a fair explanation, but the original book by Yasuhiro Monden is absolutely best for this task (see also Ohno, Taiichi (1995), *Toyota Production System: Beyond Large-scale Production* and Shingo, Shigeo (1989*) A Study of the Toyota Production System from an Industrial Engineering Viewpoint*) However, a few points on this chart are interesting enough to elaborate on.

First of all, we can see that the basis for this process is put as "*Improvement activities by small groups*" – that is, continuous improvement. This is apparent in many of the middle activities, which are based heavily on the whole-hearted participation and motivation of the workers. How this motivation is achieved is debated – some say that the reasons are relatively culture specific or even enforced (life-time employment and a seniority based wage system in the former case, peer pressure and shaming in the latter (Womack 1990: 53-53; Bornfelt 2008; Kimura 1998). But the fact of the matter is that Lean principles have been successfully moved to other countries, and motivation sought by straight-forward methods: by inspiring company and product pride, instilling team spirit and offering monetary rewards (Monden 1983: 126-130; Womack 1990: 79-80).

Secondly, standardisation of work. This not only in on the shop floor, but in the management and product development structures too – the Toyota production system strives to standardize product design, processes and skills. Design standards are sought by extensive usage of development checklists, and parameter-led development. Simple tools, but surprisingly effective. Skill standardisation is sought through intensive basic training, not for reasons of interchangeability, but rather to smooth out the flow of communication. This is only a part of the story, since Toyota is also said to encourage worker to develop "towering knowledge" in their field (Morgan & Liker 2006: 169-174) but

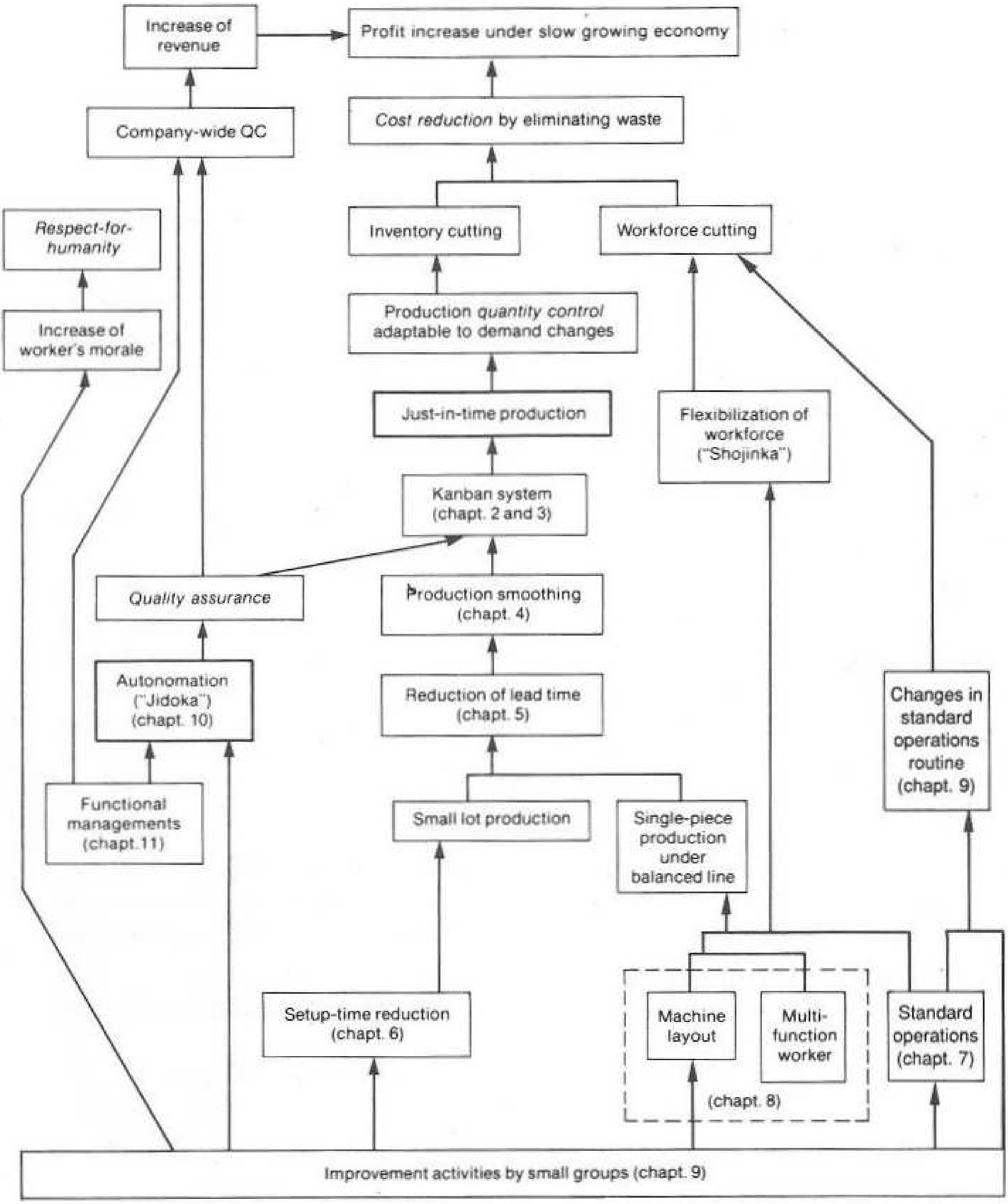


Figure 1. Focus areas and production tools of the Toyota Production System (Monden 1983: 3).

the common skills that are needed to successfully work projects together – understanding of sales-related work, the ability to write technical reports in the standardised format, etc. – are necessary for the fast-paced product development and manufacturing practises of the Toyota Production System (Morgan & Liker 2006: 100-113).

The next link is visual management. In Monden's chart, this is perhaps best embodied by the Kanban system. Kanban – the system of cards and "shopping carts" that induces the production to order/shop their parts from the previous section of production, where these parts are made on demand. This allows the system to implement the switch from push production to pull (Monden 1983: 14-28). This is of course a terribly shallow way to describe the phenomenon, but better explanations are available in abundance elsewhere, in other works. But the fact remains that visual, simple production management tools have shown themselves to be a very dependable way to guide the production, and the Kanban system itself has resulted in many positive effects; reduction of unnecessary inventory, identification of bottlenecks and the shortening of lead times are only a few of the examples (Monden 1983: 34).

This leads us neatly to the next concept, Just-In-Time production and the establishment of Takt-time in the production flow. Just-In-Time production means just that: that parts are used when they are needed, and that there should be no need for expensive inventory of components, nor of finished products (Shingo 1984: 92). By stripping away the safety-net of intermediate warehouses and inventory, all flaws and kinks in the production line are cruelly exposed. However, when these are eventually straightened out, true flow becomes possible (Womack 1990: 54-55). To further this flow, the Takt-time concept was introduced. The Japanese Takt-time has its roots in studies of a German Focke-Wulf aircraft plant, and the German "Produktionstakt" (Holweg 2006: 421). This was one of Taiichi Ohno's most long-term visions, one that he energetically worked to implement for the better part of twenty years – by making all assembly sub-stations work towards completing their work cycle in sync with the Takt-time, the whole production plant would eventually be able to flow to one beat. This system of course required considerable adjustments: a very flexible and multi-skilled workforce, that was willing to accept changes in their routines and workplace, coupled with the implementation of flexible work cells with room for more workers.

Taiichi Ohno is said to have considered Just-In-Time production one of the two legs upon which Toyota built its success. The other was their successful use of automated production. There is some debate over where the Toyota Production System stands on the workforce size issue – some say that the system suggests lay-offs due to automation and effectivization are inevitable and not unwanted, while yet others say that Toyota as a company has always preferred workers to machines due to their greater flexibility in terms of workplace arrangement and capital tie-down (Womack 1990: 102; Bornfelt 2008;). "Autonomation" is nevertheless an important aspect of the Toyota Production System. Autonomation, because the automation is not supposed to be unthinking – rather it should actively, constantly check its own results, and alert the workers whenever an error arises, thus freeing the worker to focus only on the abnormal, where his skills are necessary, and not on the standard, every-day issues. (Shingo 1984: 93-95). This may sound commonplace today, but the great degree of automatic handling of parts and materials that Toyota adopted, was – at the time they started to achieve their fame in the world – very radical.

Returning to Monden's chart in figure one, we can see that what remains at the top is the target of the improvement flow: "Profit increase under slow growing economy" by "Cost reduction *by eliminating waste*". The hunt for waste, or *muda* in Japanese, is often said to be the final aim and identification tag of all Lean activities. The Toyota Production System under Taiichi Ohno identified seven forms of waste, known simply as "the seven wastes", as a tool to identify further *muda* to be eliminated. The seven wastes are: 1. Overproduction, 2. Waiting, 3. Transport, 4. Inappropriate processing, 5. Unnecessary inventory, 6. Unnecessary/Excess motion, 7. Defects. (McBride 2003, Morgan&Liker 2006: 72). Womack and Jones (1996: 15, 314) further identify number eight: products designed to not meet the customer's needs.

Morgan and Liker (2006: 74-75) also stress the fact that the Toyota Production System today identifies not only one concept of waste, but three – Muda (non-value-added), which encompasses the original seven wastes; Muri (overburdening), which is the concept of pushing a machine of person beyond their natural limits; and Mura (unevenness), which stands for irregularity in the work-load and -schedules.

Taking a step back and reviewing what we have just seen about the Toyota Production System, it is clear that what has been done over the decades since the Second World Was is, in fact, the development of a whole new way of thinking about production. It is a mindset that has been allowed to simmer and constantly change in small steps since the beginning. And this culture, distilled into the principles of the Toyota Way (presented further below in table one) has certainly had the power to bring about impressive production results. The bottom line is that all forms of unnecessary and non-value-adding activity are frowned upon under the Toyota Production System, and that by constant attention to details, this has led to effective production unmatched. The system could wring water from even a dry towel, as Shingo (1984: 102) so succinctly puts it.

The modern Lean production system

Now we move on forward to today's definition of Lean production. But anyone studying the concept of Lean will soon realize that that the line between Lean production and the Toyota Production System is not altogether clear-cut; many of the practises described earlier are key elements of Lean production too. Drawing a line between the two might in fact seem like an attempt to draw a line in water.

However, there are certain points that serve to distinguish them. The first is the realization that the Toyota Production system is less of a system and more of a culture that has been allowed to grow forth over a stretch of several decades. The improvements that Toyota have been implementing, have been *kaizen* improvements – continuous. This leads to the fact that the improvement path of the Toyota Production System was never clearly documented, and no attempts were really made to systematize the development into a theoretical work before the world's interest in the Kanban system was piqued in the early seventies (Holweg 2007: 423).

Even Taiichi Ohno says in the foreword of Monden's book:

> *"since the Toyota production system has been created from actual practises in the factories of Toyota it has a strong feature of emphasizing practical effects, and actual practice and implementations over theoretical analysis. As a result it was our observation that even in Japan it was difficult for the people of outside companies to understand our system; still less was it possible for the foreign people to understand it (*Monden 1983: i*)".*

Because of this, Lean production can be said to be the Western world's (or simply the world outside of Toyota) attempt to make systematic use of the practises of the Toyota Production System, and continue to develop on the basis of these practises.

MIT steps into the game

This was the partial aim of the MIT international collaboration research program, the International Motor Vehicle Program, which got its start in 1979 as a 5-year research program entitled "The Future of the Automobile", led by Daniel Roos (the director of the Center for Transportation Studies) and Alan Altshuler (the head of the political science department at MIT). Daniel Jones, signed on as UK team leader and later European director of the second phase of the programme. The program's main focus was to research the role of the automobile in the future. The program, in addition to other offshoots, resulted in a work of conclusion "The Future of the Automobile" in 1984.

The second phase of the programme was led by research director James Womack. As a part of the IMVP's task to increase international discussion on the development of the automobile and its industry, conferences were held annually to gather researchers and industry people in the same setting. And one of the most burning issues of the eighties was the continuous loss of the American Big Three's (GM, Ford and Chrysler) market share to Japanese car manufacturers. The discussion naturally centred on one question: what is the driving force behind the Japanese competitive advantage? (Holweg 1997: 423-424.)

Various explanations were conceived, many of which relatively hostile: cost advantage in wages; "Japan, Inc" (or the orchestration of Japan's industrial policy by MITI, the Japanese Ministry of International Trade and Industry); cultural differences; technological espionage and trade barriers (Womack 1990: 236; Holweg 1997: 424). However, eventually, more attention was given to the study of the Japanese production solutions. The IMVP set out to describe the productivity gap between the Western World and Japan, and to measure its extent. A benchmarking methodology was developed by Womack and Jones during the mid-eighties, but the empirical side of the research would remain spare until another researcher joined the group: John Krafcik.

Krafcik was a quality engineer in the Toyota – General Motors joint venture plant NUMMI (or New United Motor Manufacturing Inc), in California before he came to MIT for MBA studies (Cusumano&Nobeka 1998: 4, 219). Together Womack and Krafcik started visiting and compiling data from initially four auto assembly plants. Krafcik presented its key learning at the annual forum:

> *"NUMMI, within its first year of operation, had achieved a productivity level more than 50% higher than that of the technologically similar [GM Massachusetts] Framingham plant, and achieved the best quality within GM's entire U.S operation. " (*Holweg 1997: 425-426*)*

Krafcik continued to gather data for his master's thesis – a total of ninety auto assembly plants in a fifteen countries visited – and finalized his output with the 1988 article "Triumph of the Lean Production System," where the term "Lean production" was first used (Womack 1990: 5-6).

The continuation of the assembly plant study over several years, and the addition of more plant data reached a sort of culmination in the now world famous book "*The Machine That Changed the World*" by Womack, Jones and Roos. It can reasonably be argued that by the time the book was published in 1990, knowledge of Just-In-Time and the Toyota Production System was already internationally available. However, one of the greatest benefits of the book was that it opened the eyes of wider public towards the possibility of Lean production, and showed those who did know about it before the importance of treating the whole logistic and management system with Lean thinking – not just the manufacturing sections.

For more information of the history and development of Lean production theory, see figure twelve in appendix one. It features a concise summary of the milestones of the development of Lean theory, assembled by Holweg. This gives us a good idea on timeline involved, and shows what other authors have contributed to the area of the research.

Differences between Lean and TPS

The question remains, though. What, if any, are then the actual differences between today's Lean production methodology and today's Toyota Production System, if the former was clearly based on the latter? Very few things, in fact. On a general level, one can say that Lean Production has ever been more focused on the implementation of specific tools, while the Toyota Production system has focused more on teaching through their philosophy, the Toyota Way. This is a quite natural outcome, since Toyota thinks of their system as a whole, developed through incremental improvement. Lean production, on the other hand, is the attempt to introduce an action plan intending to bring other companies up to and even beyond the level of Toyota. These differences can be seen as a sort of cultural difference: the impatience of the western business leaders to get something done, something visible, versus the eastern long term commitment attitude. Lean Production is simply said to be an easier concept to grasp by the western mind.

Kochnev's (2007) study of literature on the Toyota Production System and Lean production focuses on bringing the differences into contrast. On each of the 14 Business Principles of the Toyota Way (see table 1 below) as depicted in Jeffery Liker's book "The Toyota way" (2004), he investigates what points are treated the most differently in Lean production, in books and literature.

Table 1. The business principles of the Toyota Way. (Liker 2004: 24)

1 Base your management decisions on a long-term philosophy, even at the expense of short- term financial goals.
2 Create continuous process flow to bring problems to surface.
3 Use "Pull" systems to avoid overproduction.
4 Level out the work load.
5 Build a culture of stopping to fix problems, to get quality right the first time.
6 Standardized tasks are the foundation for continuous improvement and employee empowerment.
7 Use visual controls so no problems are hidden.
8 Use only reliable, thoroughly tested technology that serves your people and processes.
9 Grow leaders who thoroughly understand the work, live the philosophy and teach it to others.
10 Develop exceptional people and teams who follow your company's philosophy.
11 Respect your extended network of partners and suppliers by challenging them and helping them improve.
12 Go and see for yourself to thoroughly understand the situation.
13 Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.
14 Become a learning organization through relentless reflection and continuous improvement.

Kochnev’s conclusion is that principles 1, 4, 8, 9, 11 and 13 are not reflected in Lean production methodology, or are at least depicted in a significantly different way. Again, we see that the differences that stand out most clearly lie in planning horizon and individualism; something also inherent n the different cultures that spawned the philosophies. Thus principles number one and nine are not easily implemented in the western business firm because of difference in time frame, and we can see eastern conservatism and consensus-thinking in principles eight and thirteen.

The two remaining principle differences are more general, more moderate. Levelling work load is a more stressed sector of improvement in the Toyota Production System, implementing the Takt-time concept; Lean Just-in time does not necessary put as much focus on this issue. And supply management – as Kochnev himself puts it:

> *"[Lean methodology is] more focused on the mechanics of the supply-chain, while The Toyota Way is more concerned with partnering for success with its suppliers and helping them improve by sharing and teaching the TPS principles."*

Be his how it may, in the end one is forced to concede that the differences between the two systems are quite few and quite indistinct. However, the most important thing is perhaps not to focus on the differences, but rather to realize that the aim is the same under both systems: the reduction of waste in all its forms. It is only natural to conclude then, that they share many of the methods that have been seen to get the job done, regardless of origin.

2.2. Design for Manufacture and Assembly

As we saw in the previous section, Lean production can be thought of as a collected wealth of improvement tools; tools aimed at problem solving and improvement. In this work we will focus more specifically on one of these aspects of Lean production: Design for Manufacture and Assembly, or DFMA for short. It is such a basic Lean effort, that it is often overshadowed by more new-fangled and overwhelming initiatives, but it is nevertheless a concept that can tangibly reduce both material waste and process imperfections.

Design for Manufacture and Assembly is a combination term, using Design for Manufacture and Design for Assembly together. The two terms are similar, but not exactly the same. Design for Manufacture means changing a product design to reduce parts count and thus the cost of manufacturing, while at the same time keeping the original product function intact. Design for Assembly, on the other hand, means changing a product design to reduce the cost of assembly. This involves designing for fewer assembly steps, faster methods, shaping components differently, etc. (Shipulski 2008.) Using fewer parts and faster processes is Lean thinking in its essence.

Design for Manufacture is a concept that was developed earlier than Design for Assembly, if in fact one can say that it was developed at all. Henry Ford is said to have initiated the concept, even though it was not know as such at the time – it was simply common sense. According to him, a manufacturer should always study what all is absolutely relevant for the product and eliminate the useless parts completely. This concept should apply to any object on its way to the shop floor, irrespective of its size and value (Rygler 2007).

Design for Assembly on the other hand got its beginning in the late 1950's and early 1960's, when companies started to realize that the current design methods were inadequate for the new style of automated manufacturing. Especially robotic manufacturing systems required the manufacturers to start seeing the assembly process in a new way. (Causey 1999: 222) One of the earliest works on the topic was General Electric's "*The Manufacturing Producibility Handbook*". The development continued in different companies all throughout the seventies and eighties and eventually many of the rules for correct conduct were quantified and programmed into computers programs for automated analysis of designs. Through the nineties, more emphasis went into designing not only for manufacture, but for all later aspect of the product, such as service, repair, disassembly and recyclability (Causey 1999: 223).

The original method was strictly verbal; a general set of rules or guidelines that required a human to interpret and design differently for each specific case. The second wave represented a more quantitative approach. (Stone, McAdams & Kayyalethekkel: 2004: 303.) Boothroyd and Dewhurst's "*Design for Assembly: A Designer's Handbook*" from 1983 is perhaps the best known work of that methodology, even though the "Assemblability evaluation method" (AEM) by Hitachi is said to have come out a little earlier (see Ohashi T. et al. (1983). *The automatic assembly line for VTR mechanisms*) The Boothroyd Dewhurst, Inc. company is the owner of the ''DFMA'' trademark, presently.

The Boothroyd and Dewhurst method originally assigned each part of the design with a numeric value depending on its manufacturability. The numbers are summed for the entire design and the resulting value is used as a guide to the overall quality of the design. After this, the product is redesigned, using the numerical values as an indicator of where to redesign the most. (Stone et al. 2004: 303.) This is still a method that requires much insight into design and knowledge of alternatives by the designer, however.

These approaches eventually evolved into today's modern methodology, in which the entire process is fully automated. By building an expert system using the general design rules, the program can be made to analyse a design and optimise it by repeatedly iterating the design according to the rules. (Stone et al. 2004: 303.) This approach is still a field of active research, however, as the process is difficult and inherently qualitative – not the type a machine can easily be made to understand.

General guidelines

Causey (1999: 226-229) presents some of the basic rules on how Design for Manufacture and Assembly should be implemented, for the use with a automated robot assembly line, similar to that of an automotive industry producer (also see Rampersad (1996: 14) and Edwards (2002: 654-656) for further sets of instructions). They are presented here as an example of the principles that guide the redesign process, to illustrate which type of changes the DFMA may produce.

1. *Use snap fits rather than threaded fits*. Screwing and nut or a screw is a time-consuming process, even to a robot. And if the robot cannot perform an unlimited amount of rotations, it will have to release and regrip the screw several times, adding time to the operation. Also, the possibility of threading the screw wrong is likely, resulting in a scrapped piece. This adds time to the operation and increases the waste potential of the process.

2. *Minimize assembly forces*. If large force is required to assemble parts then dedicated assembly machinery may be necessary. Since most robots are only

capable of relatively small force (using electric motivators) this means that the robot will have to hand off the part and move out of the way while the dedicated machine is used. More time is required for the operation and more opportunities for part error arise.

3. *Design generous tolerances*. When less precision is necessary when assembling, reliability is increased. Assembly robots are often less precise than dedicated machinery. A guidance structure (chamfer) will make the structure more tolerant to the robot's imperfect aim.

4. *Design smooth gripping surfaces*. This will allow the gripper to correct any misalignment of the part when it retrieves it. Parts with serrated edges will easily hang on to the edges of the gripper jaws rather than finding its right alignment.

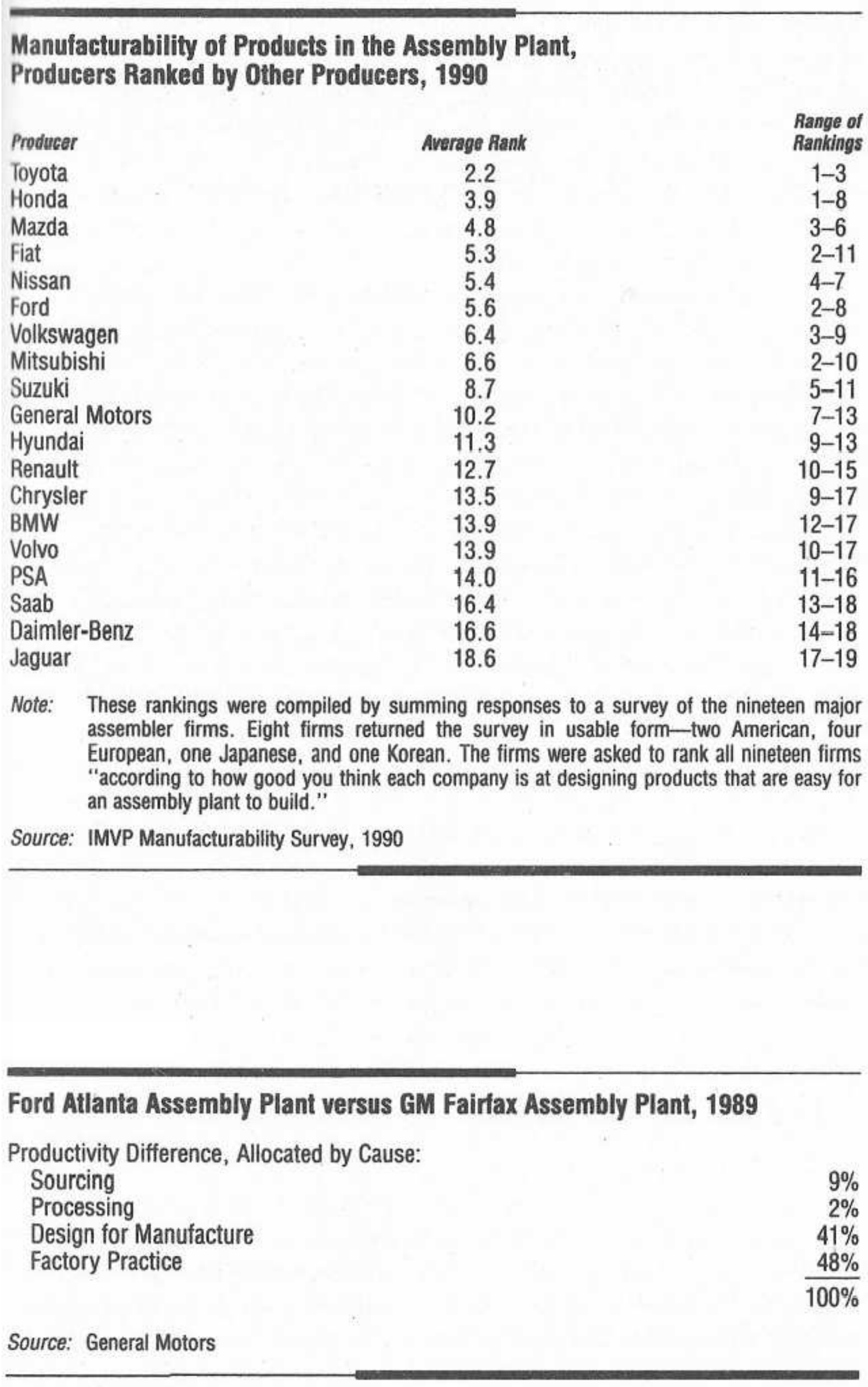
5. *Design for vertical assembly*. It is easier and quicker to assemble components by stacking them on than by any other motion. Moving through many different motions and directions is generally slower than a single dimension move only. By designing with this in mind, a tangible increase in the assembly speed can be realized. See also Rampersad (1996: 9-11)

6. *Minimize assembly component count*. The original principle of Design for Manufacture. Designs with a minimum number of components reduce the number of tools and feeders required. A simpler product is a more reliable product plus cheaper, faster to produce and faster to assemble.

7. *Design parts and grippers together*. This way the gripper can be made to handle more than one type of part, so that a minimum number of grippers are needed for any given assembly. In addition, gripper and component material can be matched to improve the security of grip and reliability of the system.

DFMA and the Asian car manufacturers

Leaving the theory aside for a moment, we can ask ourselves why this specific tool – DFMA – is so relevant to this study of Lean production. The answer is: because the Asian car companies are said to be good at it. In "*The Machine That Changed the World*" Womack et al. (1990: 96-97) present the results of an IMVP survey where car manufacturers were asked to rank each other in terms of manufacturability. They should know, it is argued, since car manufacturers regularly purchase and disassemble competitor's cars, looking for innovations and other interesting features. From the survey result, presented in figure two, we can see two things: as the lower figure shows, Design for Manufacture is a tangible part of the effective running of a automotive production plant, and in addition we can see that Toyota, Honda and Mazda (all Japanese automakers) rank the top three in perceived manufacturability. Interesting results, but this is of course something that we will investigate more closely further on in the work.



Manufacturability of Products in the Assembly Plant, Producers Ranked by Other Producers, 1990

Producer	*Average Rank*	*Range of Rankings*
Toyota	2.2	1–3
Honda	3.9	1–8
Mazda	4.8	3–6
Fiat	5.3	2–11
Nissan	5.4	4–7
Ford	5.6	2–8
Volkswagen	6.4	3–9
Mitsubishi	6.6	2–10
Suzuki	8.7	5–11
General Motors	10.2	7–13
Hyundai	11.3	9–13
Renault	12.7	10–15
Chrysler	13.5	9–17
BMW	13.9	12–17
Volvo	13.9	10–17
PSA	14.0	11–16
Saab	16.4	13–18
Daimler-Benz	16.6	14–18
Jaguar	18.6	17–19

Note: These rankings were compiled by summing responses to a survey of the nineteen major assembler firms. Eight firms returned the survey in usable form—two American, four European, one Japanese, and one Korean. The firms were asked to rank all nineteen firms "according to how good you think each company is at designing products that are easy for an assembly plant to build."

Source: IMVP Manufacturability Survey, 1990

Ford Atlanta Assembly Plant versus GM Fairfax Assembly Plant, 1989

Productivity Difference, Allocated by Cause:	
Sourcing	9%
Processing	2%
Design for Manufacture	41%
Factory Practice	48%
	100%

Source: General Motors

Figure 2. Results of the IMPV Manufacturability survey 1990 (Womack et al. 1990: 96-97).

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2.3. Asian car manufacturers and Lean production

Now, considering the fact that we have so far mostly talked about Toyota, it is advisable to take a step back and look at the bigger picture. What are the regional implications of what we have studied? What success did the other Asian car producers achieve, and what happened to the European brands? In this section we will study the production regions as a whole, and see what trends have been at work the last few decades.

The other Asian car manufacturers

In general, the literature on Lean production makes two simplifications when talking about region and produce. When speaking about Toyota, the term "Japanese auto manufacturers" in plural is used quite casually. Furthermore, "Asia" is mostly used synonymously with Japan.

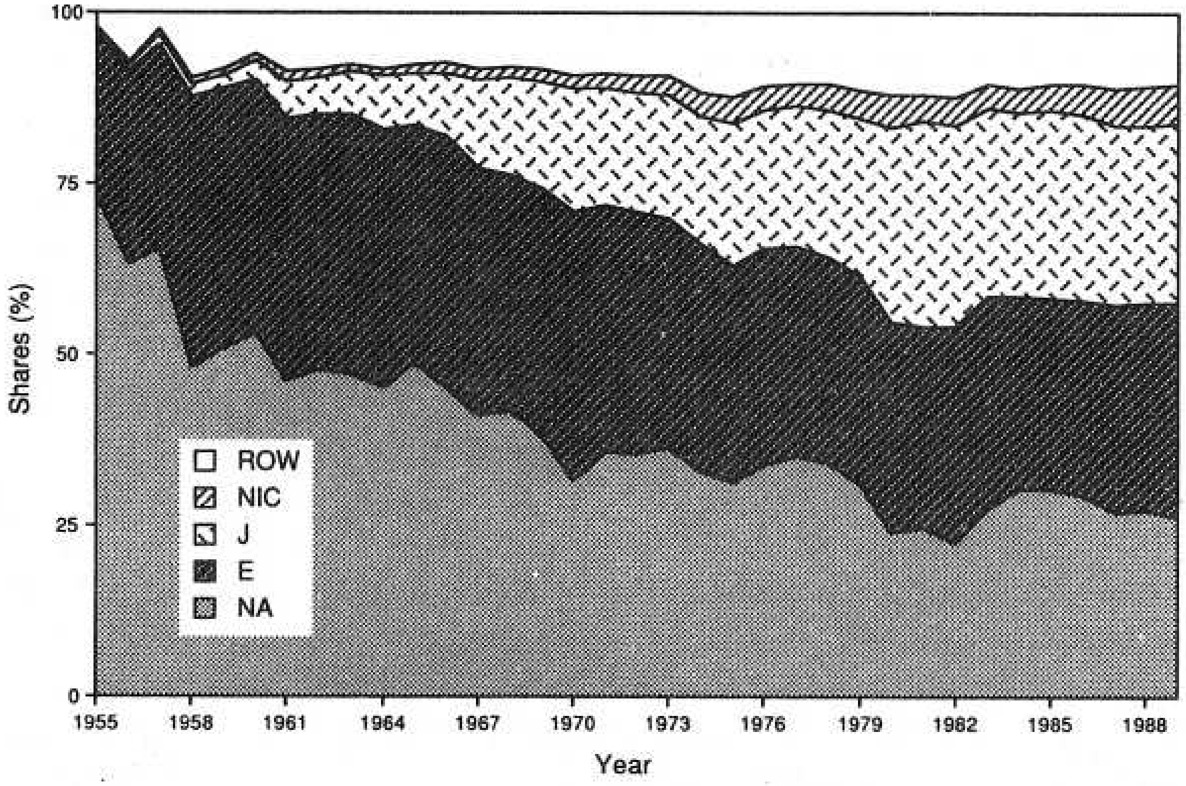
There is of course a certain basis for this custom. As Michael Cusamo writes in his text *"Japanese Technology Management: Innovations, Transferability, and the Limitations of "Lean" Production"* (1992), the nine major Japanese automakers absorbed the Lean production principles soon – a loose period of time from the 1960's to the first half of the 1970's. Thus they were able to use their skills in manufacture and product development to aggressively expand from the late 1970's forward. Toyota led the way, accompanied by Honda, said to have had a comparative advantage in its product development processes (Womack 1990: 109-112). Honda continues to be a strong product developer even today, and a entire chapter could well have been dedicated here to Honda's best product development practises..

It should not be assumed that the Japanese automakers all took exactly the same path forward, however; by natural reasons the companies adapted the best practises to fit their own company. For instance, Honda, having a more dispersed factory network than Toyota, experienced traffic and rush-hour problems that disrupted their Just-In-Time system, forcing them to keep somewhat larger stocks of inventory than their Toyota counterpart. (Cusamo 1992.) Furthermore, it should not be said that all Japanese companies are equally skilled in Lean production. Some have more Lean production mentality than others, while others have kept more of the traditional mass production philosophy intact.

As for the other Asian countries, there are not many stories of success outside of Japan. Womack et al (1990: 261-263) use South Korea's Hyundai as an example of the situation in the newly developing Southeast Asian countries, at the time. Making only cheap, low quality trucks sold mainly to other developing countries on price alone, the Korean government saw their chance for change in the economic crisis of 1979. Japanese exports had grown somewhat dearer, and the Korean government seized on the chance to capitalize on their own lower wage rates. They started an extensive mass production program of a basically Japanese design car model (the Hyundai Excel), and succeeded very well in their endeavour – at first. Initially, the Hyundai Excel made substantial export sales. But only two years later the Korean currency started to appreciate, worker's wage demands started rising. This quickly ate up the only production advantage the Korean's had, and when prices started to converge, the poor quality of the Korean output started to show. Furthermore, Japan's initial aggressive exports strategy had already made the rest of the world touchy about cheap foreign imports, making Korea's continued success even harder.

So all in all, one can be excused for thinking that Japan's other automakers are similar to Toyota (at least in varying degree) and that the other Asian countries were not as successful in their production practises. Furthermore, as we can see in figure three, Japan was (and is) certainly in a class of its own when considering world share of motor vehicle production. The other Asian countries (mainly China and Korea) are included in two other categories: Newly Industrializing Countries and Rest Of World. These shares of world production are, however, marginal at best, and not showing very substantial growth with time. Japan, on the other hand, increased its market share from zero to approximately 25 percent of the world production over a scope of 30 years. It is interesting to notice, also, that their gain was clearly North America's loss (at least when considering production figures). And finally, the Europeans? As we can see, their production figures have remained remarkably unchanged throughout the entire period – a curious stability in the face of the Japanese expansion. Are European car producers also masters of Lean production?

Shares of World Motor Vehicle Production by Region, 1955–1989



Note: This figure includes all vehicles produced within the three major regions, by all companies operating in those regions. In addition, it groups the production of the newly industrializing countries and of the rest of the world.

NA = North America: United States and Canada
E = Western Europe, including Scandinavia
J = Japan
NIC = Newly industrializing countries, principally Korea, Brazil, and Mexico
ROW = Rest of the world, including the Soviet Union, Eastern Europe, and China

Source: Calculated by the authors from *Automotive News Market Data Book*, 1990 edition, p. 3.

Figure 3. Shares of World Motor Vehicle Production by Region, 1955-1989 (Womack et al 1990: 44).

The European car manufacturers

The literature suggests that the answer is no. Historically, the European car producers were characterized by their heritage of craft production, beginning with the first automobiles of Daimler, Benz and their peers. This practise continued even up until the Second World War. The Ford Motor Company made serious attempts at establishing mass production plants in Britain and Europe before this, of course, and European manufacturers struggled to implement the new ideas on their own. But the change did not truly catch on before after the wars, when many old customs were forced to die out of necessity. Volkswagen caught on to the mass production trend strongly (the Volkswagen Beetle being an excellent example), and Renault, Fiat and others followed the same suit. (Womack et al 1990: 228-236.)

However, according to Womack et al (1990: 239-240), the Europeans reacted much in the same way to Lean production as to the new ideas of mass production: sluggishly. If North America came second to the Japanese in discovering Lean Production, apparently Europe came third. So if not through Lean Production, how did the European producers keep their sales intact in the face of the new competition, as is evident from figure three?

The answer, Womack et al (1990: 239, 254) feel, is trade barriers. The "fortress Europe" concept, that limited European openness to foreign exports, granted the European automakers a substantial, safe market for their own cars, produced with high efficiency or low. Market limits and import tariffs were used widely. The North American way – very free market access for any company willing to build an assembly plant on American soil – was thought of as naïve in Europe. It was considered that the result would be numerous simple European assembly plants where no value was added, intellectually run from Japan.

Whatever the truth of these thoughts may be, it is doubtful whether the European could have managed to keep their market share as constant under entirely free competition. In figure four we can see statistics over labour productivity and defect rates in the auto components' industry, in selected European countries and Japan (Oliver, Delbridge & Lowe 1996: 89). As we can see, the Japanese figures are in the lead – presumably by Lean production. However, we can also see that there are substantial internal differences between the European producers. Europe's internal markets are certainly more fractioned than North America's or Japan's.

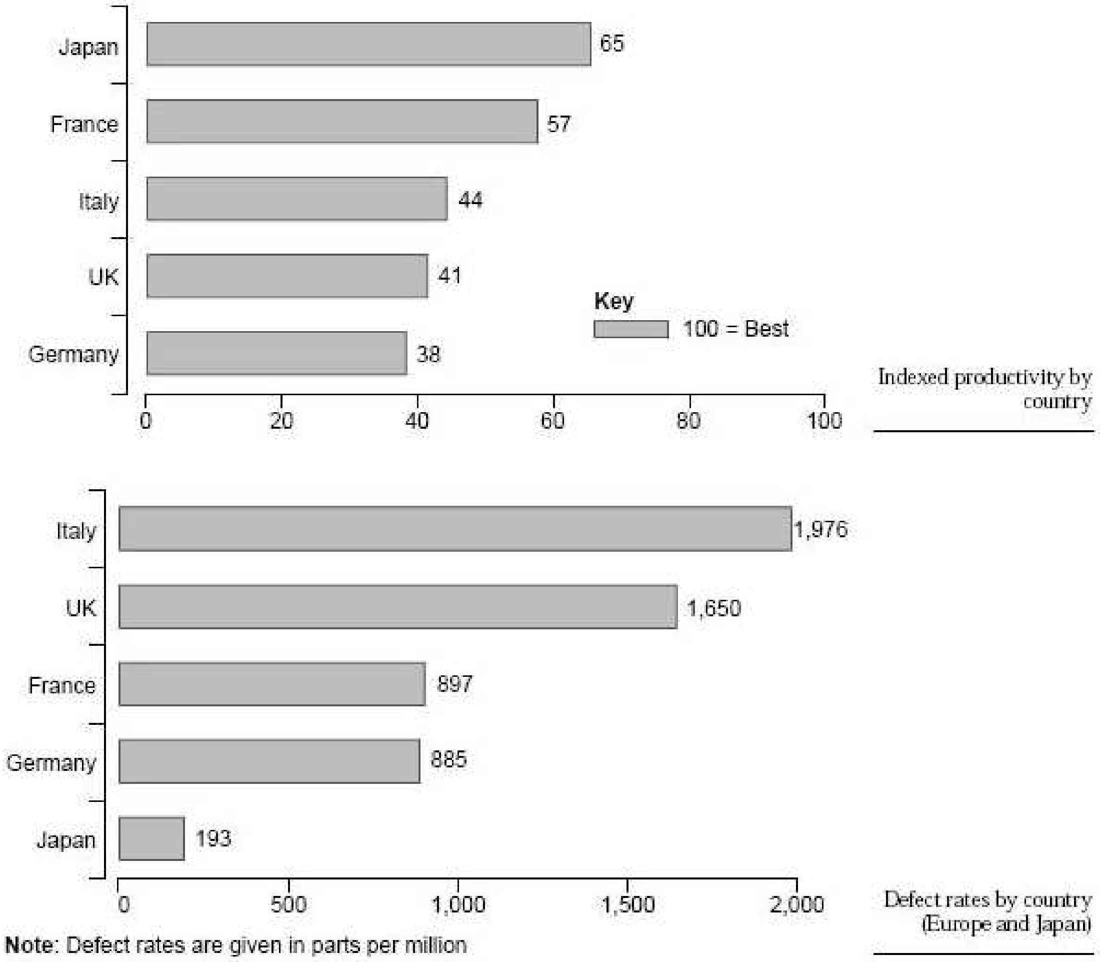


Figure 4. Productivity and defect rates in the auto components' industry, Europe and Japan (Oliver et al. 1996: 89).

So while the European producers as a whole are not well versed in Lean Production, there are exceptions. The chapter "*Lean Thinking versus German* Technik" of Womack & Jones (1996, 189-218) is the account of how the Porsche company implemented Lean production techniques in the time between 1991 and 1994. They did this under the guidance of Japanese experts, having seen a crisis brewing in their current situation. This was a truly significant changeover since Porsche has ever been seen as "The" representative of craft design. Each car was hand finished to rectify any mistakes, ensuring that the final product was perfect. However, this custom, combined with the high prices charged for one automobile, just covered the fact that many mistakes were made in the production process and that rework was necessary – at all. So this, in combination with unfavourable currency changes (the mark strengthening against the dollar, Porsche's biggest market), led to Porsche's situation becoming unstable. The change to Lean production, in effect, seemed the only way to go.

However, it should be stressed that the European markets have even more variation than this: some companies chose to explore totally new and different production solutions to better suit their own needs – much like the Japanese themselves in the beginning. One of the most advanced experiments in new production methods was the Volvo model, tested out in its plants in Uddevalla (opened 1989) and Kalmar (opened 1972). This was not a Lean Production method after the Japanese model, but instead an individually developed system, more appropriate to the labour conditions of Sweden.

According to Muffatto (1999: 20-22) the main point of the Kalmar facility were the abandonment of the traditional moving line in favour of a series of independent lines, in sequence and separated by buffers. The product was still in motion on each line, but current model could be changed much more quickly than with a conventional line – a significant increase in flexibility. The second and even more non-conforming plant at Uddevalla, on the other hand, implemented the "dock" system: assembly was carried out using a stationary production cell system. Each work cell was responsible for completing a significant portion of the car; each group working on four vehicles in various stages of assembly with a complete cycle time of two hours.

The system was built with focus on the worker. Since each worker got to see the product finished by his or her own hand, much of the mechanic drudgery of the moving assembly line was eliminated. The system was, in addition, very flexible: the capacity was there to assemble a large number of variations and models, and the changeover of models was easy. However, it was criticized by Lean production proponents for being less productive in terms of output than the Lean Japanese method (Womack 1990: 102). Muffatto (1999: 21) rebuffs this critique: according to him the results at the Uddevalla plant were good – comparable to that of the Japanese producers even, if all the benefits from increased flexibility are fully observed.

According to him, (Muffatto 1999: 21) the most interesting feature of the system was its effect on lead times. In fact, return to normal productivity levels after model change-over, was 50 percent less than the industry norm. This factor later made the Volvo experiment of considerable interest to the proponents of Time Based Competition and Quick Response Management, which focus on the competitive advantage of reducing lead times over reduction of cost through waste-elimination (see for instance Rajan, Suri (1998). *Quick Response Manufacturing: A Companywide Approach to Reducing Lead Times*)

However, the Volvo experiment came to an end. The two model plants for the Volvo system, Uddevalla and Kalmar, were closed in 1993 and 1994 respectively. Volvo introduced another production concept based on the pre-assembly of modules to be finally assembled by highly automated lines. This choice indicated that Volvo has decided to abandon its own model, and that the Japanese model had "won". However, Muffatto (1996: 22) chooses to see this as a result of the path Volvo took with respect to internationalisation of its production and its partnership policies rather than of weakness of results.

In conclusion, despite the local efforts of certain European car producers, Europe lagged behind Asia and North America in industry productivity (in the beginning of the nineties). Japan was leading, by means of the Lean production methodology and the original Toyota Production System, while North America was struggling in the process of implementing Lean. By Japanese instruction or by own initiative, they were beginning to get to grips with the method, however. This is the setting in which this work will make its analysis; this is the hypothetical basis for what we expect to see from the data analysis. What the analysis itself will say, however, remains to be seen.

3. BROWSING FOR THE RIGHT CARS AND PARTS

In the previous chapter we saw the theoretical background for the questions we hope to answer on the basis of the data analysis. We saw that Design for Manufacture and Assembly is an important aspect of Lean Production; we saw that the Asian automakers are experts in Lean thinking, and that according to the survey carried out by Womack et al (as seen in figure two), the Asian are well versed in DFMA. Now let's see whether we can find additional evidence of this. This section presents the methods used for selection of the data: sample cars and relevant sub-assemblies.

3.1. Methods

Out of what we saw in the previous section, we have the first research question: on the basis of data on twelve cars (four Asian, four North American and four European) from insurance collision estimation manuals from the years 1990 and 1991 – will we be able to see that the Asian cars contain fewer parts and can be repaired in less time? Secondly, will the results of the cars of one production region be close enough to each other that something can be said reliably about a region's success in DFMA and Lean design? And finally, the third research question: what cars will have the least parts and shortest service times, or most parts and longest service times?

A few points of definition in the questions. Why twelve cars? This is due to reasons of comparability and availability of data, as will be seen later on in the car selection chapter. As for the data source, the Collision Estimating Guides - Mitchell International, San Diego, California is an established firm in the insurance, collision repair, medical claims, and auto glass replacement industries (Mitchell International 2009). Its guides are used by insurance companies and collision repair facilities to estimate monetary values for the time and parts spent to repair a damaged sub-section of a car. Their annual guides account for the greater part of a year's models.

As such, they can be seen as a relatively unbiased source of information on parts count and repair times of certain car models. Admittedly, to service a car is not the same thing as assembly in an assembly plant. However, one could reasonably imagine that a subsection of a car that uses fewer parts and takes a short time to attach should also be easy to remove and disassemble.

The estimation guides used for data are from 1990 and 1991 – this because differences in Lean production measure and between production region should still be quite visible, at that point in time. The car companies have been growing more similar in their production methods as of late, a trend that is also discussed in Womack et al (1990), Womack & Jones (1996), Cusumano & Nobeka (1998) and Muffatto (1999). This would suggest the differences between the results of selected cars growing less visible, as we come closer to today's date. Conversely, the differences may have been greater before the chosen point in time, in the seventies and eighties. However, this is perhaps the most suitable time period by another reason: it connects nicely to the book "T*he Machine That Changed the World*", which was released around that time.

Data selection and Analysis

Then how are we to find the answer to these questions? First of all, we must select the cars to be used as a proxy of the Asian, North American and European production. The maximum amount of cars for the time period should be used – but the cars should also be entirely comparable in build. Therefore we must limit ourselves to one type, size and class of car, and select the greatest amount of cars possible for that comparison. For these cars, we must select a (preferably large) amount of sub-sections, or assembly sections that can act as a proxy for the time it would take to dissemble and assemble the entire car. These should be general enough to be present on every car that we select (no optional sections, such as sunroof, air conditioning, etc.). On the basis of this selection of data, we will then perform a simple analysis to determine the answers to the research questions.

To answer the first research question – whether Asian cars are designed more Lean (or DFMA) – we will check how often a car is faster to service than average or contains fewer parts than average, when comparing the data for each sub-assembly of the cars. The more times a car is below average, in service time and in parts count, the more Lean its design. In addition we swill sum up all the Asian cars' 'below average' –instances in one lump, all the North American in another, all the European in a third. Finally we will perform a chi squared test to see whether there are statistically significant differences between production regions – whether the production region affects the frequency of 'Leaner than average' (more DFMA) outcomes.

To answer the third research question – which cars are most Lean in design – we will make scatterplots for both time usage and parts usage. On one axis will be the frequency of 'Leaner than average' outcomes for each car and on the second axis, the sum total of the time used for repairs, or the parts total. From this scatterplot we should be able to pinpoint the most and least Lean cars, but also be able to observe whether there is any regional cohesion between the car models, thus answering the second research question.

3.2. Selecting the cars

There is reason to choose the cars with care, taking several different points into consideration for maximum comparability. If the cars are not clearly similar in design (say the difference between a sedan model and a truck model) all differences in assembly time and parts count could easily be dismissed as model specific. However, if we select cars which are of the same body type, of same motor and drive type (generally) and being roughly the same in size, we can already start assuming that any differences found are, to a good degree, significant. Also – a practical point – the cars should be present in the collision estimating guides.

At first, a shortcut to a good selection seemed to be the smartest route. If a good classification system of cars categorized by size, price and type could be found, the initial selection would certainly be helped along greatly. Such a registry does in fact exist – the international ACRISS or SIPP code classification. ACRISS stands for the Association of Car Rental Industry Systems Standards, and is a set of car classifications jointly agreed upon by the major car rental companies of the world (Avis, Hertz, Budget, Europcar and several others). The code for a car is four letters long, the first giving the class of the car (Compact, Economy, Intermediate, Premium, Elite, etc.) and the other three giving details about the specific car’s type (door number and body type), drive system/transmission and motor type, respectively (ACRISS Selling Guide 2008). The car class (the first letter) is furthermore derived from an algorithm dependent on price class and engine size (ACRISS secretariat 2008), making this classification well near ideal for making comparisons. Just one small problem, though. They only do modern cars.

After communicating with the ACRISS secretariat, the problem stood clear. While they would helpfully share the classifications of a set of cars, most of the cars that seemed of interest in the guides are now discontinued, or have at least evolved substantially from their origin. Because of this, the ACRISS classification was not to be of use in this specific selection. As for a personal guess, however, the cars that were eventually chosen would probably fall under the intermediate or standard classes of the ACRISS classification, had the system been grading models as far back as 1990.

The next try was more based on hard work and, as such, naturally gave better results. The source for comparison this time was Road & Track Magazine’s “Complete Car Buyer's Guide –91”, which exhibits less narrowly defined classes (only five – Sports & GT, 2-seaters, Family, Economy and Luxury). This guide, however, together with additional data from the Finnish car sales’ portal Autotalli.fi (approximately Garage.fi), nevertheless provided enough information to make an educated selection.

The car type, then. The easiest class of cars to compare is probably the sedan type family car, used and marketed over the whole globe as it is – a fact supported by the availability of data in the collision estimating guides. Furthermore, the general family sedan seems to be a front motor, front wheel drive, four door car, available with a five gear manual transmission (even though automatic transmission is certainly more common in the United States). There are differences in equipment levels and superficial design between brands, but the basic structures used are often similar. In addition to these features, the price level of the car and the motor size should preferably be similar between models. This to guarantee that that the level of extra equipment and trimmings remain at the lowest possible level, and that the car remains a certain size.

Based on these parameters, it is eventually possible to make a selection of twelve similar, suitable cars manufactured in 1990-91. These, together with their specifications for price, measurement, drive type, engine and country of origin are presented in table two. The first four of the models, from Honda, Hyundai, Nissan and Toyota are of course Asian. The second four are European and the last three are North American.

The number twelve is mainly a result of necessity: while there are more than twelve such car models manufactured at this specific point in time, only four such comparable models are manufactured in Europe AND presented in the collision estimating guides. For a fair comparison to be possible, there cannot be less of one region's models than of the other's. A harsh constraint, certainly, but the world seldom offers ideal data. There are several significant American and Asian models that were left outside of the analysis just because of this fact, however.

The cars themselves are all well-known models, much sold, and much used. For instance, the Ford Taurus is still in production, and since its launch in 1986, it has sold over 6,7 million units worldwide as of 2007 – the fifth best selling North American model in Ford's history (Cars-directory 2009a). The Toyota Camry, similarly, was the best selling car in the United States for nine out of ten years between 1997 and 2007 (Cars-directory 2009b). Honda Accord was the best-selling Japanese car there for 20 years (1982-97) and has sold around ten million units in the U.S. market alone (Cars-directory 2009c).

The list continues. The Volkswagen Passat has been one of Volkswagen's best-selling and most-profitable models in nearly every market, the Peugeot 405 was voted European Car of the Year for 1988 by the largest number of votes in the history of the contest and the Nissan Bluebird is one of the longest-running nameplates from a Japanese automaker (started 1957) (Cars-directory 2009d,e,f). Even the Saab 900 was a big brand for the small producer, with around a million units sold in all (Cars-directory 2009g). Together, these cars made out a sizable portion of the world's car fleet at one point in time.

As for the Asian contingent, the Hyundai Sonata can be considered something of an Asian wildcard, for the sake of not examining only Japanese car companies. The same thing could be said for the Saab model, since it is a comparatively small batch model compared to the others. It should nevertheless be interesting to see how the small Scandinavian manufacturer's model fares against the larger companies. As for the Audi and Volkswagen models, one could reasonably expect a turnout quite similar to each other, the former company being a wholly owned daughter company of the latter. Finally the American models – chosen along the lines that each member of the "Big Three" should have at least one candidate present (GM gets two).

The cars chosen are reasonably similar in design, price and build. The lengths and widths of the cars are within ten centimetres of each other, the door/seat combinations are the same, save for one or two cases. The motor size range is as small as possible, only a bout a half litre in cylinder displacement. Same type of gearbox, same drive layout is also used.

There are differences, of course – we can clearly see that the American cars are in the upper range concerning the motor size (Cylinder displacement, cc), which is natural, since it is difficult to find models with even this small engine size in the United States (at this point in time, naturally). Conversely, it is difficult to find family models from Europe and Asia with over 2500 cc cylinder displacement. The same relationship is visible also in car size, the American cars generally being larger and often using a six seats, automatic transmission layout. The goal of the selection just had to be the smallest possible range of difference.

Table 2. The selected cars.

	Honda Accord DX	Hyundai Sonata GL	Nissan Stanza/Bluebird XE	Toyota Camry Gli Kat	Audi 80 2.0E	Peugeot 405 Mi16	Saab 900 i Kat	Volkswagen Passat GL	Ford Taurus L	Dodge Spirit	Chevrolet Corsica LT	Buick Skylark Ltd	Min	Max	
Year	-91	-91	-91	-91	-90	-90	-90	-90	-91	-91	-91	-90			
Base price, Road&Track, AM$	12345	10700	11900	11948	N/A	15300	N/A	14990	13717	10925	10070	10725	10070	15300	$
Base price, Autotalli.fi, EU€	23950	N/A	N/A	23025	28424	27953	24135	29584	N/A	N/A	25195	N/A	23025	29584	€
Country of origin	Japan, U.S.A.	South Korea	Japan	Japan, U.S.A.	Germany	France	Sweden, Finland	Germany	U.S.A.	U.S.A.	U.S.A.	U.S.A.			
Body type	Sedan	Sedan	Sedan	Sedan	Sedan	Sedan	Sedan	Sedan	Sedan	Sedan	Sedan	Sedan			
Body/seats	4D/5	4D/5	4D/5	4D/5	4D/5	4D/5	5D/5	4D/5	4D/6	4D/5	4D/5	4D/6			
Drive layout*	F/F	F/F	F/F	F/F	F/F	F/F	F/F	F/F	F/F	F/F	F/F	F/F			
Length, cm	184,8	184,3	179,9	182,1	176,0	177,7	184,5	180,0	188,4	181,2	183,4	180,0	176,0	188,4	cm
Length, inch	469,4	468,1	456,9	462,5	447,0	451,4	468,6	457,2	478,5	460,2	465,8	457,2	447,0	478,5	in
Width, cm	67,9	68,9	66,9	67,4	67,6	67,5	66,5	67,1	70,8	68,1	68,2	66,6	66,5	70,8	cm
Width, inch	172,5	175,0	169,9	171,2	171,7	171,5	168,9	170,4	179,8	173,0	173,2	169,2	168,9	179,8	in
Height, cm	53,9	55,4	54,1	54,1	54,3	55,2	56,1	56,2	54,1	33,5	56,2	52,1	33,5	56,2	cm
Height, inch	136,9	140,7	137,4	137,4	137,9	140,2	142,5	142,7	137,4	85,1	142,7	132,3	85,1	142,7	in
Curb weight, kg	1243	1286	1295	1399	1438	1232	1281	1184	1383	1290	1243	1177	1177	1438	kg
Curb weight, lb	2740	2835	2855	3085	3170	2715	2825	2610	3050	2845	2740	2595	2595	3170	lb
Engine type	125-bhp sohc 16V inline-4	116-bhp sohc 12V inline-4	138-bhp 12V inline-4	115-bhp dohc 16V inline-4	110-bhp sohc inline-4	150-bhp dohc 16V inline-4	128-bhp dohc 16V inline-4	134-bhp dohc 16V inline-4	105-bhp ohv inline-4	100-bhp sohc inline-4	95-bhp ovh inline-4	110-bhp ovh inline-4	95	150	bhp
Cylinder displacement, cc	2156	2350	2389	1998	1984	1905	1985	1984	2499	2507	2190	2471	1905	2507	cc
Transmission**	5M	5M	5M	5M	5M	5M	5M	5M	5M	5M	5M	5M			
Suspension front/rear	ind/ind	ind/beam	ind/ind	ind/ind	ind/ind	ind/ind	ind/beam	ind/beam	ind/ind	ind/beam	ind/beam	ind/beam			
Brakes front/rear	disc/ drum	disc/ drum	disc/ drum	disc/ drum	disc/ disc	disc/ disc	disc/ disc	disc/ disc	disc/ drum	disc/ drum	disc/ drum	disc/ drum			
Road & Track Classification	Family	Family	Family	Family	Family	Family	N/A	Family	Family	Family	Family	Family			

* F/F stands for Front motor/Front wheel drive

** 5M stands for Manual gearbox, 5 gears

We can notice, also, that there are variations in the suspension and brake systems too. These are more or less region specific, and more or less impossible to work out of the comparison. The differences are not awfully large, however, as the subsequent parts and service time data revealed: never more than one or two parts, and never revealing a clear relation to faster service times. Thus we can only conclude, again, that the world seldom offers ideal data, and that no two cars are ever sufficiently alike to be totally comparable. Nevertheless, our study is one of Lean design – and as such, we can assume on several accounts that surely the more Lean-aware company would have chosen the system most beneficial to these principles. If so, the comparison should still be relevant to us.

3.3. Selecting the assemblies

For these twelve cars we must choose a goodly number of sub-assemblies, and collect their time and parts data. This is, much like the cars, a choice dictated by availability, since it is imperative that all the chosen cars share the same stat. At the same time, the assemblies chosen must be general enough to be present on all models.

In appendix one: figures 13-15, we see a few pages copied from the collision estimating guides, showing a few assemblies for the Toyota Camry model. The full listing for one model is 10-15 pages, but a sample should be enough to show the idea of the data gathering. As we can see, most of the assemblies have a collection stat in the beginning of the assembly listing, describing how long it would take to either R&I (Repair and Install), O/H (Overhaul) or Refinish said assembly.

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

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

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

> *"**Overhaul (O/H):** Remove an assembly, disassemble, clean and visually inspect it, replace needed parts, reassemble and reinstall on the vehicle making any necessary adjustments."*

This is a more time consuming process than Remove & Install, and both stats are often given together, just for the estimator to choose method.

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

In general, the ranking of the three indicators is such that Overhaul beats Remove and Install, which in turn beats Refinish. This because the more time is actually used to disassemble parts and assemble them, the more does the basic design come into play – an assembly designed to the principles of DFMA should be make this process faster, and visibly so.

A few points on the data presented in the estimating guides. The labour times shown in the guides are given in hours and tenths of hours, thus 0,1 hours represent six minutes. As is also explained in the guides

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

Because of this fact, the assembly aspect of the service operations can be considered to be quite close to actual assembly, even though some work moments may be performed by robot or specialized machinery in the assembly plant.

The parts stats are collected in the simplest possible way – counting the numbered parts and assemblies of the sub-section. This even though some parts are not included in the numbering, or already included in a larger, numbered assembly. Why? Because to do this another way would include value judgements on every point, something that only a good mechanic could with any reliability. As it is, the parts count may be sketchy, but most importantly, exactly as sketchy for every car and every assembly. In other words equal.

The service time and parts of the selected assemblies are shown in tables three and four respectively. The assemblies are chosen by default: any assembly that has a suitable comparative service time stat and a suitable comparative parts chart is recorded. Table five shows the list of assemblies that were not chosen, and the motivation. In most cases an assembly yields both time and a part data, but in a few cases (also listed in table five) there is a good comparable stat for one but not the other – in these cases only the one has been recorded. As we can see from the time data, there are some instances where more than one service stat is recorded (i.e. an assembly has a stat for both Remove & Install AND Overhaul, or for Refinish AND Remove & Install). In the coming analysis, only the "best" data on the basis of the earlier definition will be used, but here our only objective is to gather as much data as possible.

The data is labelled as exactly as necessary – if there are different service times or parts counts for assemblies on different sides of the vehicle, for instance, it is important to state which of these we will be comparing.

Table 3. Service time data for the selected cars.

Service time (Hours)	Honda Accord DX	Hyundai Sonata GL	Nissan Stanza/Bluebird XE	Toyota Camry Gli Kat	Audi 80 2.0E	Peugeot 405 Mi16	Saab 900 i Kat	Volkswagen Passat GL	Ford Taurus L	Dodge Spirit	Chevrolet Corsica LT	Buick Skylark Ltd
	ASIA				EURO				USA			
Front suspension, one side (Right) R&I - including brakes	2,0	1,5	1,5	2,0	2,0	3,0	2,0	2,5	2,0	2,0	2,0	2,0
Front suspension, one side (Right) O/H - including brakes	3,6	2,5	3,2	3,4	4,7	5,5	6,4	3,5	3,3	3,5	2,7	2,7
Rear suspension, one side (R&I) - including brakes	2,5	2,5	2,0	1,5	2,5	3,0	3,0	2,5	2,0	1,5	1,5	1,5
Steering linkage/gear R/I Complete	2,6	1,4	3,6	3,0	1,6	3,5	1,2	1,7	2,3	2,6	2,6	2,7
Front door Refinish outside + Jambs&Interior	3,2	3,4	3,2	3,3	3,3	3,5	3,5	3,2	3,3	3,5	3,3	3,3
Front door R&I Door Assy	1,2	0,5	0,4	0,7	1,0	1,0	0,8	0,7	1,0	1,0	1,0	0,5
Rear door Refinish outside + Jambs&Interior	3,2	3,3	3,2	3,2	3,2	3,5	3,0	3,2	3,2	3,4	3,1	3,0
Rear door R&I Door Assy	1,2	0,3	0,4	0,5	0,8	1,0	0,8	0,8	1,0	0,4	0,8	0,8
Quarter panel (refinish outside) w/o interior/exterior trim	2,3	2,3	2,5	2,4	2,2	2,1	2,8	2,4	2,1	2,4	2,1	2,5
Front bumper Refinish Front Cover	2,4	2,4	2,2	2,1	2,5	1,8	1,5	2,1	2,3	2,2	2,5	2,0
Front bumper R&I	1,0	1,0	1,2	0,9	0,8	1,2	0,8	0,6	0,5	0,7	0,7	1,0
Front bumper O/H	1,8	1,5	2,2	1,6	2,0	2,0	2,0	1,2	1,0	1,7	2,2	3,0
Front fender (one side) w/o exterior trim Refinish outside	2,3	2,6	2,5	2,5	2,4	2,3	2,0	2,4	2,3	2,4	2,4	2,9
Front fender (one side) w/o exterior trim R&I Fender assy	0,8	1,2	1,5	1,2	2,6	1,3	5,0	1,8	1,5	1,7	1,5	1,5
Hood Refinish outside	2,9	3,1	3,0	3,0	2,8	2,9	3,4	2,7	3,0	2,9	3,0	2,9
Hood R&I Hood assy	0,4	0,4	0,6	0,5	0,6	0,6	1,0	0,6	0,6	0,4	0,5	0,5
Front drive axle R&I one side	1,1	1,0	0,9	2,1	0,9	1,6	1,9	1,1	1,3	1,5	1,5	1,5
Rear bumper R&I	0,6	0,5	0,8	0,8	0,8	0,8	0,8	0,6	0,5	0,6	0,6	1,0
Rear bumper O/H	1,3	1,0	1,8	1,3	2,0	1,6	1,8	1,2	0,9	1,3	1,6	2,5
Seat (front, driver's) R&I	0,3	0,4	0,3	0,3	0,5	0,4	0,3	0,5	0,3	0,3	0,3	0,3
Engine R&I engine/trans assy (manual trans)	8,5	5,2	6,7	8,2	6,0	9,5	7,0	5,6	5,3	6,0	4,7	8,4

Table 4. Parts data for the selected cars.

Parts count	Honda Accord DX	Hyundai Sonata GL	Nissan Stanza/Bluebird XE	Toyota Camry Gli Kat	Audi 80 2.0E	Peugeot 405 Mi16	Saab 900 i Kat	Volkswagen Passat GL	Ford Taurus L	Dodge Spirit	Chevrolet Corsica LT	Buick Skylark Ltd
	ASIA				EURO				USA			
Front suspension, one side (Right)	33,0	29,0	19,0	18,0	20,0	21,0	23,0	25,0	9,0	26,0	18,0	20,0
Rear suspension	30,0	17,0	15,0	16,0	13,0	19,0	17,0	17,0	17,0	25,0	12,0	14,0
Steering linkage/gear	24,0	8,0	15,0	8,0	10,0	10,0	8,0	6,0	6,0	9,0	8,0	11,0
Front door Glass&Parts	10,0	9,0	8,0	10,0	4,0	10,0	8,0	13,0	8,0	7,0	13,0	7,0
Rear door Glass&Parts	10,0	11,0	10,0	9,0	3,0	13,0	13,0	10,0	8,0	8,0	13,0	7,0
Quarter panel w/o interior/exterior trim	9,0	2,0	9,0	11,0	10,0	5,0	10,0	13,0	4,0	15,0	13,0	9,0
Front bumper	10,0	5,0	7,0	10,0	8,0	8,0	20,0	8,0	7,0	10,0	15,0	9,0
Front fender (One side) w/o exterior trim	4,0	4,0	5,0	5,0	5,0	3,0	13,0	8,0	4,0	6,0	6,0	5,0
Hood	11,0	11,0	12,0	9,0	12,0	13,0	13,0	9,0	10,0	9,0	8,0	9,0
Front drive axle	9,0	4,0	3,0	8,0	5,0	3,0	5,0	7,0	3,0	9,0	8,0	8,0
Rear bumper	7,0	4,0	10,0	7,0	6,0	9,0	11,0	7,0	5,0	10,0	7,0	7,0
Air cleaner	14,0	11,0	9,0	6,0	12,0	6,0	9,0	7,0	4,0	5,0	7,0	4,0
Cooling system	14,0	13,0	25,0	9,0	9,0	17,0	11,0	21,0	6,0	11,0	14,0	16,0
Instrument panel	21,0	14,0	15,0	15,0	5,0	16,0	6,0	19,0	6,0	13,0	15,0	11,0
Center console	9,0	14,0	9,0	8,0	3,0	10,0	8,0	5,0	17,0	8,0	12,0	9,0

Table 5. Rejected assemblies.

Data for Parts, none for Time

Assembly	*Motivation*
Air cleaner	No assy stat
Cooling system	No complete assy stat, only hoses R&I
Instrument panel	No comparable assy stats
Center console	No comparable assy stats

Data for Time, none for Parts

Assembly	*Motivation*
Seat (front, driver's)	No comparable assy part chart
Engine/trans assy	No comparable assy part chart

Rejected assemblies

Assembly	*Motivation*
Wheel	Car dependent
Steering column	Steering wheel sometimes included
Electical system	Model dependent
Emission system	Model dependent
Air conditioning	Model dependent
Sunroof	Model dependent
Luggage lid / Liftgate	Model dependent
Headlamp front assy	Model dependent
Lamp assy back	Model dependent
Grille	Model dependent
Ground effects	Model dependent
Windshield	Similar for all
Quarter glass	Similar for all
Back window	Similar for all
Steering pump	Very engine dependent
Rear body	No comparable assy
Fuel tank	No comparable assy
Roof	No comparable assy
Rocker/pillars/floor	No comparable assy
Cowl & Dash	No comparable assy
Front inner structure	No comparable assy
Radiator support assy	No comparable assy

4. DIGGING IN THE DATA

In this section we will focus on answering the research questions on the basis of the research data: will Asian cars be Leaner in design, considering their expertise in the field of Lean production, will the cars' results be so close for different companies in the same region that something can be said about the region's expertise and what cars will in fact come out on top and bottom in the test? To do this, we must normalize the data for comparison, and evaluate it, visually and by statistical method.

4.1. Normalization of data

Once the data is collected, it must be made fit for analysis. A normalization of the data is necessary, so that one is able to compare not only between the cars, but also between individual assemblies. But even before this is done, some of the service time data must be cut out. Namely, as mentioned in the data selection section, there is more service time data collected than is good to use in the analysis; see for instance the data for the front fender assemblies. In this case there are measurements not only for one type of repair, but three. And since the different repair indicators are closely linked (if one takes a long time, the other take a long time), using them all in the analysis would result in a systematic bias. Therefore, we will weed out the "unnecessary" data. The principle we follow here is the one stated earlier on - that Overhaul beats Remove and Install, which in turn beats Refinish. The resulting time data is given in table six. The parts data, on the other hand is good as it is. For one assembly there can be several service time indicators, but only one parts count. Thus we leave the parts data as is.

Having done this, it is interesting to see what the data dells us already now. For easier visualisation, the time and parts data can be presented as graphs, showing the repair time and parts data for each assembly, for each car model. One line represents a car; all the assemblies it contains. The aim is of course for a car model to show as low a line as possible on the y-axis – a Lean design car takes little time to service, and uses few parts.

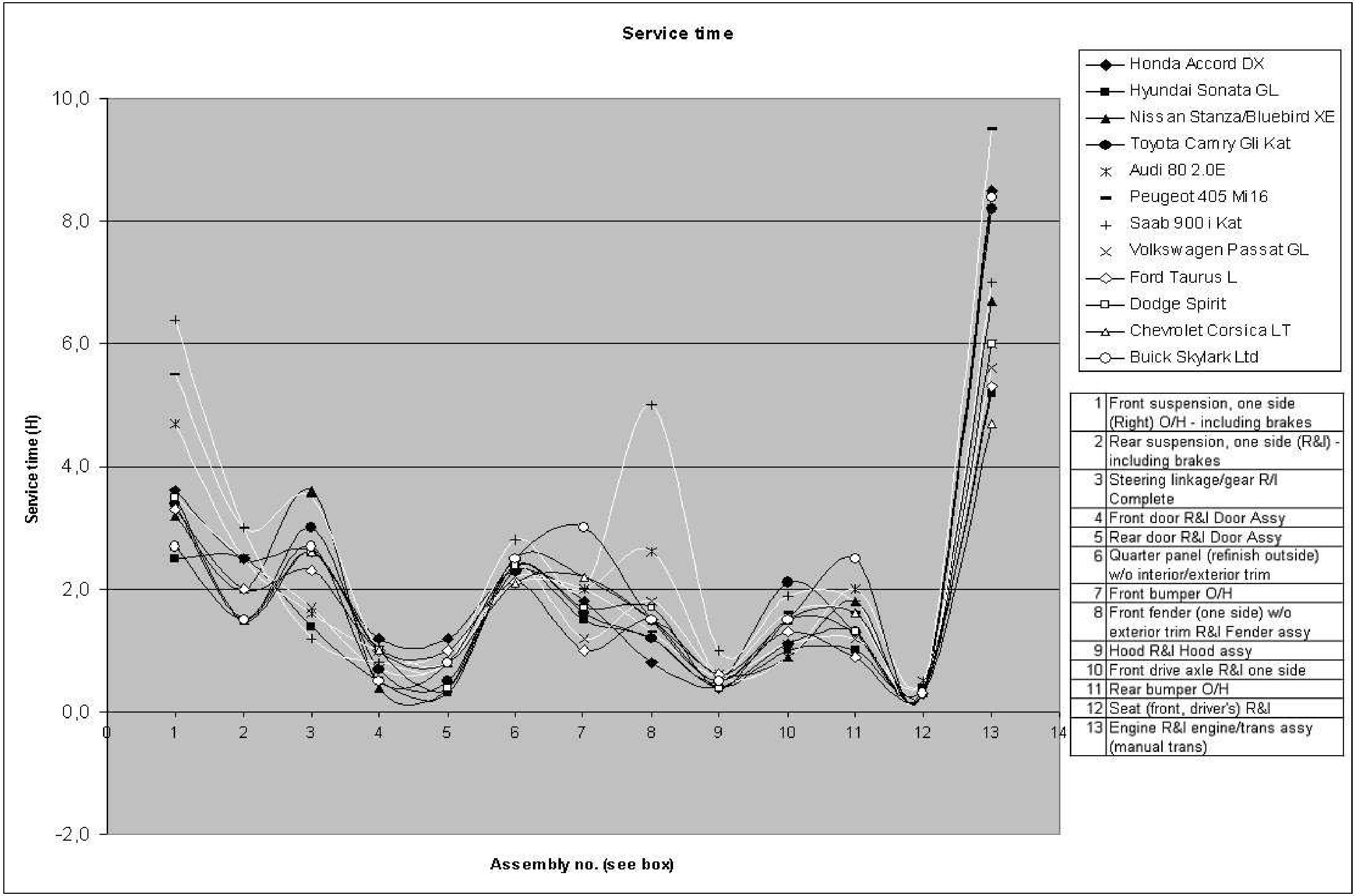


Figure 5. Service time per assembly (hours).

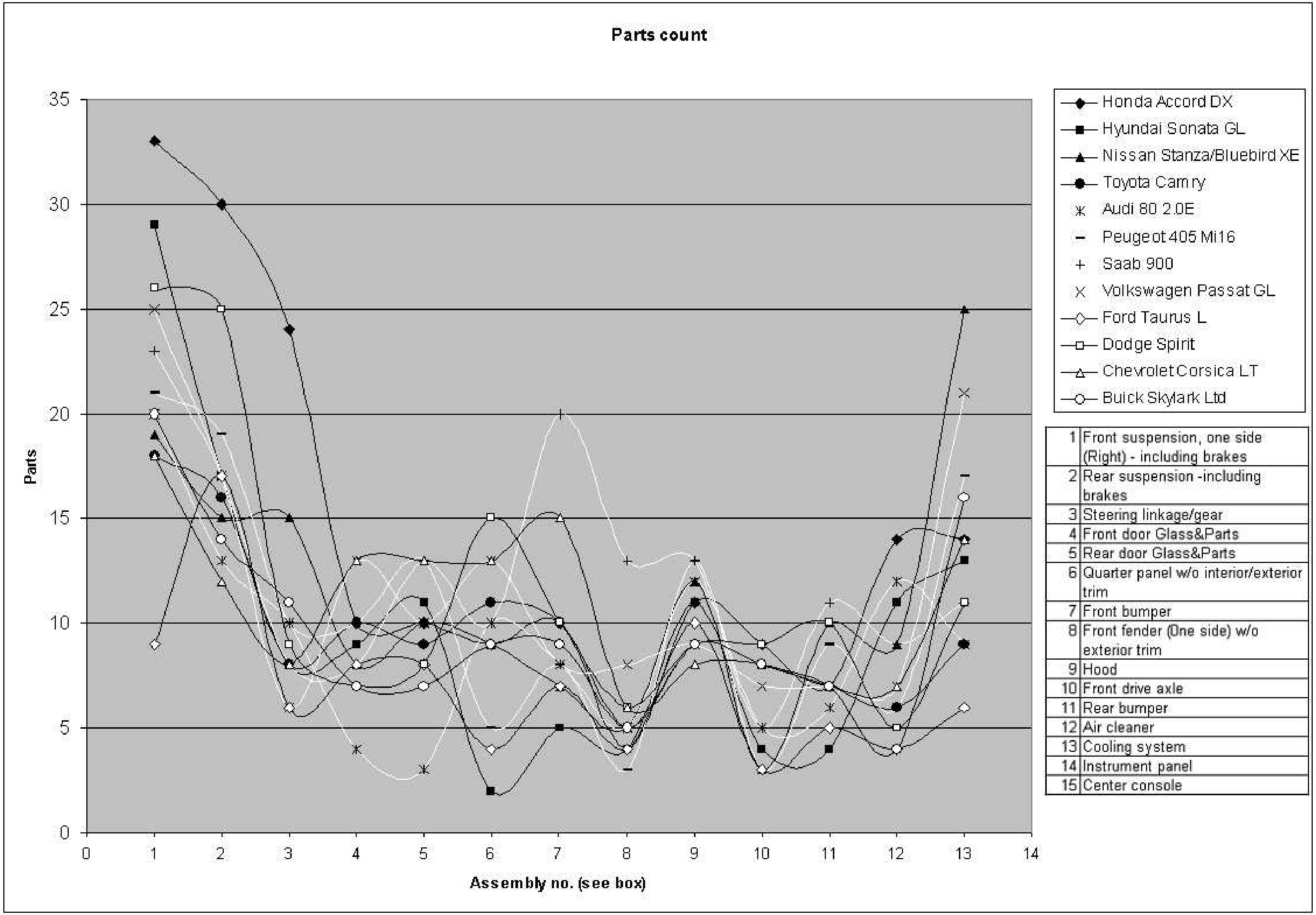


Figure 6. Parts count per assembly.

Figures five and six show service times and parts count, respectively. That there are differences between assemblies here is no surprise, of course. An engine is bound to take longer to service than a seat. However, we can see here that there are assemblies where there is very little spread between car models, and other where there is much. One would assume that assembly complexity would be a major factor here, but it is hard to say directly form the graphs (front drive axle spread is almost smaller than rear bumper spread, for instance). However, more interestingly, we can see that the parts graph is much more chaotic than the service chart. While the latter seems to follow a relatively tight band (except for outshoots such as the Saab reading on the front fender) the parts graph fluctuates wildly, only barely following a certain trend.

Normalization

Now let us go back to the data in its pure form. To normalize this data, one of the simplest methods is of course to use the comparison to average: if one calculates the arithmetic average of all readings for one assembly type, and then compares each individual value to this average, we will easily see which models contribute negatively or positively to the average. In other words, which models are faster than average to service, and which models use fewer parts than average.

This procedure is shown in tables six and seven. Both tables are built in the same way: the higher table show the actual count – actual service time in hours, or actual parts count. The lower table is a derivative of the higher – it shows how much each measurement above differs from the average of that assembly type. The average is at the base of each column in the higher table. One assembly type is shown as one column, each model's data for that particular assembly shown there. One car model represents one row in each the table. So, for instance, we can see that the average time to overhaul the front suspension of the cars is 3,8 hours. However, on the Honda Accord you can do this somewhat faster: it only takes 3,6 hours. And as we can see in the lower table, this is 4 percent faster than the average.

We are interested in Lean design here. Because of this, the negative values are more interesting – a car model with many negative values in the lower table is one that is often faster than average to repair, and often uses fewer parts than average in its assemblies. Negative is a good thing. Because of this, the positive values in the table are marked, to increase the visual transparency of the table – the fewer marked cells a model has in its line, the more "Lean" it is.

In addition, we are naturally not interested only in the direction of the values; we are also interested in their magnitude. Any large number is something that affects the average, and in turn may say something about the technology used in that particular assembly. A large negative number hints of thoroughly Lean design.

Now, to see what the tables tell us. By glancing quickly at the marked percentages of the lower tables, we see that the Asian car models are looking good in the service times. Their marked cells are in minority, quite clearly. Similarly, they are in majority to the European brands. Nothing said so far about the magnitude of the cells, just the frequency. However, this glance seems to point toward what the theory told us.

On the other hand, the parts table is less easily read: the table gives us a relatively even distribution over the field, marked and unmarked cells in equal numbers. Interestingly enough, the North American cars seem to be stronger in this comparison –stronger than the Asians – even though it is of course too early to say for sure.

Table 6. Service time (percent of average).

SERVICE TIME (HOURS)

		Front suspension O/H	Rear suspension R&I	Steering linkage/gear R/I	Front door R&I Door Assy	Rear door R&I Door Assy	Quarter panel Refinish outside	Front bumper O/H	Front fender R&I assy	Hood R&I assy	Front drive axle R&I	Rear bumper O/H	Seat (driver's) R&I	Engine/transmission R&I assy	**Sum Total (H)**
Honda Accord DX	ASIA	3,6	2,5	2,6	1,2	1,2	2,3	1,8	0,8	0,4	1,1	1,3	0,3	8,5	27,6
Hyundai Sonata GL		2,5	2,5	1,4	0,5	0,3	2,3	1,5	1,2	0,4	1,0	1,0	0,4	5,2	20,2
Nissan Stanza/Bluebird XE		3,2	2,0	3,6	0,4	0,4	2,5	2,2	1,5	0,6	0,9	1,8	0,3	6,7	26,1
Toyota Camry Gli Kat		3,4	1,5	3,0	0,7	0,5	2,4	1,6	1,2	0,5	2,1	1,3	0,3	8,2	26,7
Audi 80 2.0E	EURO	4,7	2,5	1,6	1,0	0,8	2,2	2,0	2,6	0,6	0,9	2,0	0,5	6,0	27,4
Peugeot 405 Mi16		5,5	3,0	3,5	1,0	1,0	2,1	2,0	1,3	0,6	1,6	1,6	0,4	9,5	33,1
Saab 900 i Kat		6,4	3,0	1,2	0,8	0,8	2,8	2,0	5,0	1,0	1,9	1,8	0,3	7,0	34,0
Volkswagen Passat GL		3,5	2,5	1,7	0,7	0,8	2,4	1,2	1,8	0,6	1,1	1,2	0,5	5,6	23,6
Ford Taurus L	USA	3,3	2,0	2,3	1,0	1,0	2,1	1,0	1,5	0,6	1,3	0,9	0,3	5,3	22,6
Dodge Spirit		3,5	1,5	2,6	1,0	0,4	2,4	1,7	1,7	0,4	1,5	1,3	0,3	6,0	24,3
Chevrolet Corsica LT		2,7	1,5	2,6	1,0	0,8	2,1	2,2	1,5	0,5	1,5	1,6	0,3	4,7	23,0
Buick Skylark Ltd		2,7	1,5	2,7	0,5	0,8	2,5	3,0	1,5	0,5	1,5	2,5	0,3	8,4	28,4
Column Average		3,8	2,2	2,4	0,8	0,7	2,3	1,9	1,8	0,6	1,4	1,5	0,4	6,8	

SERVICE TIME (PERCENT OF AVERAGE)

		Front suspension O/H	Rear suspension R&I	Steering linkage/gear R/I	Front door R&I Door Assy	Rear door R&I Door Assy	Quarter panel Refinish outside	Front bumper O/H	Front fender R&I assy	Hood R&I assy	Front drive axle R&I	Rear bumper O/H	Seat (driver's) R&I	Engine/transmission R&I assy
Honda Accord DX	ASIA	-4 %	15 %	8 %	47 %	64 %	-2 %	-3 %	-56 %	-28 %	-20 %	-15 %	-14 %	26 %
Hyundai Sonata GL		-33 %	15 %	-42 %	-39 %	-59 %	-2 %	-19 %	-33 %	-28 %	-27 %	-34 %	14 %	-23 %
Nissan Stanza/Bluebird XE		-15 %	-8 %	50 %	-51 %	-45 %	7 %	19 %	-17 %	7 %	-34 %	18 %	-14 %	-1 %
Toyota Camry		-9 %	-31 %	25 %	-14 %	-32 %	2 %	-14 %	-33 %	-10 %	54 %	-15 %	-14 %	21 %
Audi 80 2.0E	EURO	25 %	15 %	-33 %	22 %	9 %	-6 %	8 %	44 %	7 %	-34 %	31 %	43 %	-11 %
Peugeot 405 Mi16		47 %	38 %	46 %	22 %	36 %	-10 %	8 %	-28 %	7 %	17 %	5 %	14 %	41 %
Saab 900		71 %	38 %	-50 %	-2 %	9 %	20 %	8 %	178 %	79 %	39 %	18 %	-14 %	4 %
Volkswagen Passat GL		-7 %	15 %	-29 %	-14 %	9 %	2 %	-35 %	0 %	7 %	-20 %	-21 %	43 %	-17 %
Ford Taurus L	USA	-12 %	-8 %	-4 %	22 %	36 %	-10 %	-46 %	-17 %	7 %	-5 %	-41 %	-14 %	-22 %
Dodge Spirit		-7 %	-31 %	8 %	22 %	-45 %	2 %	-8 %	-6 %	-28 %	10 %	-15 %	-14 %	-11 %
Chevrolet Corsica LT		-28 %	-31 %	8 %	22 %	9 %	-10 %	19 %	-17 %	-10 %	10 %	5 %	-14 %	-30 %
Buick Skylark Ltd		-28 %	-31 %	13 %	-39 %	9 %	7 %	62 %	-17 %	-10 %	10 %	64 %	-14 %	24 %

Table 7. Parts count (percent of average).

PARTS COUNT

		Front suspension	Rear suspension	Steering linkage/gear	Front door Glass&Parts	Rear door Glass&Parts	Quarter panel	Front bumper	Front fender	Hood	Front drive axle	Rear bumper	Air cleaner	Cooling system	Instrument panel	Center console	Sum Total
Honda Accord DX	ASIA	33	30	24	10	10	9	10	4	11	9	7	14	14	21	9	215
Hyundai Sonata GL		29	17	8	9	11	2	5	4	11	4	4	11	13	14	14	156
Nissan Stanza/Bluebird XE		19	15	15	8	10	9	7	5	12	3	10	9	25	15	9	171
Toyota Camry		18	16	8	10	9	11	10	5	9	8	7	6	9	15	8	149
Audi 80 2.0E	EURO	20	13	10	4	3	10	8	5	12	5	6	12	9	5	3	125
Peugeot 405 Mi16		21	19	10	10	13	5	8	3	13	3	9	6	17	16	10	163
Saab 900		23	17	8	8	13	10	20	13	13	5	11	9	11	6	8	175
Volkswagen Passat GL		25	17	6	13	10	13	8	8	9	7	7	7	21	19	5	175
Ford Taurus L	USA	9	17	6	8	8	4	7	4	10	3	5	4	6	6	17	114
Dodge Spirit		26	25	9	7	8	15	10	6	9	9	10	5	11	13	8	171
Chevrolet Corsica LT		18	12	8	13	13	13	15	6	8	8	7	7	14	15	12	169
Buick Skylark Ltd		20	14	11	7	7	9	9	5	9	8	7	4	16	11	9	146
Column Average		21,8	17,7	10,3	8,9	9,6	9,2	9,8	5,7	10,5	6,0	7,5	7,8	13,8	13,0	9,3	

PARTS, PERCENT OF AVERAGE

Honda Accord DX	ASIA	52 %	70 %	134 %	12 %	4 %	-2 %	3 %	-29 %	5 %	50 %	-7 %	79 %	1 %	62 %	-4 %
Hyundai Sonata GL		33 %	-4 %	-22 %	1 %	15 %	-78 %	-49 %	-29 %	5 %	-33 %	-47 %	40 %	-6 %	8 %	50 %
Nissan Stanza/Bluebird XE		-13 %	-15 %	46 %	-10 %	4 %	-2 %	-28 %	-12 %	14 %	-50 %	33 %	15 %	81 %	15 %	-4 %
Toyota Camry		-17 %	-9 %	-22 %	12 %	-6 %	20 %	3 %	-12 %	-14 %	33 %	-7 %	-23 %	-35 %	15 %	-14 %
Audi 80 2.0E	EURO	-8 %	-26 %	-2 %	-55 %	-69 %	9 %	-18 %	-12 %	14 %	-17 %	-20 %	53 %	-35 %	-62 %	-68 %
Peugeot 405 Mi16		-3 %	8 %	-2 %	12 %	36 %	-45 %	-18 %	-47 %	24 %	-50 %	20 %	-23 %	23 %	23 %	7 %
Saab 900		6 %	-4 %	-22 %	-10 %	36 %	9 %	105 %	129 %	24 %	-17 %	47 %	15 %	-20 %	-54 %	-14 %
Volkswagen Passat GL		15 %	-4 %	-41 %	46 %	4 %	42 %	-18 %	41 %	-14 %	17 %	-7 %	-11 %	52 %	46 %	-46 %
Ford Taurus L	USA	-59 %	-4 %	-41 %	-10 %	-17 %	-56 %	-28 %	-29 %	-5 %	-50 %	-33 %	-49 %	-57 %	-54 %	82 %
Dodge Spirit		20 %	42 %	-12 %	-21 %	-17 %	64 %	3 %	6 %	-14 %	50 %	33 %	-36 %	-20 %	0 %	-14 %
Chevrolet Corsica LT		-17 %	-32 %	-22 %	46 %	36 %	42 %	54 %	6 %	-24 %	33 %	-7 %	-11 %	1 %	15 %	29 %
Buick Skylark Ltd		-8 %	-21 %	7 %	-21 %	-27 %	-2 %	-8 %	-12 %	-14 %	33 %	-7 %	-49 %	16 %	-15 %	-4 %

At this point it is also possible to graph the two percentage tables, to give us an idea of what the time and parts fluctuations look like when normalized. These graphs are presented in figures seven and eight. Seeing these charts next to each other, makes us realize why normalization is necessary. The fluctuations are seldom outside the 50 percent range, negative or positive. This despite the seemingly chaotic graph of parts count in figure six. In fact, that chaos may purely be an artefact of differences in scale of the two previous graphs – something which is now corrected through the process of normalization.

Other than this, however, there is very little the graphs can tell us as to regional trends or Lean design ranking. They are simply too crowded to interpret. Nevertheless, we can point out the abnormalities here, such as the Saab's front fender in the service time charts (apparently consists of two major plates instead of being an integrated whole as most other model's) and Honda Accord's high parts usage in suspensions and steering linkage. Why are they built this way? A good question, and hard to answer. It is easy to jump to the conclusion that these models used poor DFM- and DFA-techniques, but the real reason could also be something else: accommodating some other assembly, using tried and tested parts instead of designing something new, using a cheaper solution, etc. Also, by just focusing on the one assembly, one can forget that the other assemblies, which may well get very competitive results. Because of this it is imperative not to jump to conclusions, so far.

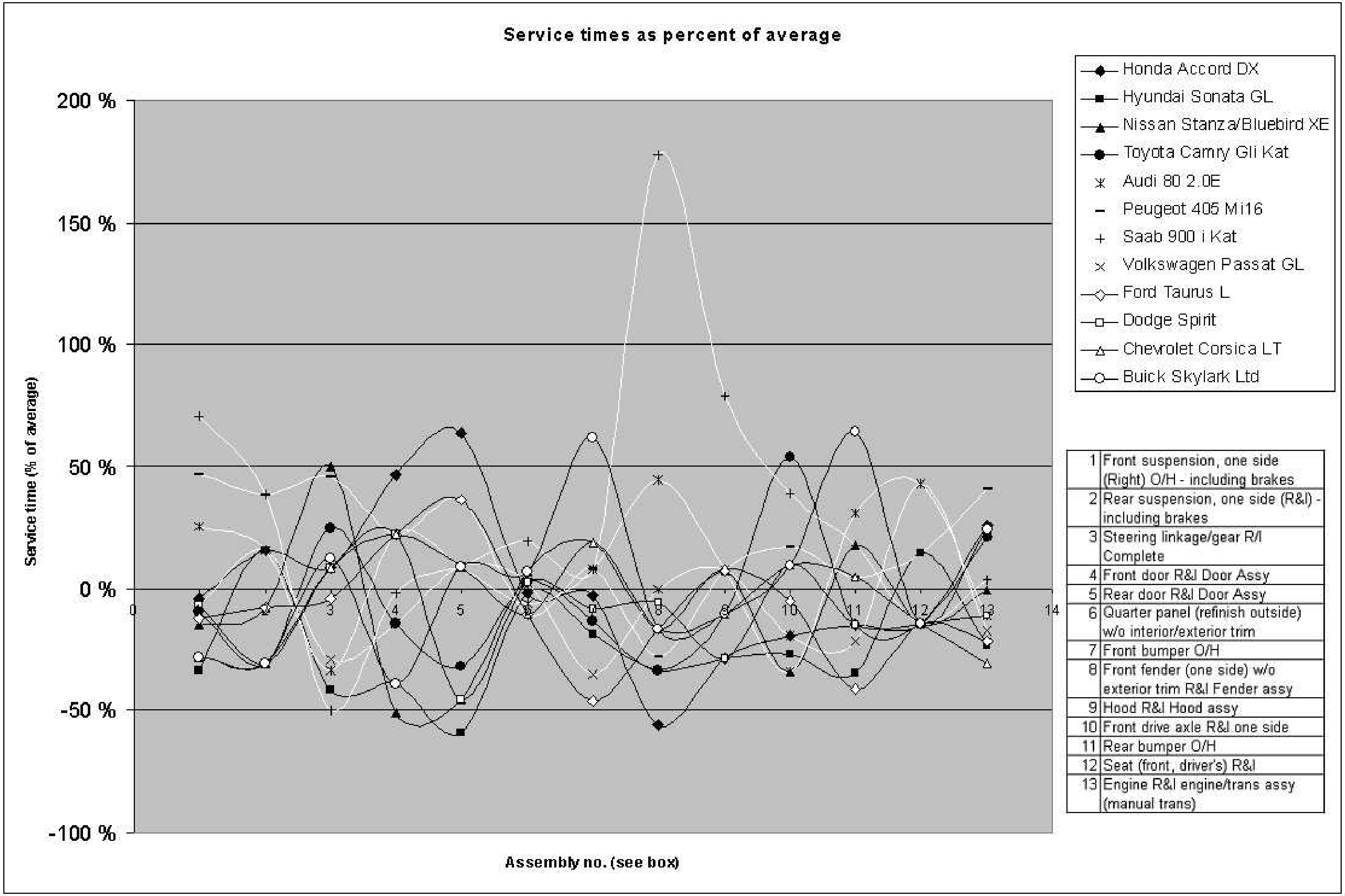
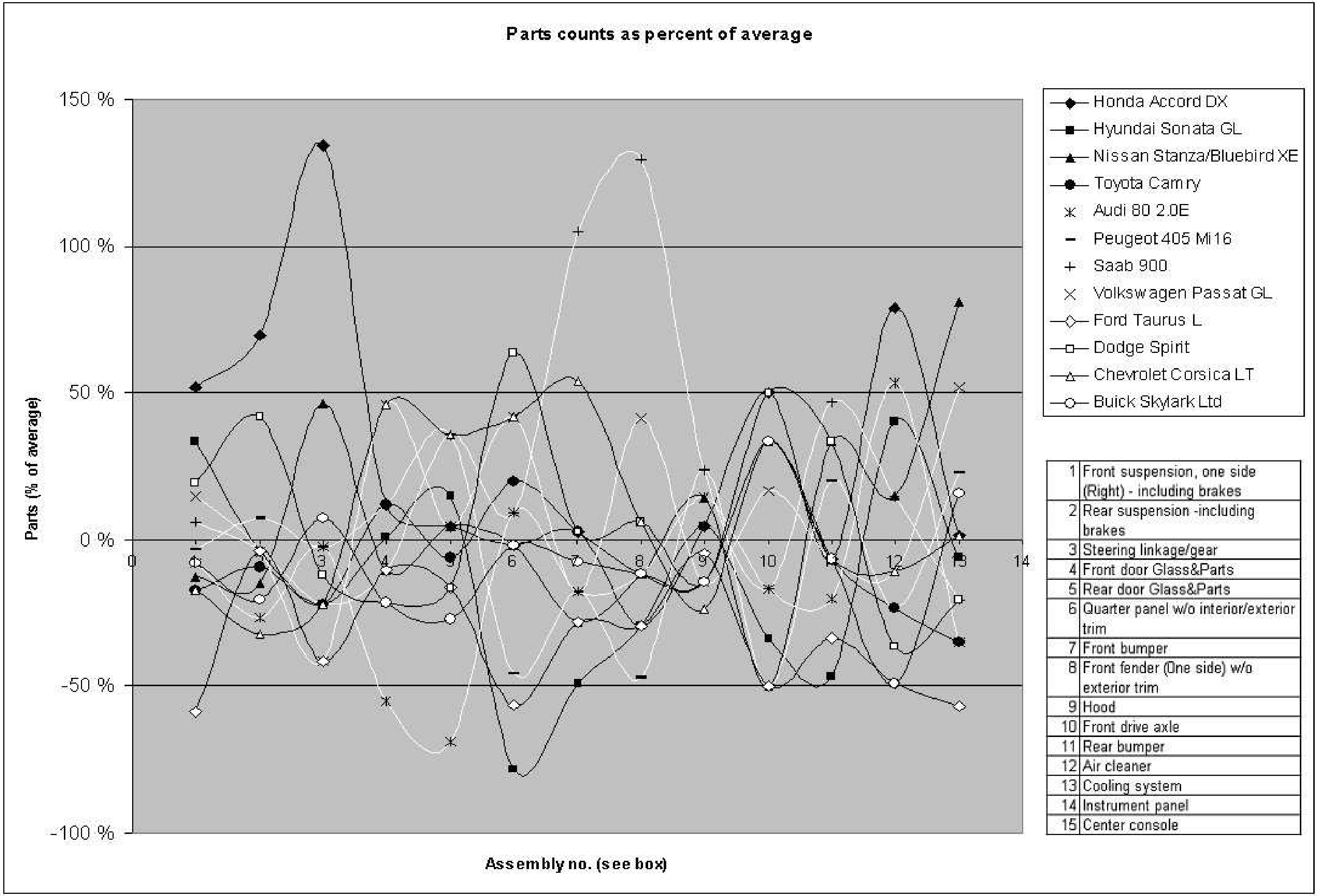


Figure 7. Service time per assembly (percent of average).



1	Front suspension, one side (Right) - including brakes
2	Rear suspension -including brakes
3	Steering linkage/gear
4	Front door Glass&Parts
5	Rear door Glass&Parts
6	Quarter panel w/o interior/exterior trim
7	Front bumper
8	Front fender (One side) w/o exterior trim
9	Hood
10	Front drive axle
11	Rear bumper
12	Air cleaner
13	Cooling system
14	Instrument panel
15	Center console

Figure 8. Parts count per assembly (percent of average).

4.2. Statistically significant differences between regions?

First of all, let us attempt to find an answer to the first research question: will Asian cars be Leaner in design, considering their expertise in the field of Lean production? To do this with some degree of objectivity, the best way is to use a statistical tool to check for significance: in this case the Chi squared test will do nicely. It is a relatively simple test to perform, and will say whether there is some statistically significant connection between production region and the Lean design level of the car models.

A few words of caution here, however. The Chi squared test is of course only as good at the data it is used on. In this case the data mass, despite being adequate for a test to be done, is nevertheless small. It is only based upon the input of twelve cars, multiplied by the number of chosen assemblies. This is still a very small data basis, prone to exaggerated irregularities. And in addition, it should not be taken to mean that any results will speak for *all* Asian cars or *all* North American or *all* European. It will simply say something about *these* Asian etc. cars. On the other hand, it is possible to see these cars as a proxy for the greater production – the cars are in most cases popular specimen that have at some point made up a sizeable part of the world's car park. As such, their build is significant. It is just necessary to see the limitations of the data clearly.

Secondly, it is only possible to test the frequency of the Lean design assemblies with this method – that is, how many unmarked cells there are in each region's fold. The Chi squared contingency test is based on frequencies as a part of a greater whole; the magnitudes are not easily incorporated into the comparison. Because of this, we will only test whether the production region has any significant impact on how often a car will get a "faster than average assembly" or "fewer parts than average assembly" result. An interesting enough comparison to make, however.

In tables eight and nine we can see the test data and the results. The test data is simply a count of how many unmarked cells tables six and seven contain for each region, for service times and parts respectively – the count for marked cells is only presented for the sake of easy comparison. For example, The Asian region of lower part of table six (consisting of the Honda Accord, the Hyundai Sonata, the Nissan Stanza/Bluebird and the Toyota Camry) contains 36 unmarked (faster than average) cells out of 52 total.

The test is done in the usual way. The null hypothesis of the test is that production region and frequency of "Fast" or "Lean" assemblies are unrelated. The calculation compares the actual, observed values with the expected values; the difference is squared and divided by the expected values. The expected values are calculated on the basis of row and column totals of the observed values. And in the end we get two values to be compared with the critical value – the critical value from the Chi squared tables is in this case 5,991: two degrees of freedom and a 95 % confidence interval (a common choice).

And the comparison shows the following: in the case of service times, since 15,561 is greater than 5,991, we REJECT the null hypothesis that production region and frequency of "Fast" assemblies are unrelated, at a 95% confidence level. Production region DOES matter. In fact, the results are so strong that they hold even on a confidence level of 99,9 % (with a critical value of 13,816).

And to see which region wins the comparison, it is only necessary to look at the regional breakdown: the Asian producers have considerably more "fast" assemblies than the Europeans and somewhat more than the North Americans. In other worlds, the Asian cars use assemblies that are easy to assemble more often than all others. A result that is thoroughly supported by the theory, of course. If anything, it is only surprising that the Asian advantage was not greater than this.

However, the second comparison – the parts count – looks somewhat different. The test's output value is only 3,258. The critical value, of two degrees of freedom and a 95 % confidence interval, is still 5,991. In this case, since 3,258 is less than 5,991, we must ACCEPT the null hypothesis that production region and frequency of "Lean" assemblies are unrelated, at a 95% confidence level. In fact, we can only reject the null hypothesis at an 80 % confidence level (with a critical value of 3,219).

Table 8. Chi squared test of service time.

		"FAST" assemblies or no. cells smaller than or equal to group average	"SLOW" assemblies or no. cells bigger than group average
Honda Accord DX	ASIA	8	5
Hyundai Sonata GL		11	2
Nissan Stanza/Bluebird XE		8	5
Toyota Camry		9	4
Audi 80 2.0E	EURO	4	9
Peugeot 405 Mi16		2	11
Saab 900		3	10
Volkswagen Passat GL		8	5
Ford Taurus L	USA	10	3
Dodge Spirit		9	4
Chevrolet Corsica LT		7	6
Buick Skylark Ltd		6	7

OBSERVED

	"FAST" assemblies	"SLOW" assemblies	
Asian	36	16	52
European	17	35	52
North American	32	20	52
	85	71	156

EXCPECTED

	"FAST" assemblies	"SLOW" assemblies
Asian	28,33	23,67
European	28,33	23,67
North American	28,33	23,67

$$\frac{(Observed - Expected)^2}{Expected} = 15{,}561$$

Degrees of Freedom	2
Probability	0,95
Critical Value	5,991

Since 5,991 < 15,561 we REJECT the null hypothesis,
that origin and "Lean-ness" of service times are unrelated, at a 95% confidence level

Table 9. Chi squared test of parts count.

		"LEAN" assemblies or no. cells smaller than or equal to group average	"CRAMMED" assemblies or no. cells bigger than group average
Honda Accord DX	ASIA	4	11
Hyundai Sonata GL		8	7
Nissan Stanza/Bluebird XE		8	7
Toyota Camry		10	5
Audi 80 2.0E	EURO	12	3
Peugeot 405 Mi16		7	8
Saab 900		7	8
Volkswagen Passat GL		7	8
Ford Taurus L	USA	14	1
Dodge Spirit		8	7
Chevrolet Corsica LT		6	9
Buick Skylark Ltd		12	3

OBSERVED

	"LEAN" assemblies	"CRAMMED" assemblies	
Asian	30	28	58
European	33	25	58
North American	40	19	59
	103	72	175

EXCPECTED

	"LEAN" assemblies	"CRAMMED" assemblies
Asian	34,14	23,86
European	34,14	23,86
North American	34,73	24,27

$$\frac{(Observed - Expected)^2}{Expected} = 3{,}258$$

Degrees of Freedom	2
Probability	0,95
Critical Value	5,991

Since 3,258 < 5,991 we ACCEPT the null hypothesis,
that origin and "Lean-ness" of parts are unrelated, at a 95% confidence level

And why is this? Service time being clearly related to related to region, but not parts count? An unexpected outcome. In all due probability, the two areas should be related, and support each other. For instance, we can remember that one of the basic steps in reducing assembly time is "Minimize assembly component count".

Furthermore, if we inspect the regional breakdown again, we see that the Asian producers in this case fall behind both the Europeans and the North Americans. The North Americans are actually quite overwhelming in this case. Of course, since the Chi squared test gave a relatively small significance to the test this time, it is possible that this does not mean anything. But it does seem as is the Asians are weaker in this comparison.

Correlation of service time and parts count

From the results obtained here it is easy to begin to doubt the correlation of the two areas of measurement, service times and parts count. If they totally unrelated to each other, it will certainly be a complicated task to say which region or company produce the Leanest cars, and the whole concept of DFMA will be suspicious. Everything points towards that the two areas should be closely linked on all counts.

To actually find out which way the issue goes, it is at this point more or less necessary to see whether the two data collections show any correlation in their breakdown. This is a relatively easy thing to do, with the data in an easily comparable format as it is. However, one thing should be done before actually calculating: the two data tables still contain a few assembly data points that are only present in one of the tables – the cases where for instance service time data could be found but no parts count chart.

If we simply delete these, (seat and engine/trans assy. in one case, air cleaner, cooling system, instrument panel and center console in the other – see table five) the data in tables six and seven is a good basis for calculating the correlation. The result, as it turns out is a significantly high, positive correlation:

0,505. We can see the same thing if we graph the two data sets against each other, total parts count time (the sum of all the chosen assemblies) against the total service – see figure nine. (For a more in depth study of the correlation and cohesion of the individual assemblies, also see figure 16. The resulting data points are relatively close together, and form a clear line, pointing upwards.)

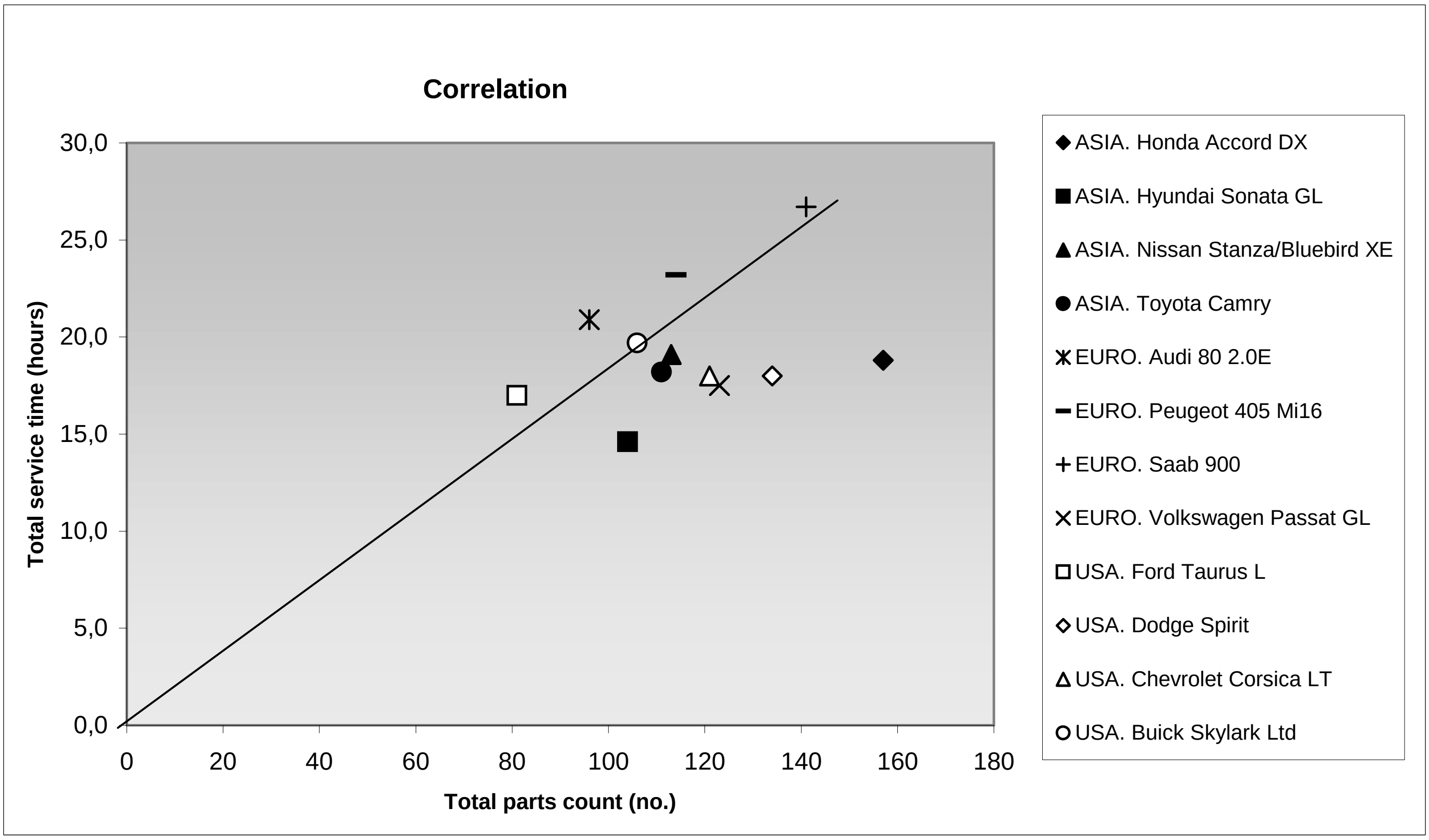


Figure 9. Correlation of Service time and Parts count.

This is a good result, showing what we suspected, that parts count and service time is indeed highly correlated. What the result also says, however, is that there is something else to the equation; that service time does not only depend on parts count. The difference between our result and perfect positive correlation, one, is also about 0,5. We can assume that it is made up from a number of different factors, such as design and material, much in the way we saw in the chapter on DFMA.

Thus the original question remains. If one chooses to consider the parts count frequency test as at least somewhat significant, it is intriguing that the Asian producers, which did so well in the service time test, would do poorly in this test. And furthermore, that the North American producers would in fact be the best in this category. Does this suggest that the American producers are good at DFM, while the Asian producers prefer DFA? An interesting thought. It is obvious, however, that more in-depth study of the individual cars models is necessary.

4.3. Scatterplots of Lean design – regional cohesion and the Leanest car

In this section we'll try to find the answers to the second and third research questions: will the cars' results be so close for different companies in the same region that something can be said about the region's expertise, and what cars will in fact come out on top and bottom in the test? This is easiest accomplished by visual means, graphing what results we have already produced in the former sections.

For instance, to see whether a car is Lean or not, the frequency – of assemblies faster to service than average or using less parts than average – is only one dimension. The magnitude of the differences is also just as important. So a measure of the total magnitude of how much more fast a car is to service or how much fewer parts it uses is also necessary.

To do this, there are two readily available possibilities. One can sum up the percentage differences from average, or even take the average of the averages – or simply calculate the total service time and the total parts count. The former method, however, has the drawback that it doesn't really mean anything tangible anymore: a car model may have seats that can be changed 50 percent faster than average, and an engine than is 50 percent slower than average. Even if the sum total of the averages is zero, the actual service time will still be dominated by the slow-to-service engine. Thus it makes sense to use the actual service times or parts count as a measure of DFMA magnitude.

The aim is of course to have as short a service time total as possible (and the same for the parts count total). For the graph to be more intuitively clear, we should put the frequency of *above* average service times and parts count on the other axis: this way the Lean "direction" is towards the origin of both axis. The result is shown in figures ten and eleven.

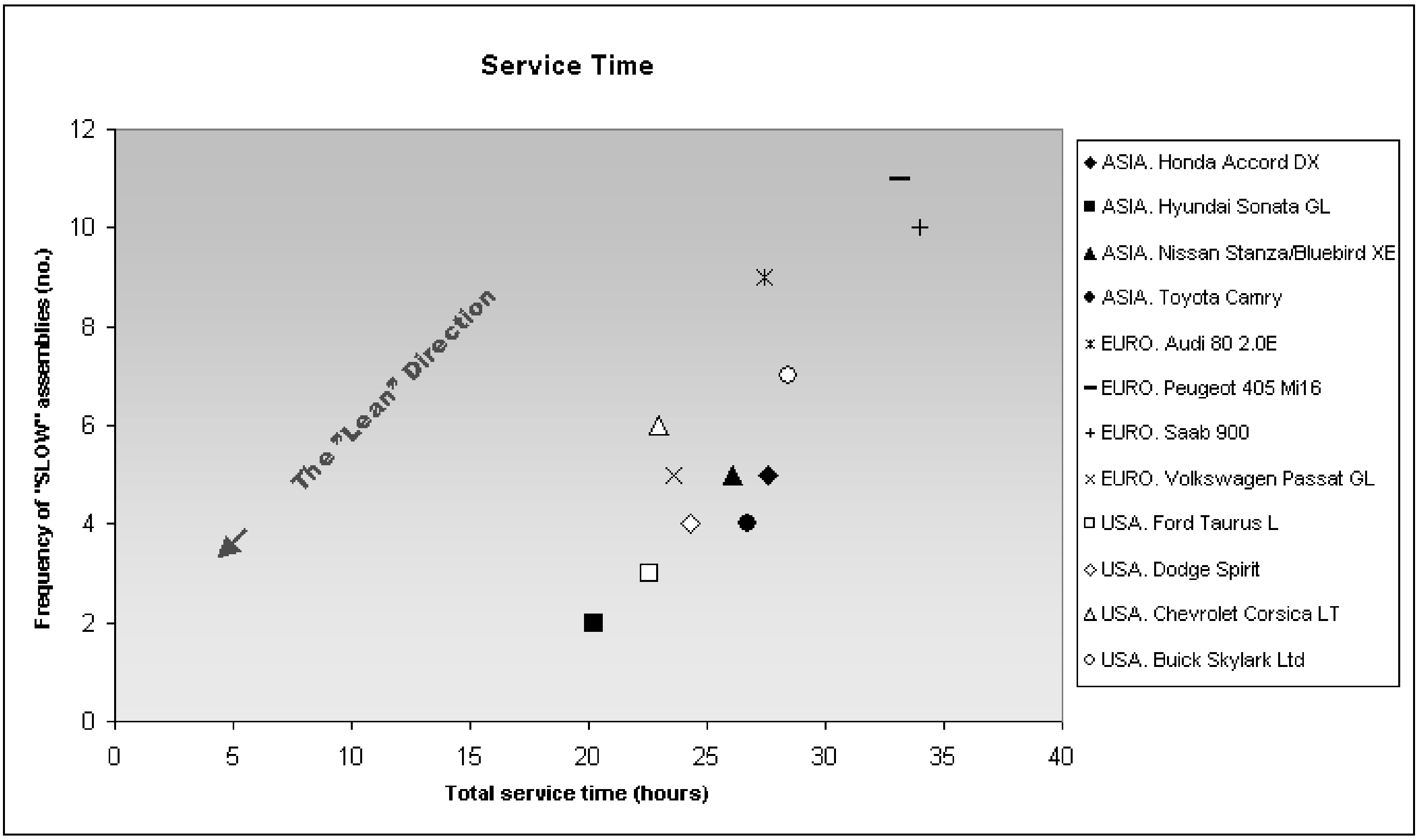


Figure 10. Individual results (Service time).

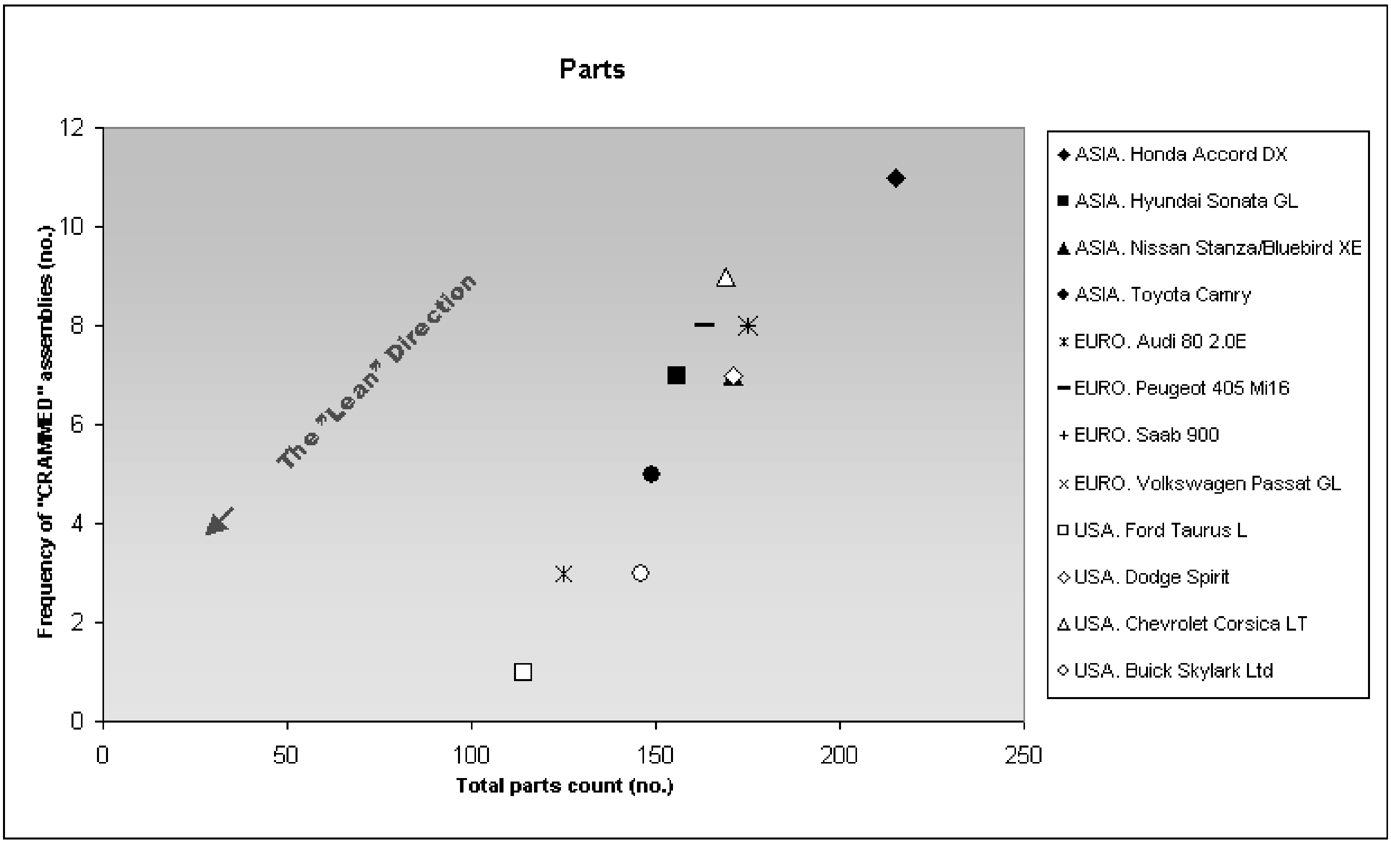


Figure 11. Individual results (Parts count).

Regional cohesion

Now we can already see some answers to the research questions. The service time graph (figure ten) shows us a relatively high degree of regional cohesion. Not perfect such, of course, but the cars are generally quite closely grouped into three distinct areas. The Asian producers probably lie furthest towards origin, but the North Americans are very close. Finally, the Europeans lie farthest away, as was expected in accordance with the theory. Again, we are struck by the fact that the difference between the Asian and North American producers is so small, when all is said and done. The staggering Asian advantage in production methods spoken of in *"The Machine That Changed the World"* seems thin in this comparison.

But we can note that the Japanese car models are tied very closely to each other: their car models are very similar to each other in DFA rating. Interestingly enough, the fourth Asian producer, South Korean Hyundai, is an outlier, in the even more Lean direction. In comparison, the European and North American producers' values are more individual.

The other graph (figure eleven) showing parts count total and the frequency of "crammed" assemblies, on the other hand, does not indicate any particular regional cohesion. The car models are if anything spread almost evenly over the "Lean line", from most Lean to least. But, if a distinction has to be made, the Asians seem to lie the farthest out, the Americas closest in. At this point we should remember the Chi squared –test's outcome, that there is no statistically significant regional trend for parts count, and that the spread between a region's producers is undoubtedly large. But nevertheless, it is interesting to speculate over this unusual turn of events.

The Leanest car

Now it is possible to say something about the individual successes of the car models. The winner of the Lean design "competition" when talking about service time is clearly the Hyundai Sonata. Conversely, the Peugeot 405 and Saab 900 probably share their place at the far end of the Lean line. The Saab is hardly a surprising candidate for this dubious honour, Saab being a generally smaller producer than the other – it is not strange that they would have a lower focus on DFA than its competitors. Furthermore, the Swedish focus on safety issues may or may not be playing its part in inflating the Saab's service time.

More surprising is the Hyundai Sonata. Not in that it is Asian, but simply because it is not Japanese. The story Womack et al. (1990: 261-263) tell about the South Koran situation, is mainly based on the launch and production of the Hyundai Excel model, which somewhat predates the Sonata (1985-1994). It is told by them that sales in the United States of the Excel model fell 50 percent between 1988 and 1990, mainly because of the poor quality of the car, and the fact that the Korean currency was beginning to strengthen against the dollar in 1988. The Sonata, must reasonably argued have been much in the same situation. It was, like the Excel, a product of the old production system and was to a great degree conceived in collaboration with other companies: it got its design done by an Italian designer, and featured a Japanese Mitsubishi engine (Cars-directory 2009h).

Because of these facts, the Hyundai Sonata's victory is remarkable. One can only speculate as to the explanation: Possibly, in this case, the car was simple in design, and thus easy to assemble, possibly Hyundai was simply well versed in the art of DFA. So whether this outcome was a fluke or not, is actually a quite important question to this work – are the DFMA and Lean production principles more unrelated than we thought? The good overall Asian result says no, but still, the suspicion is there.

In the other graph, the parts count figure, the winner is Ford Taurus and the loser Honda Accord – unambiguously so. Both results are interesting. If one reviews the background of Ford Taurus, however, it is said the focus on design in this model (first generation, 1986-1991) was tangible. In fact, Ford Taurus is was a very important new product to Ford Motor Company, the car that would end the bad streak of money and market share loss. The goal was to create something entirely new –*"a "world class" car with styling, engineering, and performance equal to or better than any similar sized car"* (The Henry Ford 1999). In doing this, design engineers, stylists, manufacturing engineers, and marketing people were brought together, and the design was created as a complete unit. Ford also used benchmarking to identifying competitive cars with the best features and trying to create equal or improved versions of them in the Taurus. It is also mentioned that *"great emphasis was put on design for quality low cost manufacturing."* (The Henry Ford 1999.) This very Lean way of acting may well account for the Taurus' overall high score in the comparison, and especially its good DFM ranking.

And the Honda Accord? Why would a car produced by one of the world leaders in Japanese Lean Production come last in this kind of comparison? Again, one can find possible explanations in the model's history: the fourth generation of the model was launched in 1990, and it sported several new engineering features. It came with a new electronic fuel injected engine, an all aluminium power train, an electronically controlled rear engine mount to reduce low frequency noise and vibration (Cars-directory 2009c). Their suspension and steering systems may well have been added to in the same run, drawing down the overall DFM value. This is in fact a train of thought that would deserve some thought in future research – do later, updated versions of the same car exhibit lower results in DFA and DFM because of the additions?

To make comparison a bit more easy, a rough ranking list can be made from the scatterplots – ranking those that come the closest to origin as best (most Lean). This will be a very unscientific ranking in that that several of the car's results are very close to each other. However, if the attempt is made, it gets easier to see if there is any overlap in the two fields.

	Service time			Parts count	
1.	ASIA.	Hyundai Sonata GL	1.	USA.	Ford Taurus L
2.	USA.	Ford Taurus L	2.	EURO.	Audi 80 2.0E
3.	USA.	Dodge Spirit	3.	USA.	Buick Skylark Ltd
4.	EURO.	Volkswagen Passat GL	4.	ASIA.	Toyota Camry
5.	ASIA.	Toyota Camry	5.	ASIA.	Hyundai Sonata GL
6.	ASIA.	Nissan Stanza/Bluebird XE	6.	USA.	Dodge Spirit
7.	ASIA.	Honda Accord DX	7.	ASIA.	Nissan Stanza/Bluebird XE
8.	USA.	Chevrolet Corsica LT	8.	EURO.	Peugeot 405 Mi16
9.	USA.	Buick Skylark Ltd	9.	EURO.	Volkswagen Passat GL
10.	EURO.	Audi 80 2.0E	10.	EURO.	Saab 900
11.	EURO.	Saab 900	11.	USA.	Chevrolet Corsica LT
12.	EURO.	Peugeot 405 Mi16	12.	ASIA.	Honda Accord DX

Table 10. Internal ranking of cars.

For instance, Ford Taurus is a strong candidate in both rankings, ultimately making it the Leanest car in this work. Saab 900 is at the other end of the spectrum, pretty much. Among the Asian cars, Hyundai Sonata and Toyota Camry get relatively strong results both times. There are no candidates that would be entirely in different ends of the rankings, even if in most cases, there are a few places difference between a models place in respective list. In any case, the results of the analysis as a whole are not exactly what one would expect. If we try and explain the parts count numbers with individual design reasons, why would then the service times exhibit a much greater degree of regional cohesion? Should also the service time numbers be explained individually?

5. DISCUSSION AND SUGGESTIONS FOR FURTHER STUDY

So let us look at some possible reasons why our results would turn out this way. The Asian car producers turned out to be the best at Design for Assembly, but not overwhelmingly so. The American producers were possibly best at Design for Manufacture, but the results were too weak to say anything definite about regional success. It nevertheless looked as if the Asian producers were much weaker in this category. Mainly it seemed that the result were highly individual in the DFM section, while reasonably regional in the DFA.

An important finding here is the fact that the Asian and especially the Japanese producers did not achieve an overwhelming victory in this analysis. According to for instance the survey carried out by the MIT International Motor Vehicle Program, the Japanese automakers have an edge in manufacturability, much in the same way that they excel at production performances. If we again study that survey data (see figure two) we see that Toyota, Honda and Nissan are first, second and fifth, respectively. The European producers trail at the end, Ford is the highest ranking of the North American producers.

This is at odds with the rankings in table ten – not necessarily to any significant degree, but nevertheless. Unless we choose to reject the indications of the IMVP survey, the discrepancy should probably be sought elsewhere. There are, in fact, at least three different possibilities why our results should differ the way they do.

Firstly – it is possible that there is a more substantial difference between the two areas of Lean design, DFM and DFA than previously suspected. The collective term DFMA may be misleading – if automobile producers treat the two methods as separate, distinct processes the outcome may well be something like the results we saw in this analysis. If automakers furthermore value DFA higher, and focus more on throughput and production figures rather than material cost, the outcome would probably be greater regularity and regional cohesion of the service time data, much like what we saw here. There is nothing that specifically speaks against this hypothesis. This could very well be the case – only a more in depth study of the individual producer companies could possibly give the answer. However, since there is no specific evidence either way, so far, it is best to leave the decision undone.

Secondly – the possibility that Lean Production and DFMA are not as thoroughly related as one might think. The data that that forms the basis of this analysis is probably quite suitable for ascertaining the DFMA level of a car model: that is why it was chosen in the first place. However, there is nothing that says that a company that truly excels in Lean production methods (such as Toyota) need be more than just good at DFMA. The two principles aim towards the same goal, but there is not necessarily any causality or cohesion between the two. It would just seem probable that this is the case. Probable is not the same thing as definite, though.

Personally, I am going to assume the third reason: inconclusive data. As stated earlier on, a data analysis based on twelve vehicles only, will not really be able to say anything certain about a region's output, nor really anything about a company's extended production. What the Chi squared analysis showed was the success of *these* Asian, American and European cars, and the fact that individual design successes stand out so pointedly (e.g. the Ford Taurus) only goes to show that a sufficiently large statistical database has not been established. As we could see, the correlation between the two design methods DFM and DFA was high, but not a hundred percent. My guess is that the individual car models in this case displayed large discrepancies between the two methods simply because of reasons unrelated to this analysis, i.e. model development stage, the trade-off between simplicity of design and model quality, etc. This sort of variation could only be reduced by increasing the sample size.

Furthermore, this data analysis was, of course, a point sample: one year only, and only one type of car presented. The automakers ranking their competitors have most probably seen a wide spectrum of cars over along period of time, allowing them to focus on the trend rather than the year's crop. This would certainly smooth out wilder peaks and slumps in a company's production.

Further study

The logical next step, then? To broaden the scope of the data basis, over several years and more models, probably. That might enable the analysis to see what the automakers of the IMVP survey saw, or if not, provide a more secure basis to make contradictory assumptions from. If the outcome still shows discrepancies with the survey data, then it may start to make sense to doubt the survey instead of objective data – perhaps there are things of interest to be found in the discrepancies.

And how will this best be achieved? The only way to expand the year 1990 database is to allow other body types and layouts into the comparison, since the sedan, family model comparison was already exhausted in this work. The different models will not be directly comparable to each other, but the Chi squared type analysis of how often a specific car model has displayed "above average" or "below average" results should be possible to perform on an extended model database too. The economy car class has several different possible subsets, based on door layout and motor size, the family car class could be augmented by a station wagon class and a separate section for sports car or luxury cars could also be a possibility.

To broaden the spectrum over further years simply means gathering more Michell International Collision Estimating guides and repeating the process. To move forwards in time would give the possibility to see whether the different production regions have really started to converge in their design practises, and whether the Asian automakers have been able to keep their grip on the lead position. A sample point close to our time, and possibly one in between, would already mean a much clearer picture of what has been happening since the time of *The Machine.*

6. CONCLUSION

In conclusion, it can only be said that the data analysis produced good results, but with a somewhat counter-intuitive twist at the end, that makes it necessary for the study to continue.

The original point of interest was to answer whether Asian cars really are Leaner in design, and whether the selected cars' results would be so close that something can be said about the region's expertise. And, of course, to see what cars would come out on top and bottom in the test. These questions were answered, yes, but what does it all mean? The answers, respectively, would be: *only in the DFA section, only in DFA section, top: Hyundai Sonata and Ford Taurus, bottom: Saab 900 and Honda Accord*. We tested the significance of production region on the usage of "Leaner" assemblies in car models and got the answer that there *is* a significant impact on service times. On parts count, there is *probably* not. Furthermore, we saw that there is a relatively good degree of regional cohesion in the test results on service times – but not in the parts counts'.

Interestingly enough, at least three of the car models that either "won" or "lost" the comparison are – if not unexpected – than at least contrary to the theoretical assumptions that we made in the beginning of the study. The supremacy of traditional production methods in producing the fast service Hyundai Sonata is one example, and the failure of the Lean production system in producing the crammed parts Honda Accord is another.

The theory, based to a high degree on the findings of the MIT International Motor Vehicle Programme, indicates the Asian and especially Japanese strength in Lean production methods: the system originated there, and spread from there – logically the Japanese are well versed in the principles of Lean. Less clear, but nevertheless quite convincing, is the linkage between Lean production and Design for Manufacture and Assembly. One is not the offshoot of the other, but the two principles aim in the same direction: a Leaner design of the car. Linking these two areas of thought is a logical step. However, the results seem to show a (slight) discrepancy between the two. It does not seem necessary for a Lean producer to be completely successful in the DFMA analysis.

There are, of course, several differing explanations as to why the outcome of the analysis would turn out the way it actually did – a separation of DFM and DFA, for instance, or that the cars' results despite the Chi squared analysis can be considered to be individual, not regional. It is clear that if some models were able to stand out as pointedly as they did, mainly because of individual merits, the data sample should be expanded. This should serve to give us a clearer view of why and how the Asian producers have earned their reputation as the most Lean designers, or at least create a more stable basis to make other assumptions from.

As for the significance of Lean Design and DFMA to the greater picture – consider the figures presented by Holweg and Pil (2004: 52) in summing up the development of the auto industry since 1990. The number of Japanese labour hours per vehicle was – in 1998 – 16,8 hours. This was more than thirty percent less than North America's 24,9 hours and more than fifty percent less than Europe's 35,5. The interesting thing, though, is that a decade later, in 2000, the Japanese productivity was still more than 25 % better than the North American and 35% better than the European (at 12,3 h, 16,8 h and 28,0 h respectively).

And the reason? Continuous improvement and sensible solutions such as Lean Design and DFMA. Implementing small improvements that cumulate over time to form an unmatched level of quality and production efficiency. Cost reductions that chip away at the greater costs, leaving small but significant contribution to the overall picture – and in the end, competitors are left standing, wondering where their market share went. Logically these kind improvements formed the basis of Asia's strong track record in automobile production, True, over the last two decades, there has been considerable convergence, happening, and the auto industry around the world now stand much closer to each other in terms of production practises. It should be noted, however, that much of this improvement, has happened through import of lean principles: as Holweg and Pil (2004: 51) somewhat dryly put it:

> *"Ford launched its Ford Production System; Lee Iacocca at Chrysler renamed lean production "agile manufacturing", and Mercedes-Benz and Volkdswagen translated kaizen as kontinuierlicher Verbesserungsprozess (KVP). Regardless of the name, the central tenets of Toyota's practises became the focus of improvement, at most major car producers."*

At the writing moment, the global recession is just gearing up, and it is treating all automakers harshly. Car sales have sunk by 41 percent since last year's February, with individual results of major producers varying from about 35 percent to 53 (GM taking the dubious place at the top). Seeing how this is being quoted as the worst industry sales situation in 40 years, this means that none of the worlds auto companies stand unaffected. (Welch & Kiley 2009.) In addition, the automotive industry as a whole now stands in front of a revolution of kind: perhaps the true advent of a new kind of car – energy efficiency, electricity, and hybrid technology being the name of the game. Perhaps now will even be the time when the true customer order car system will finally be implemented too, after almost thirty years of discussion (Holweg & Pil 2004). Now is the time for all auto companies to look over their deck and shuffle out all practises that do not fit the new way.

But the best thing about Lean practises such as Lean Design and DFMA, is that they are viable tools in whatever the car companies finally choose to do. They need not be discarded, since they will continue to make sense, regardless. They will not make a company a giant in a day, but they may well be the thing that makes a company a giant over time. They may well be the thing that makes or breaks a company in the long run of things, and they may well mean the difference between profit and loss when the times get tough. Whatever the future is about to bring, be it tank trucks or electrical go-carts, hovercraft or horse carriges, customer order or mass production – Lean design and DFMA will simply be there to make it better. The brave new world of the tomorrow will stand on the back of the DFMA of today – and that's a fact.

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APPENDIX 1. Figures

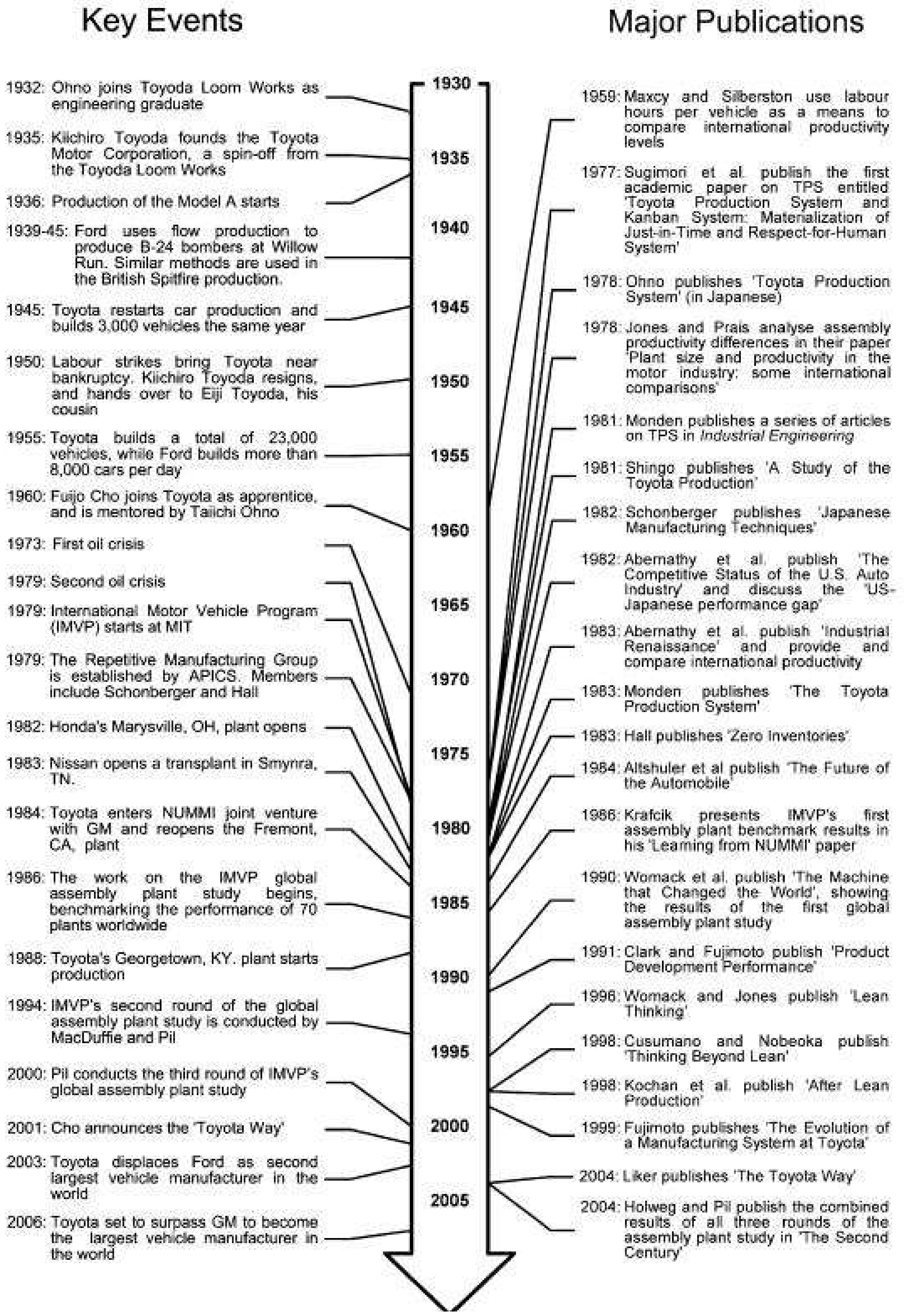
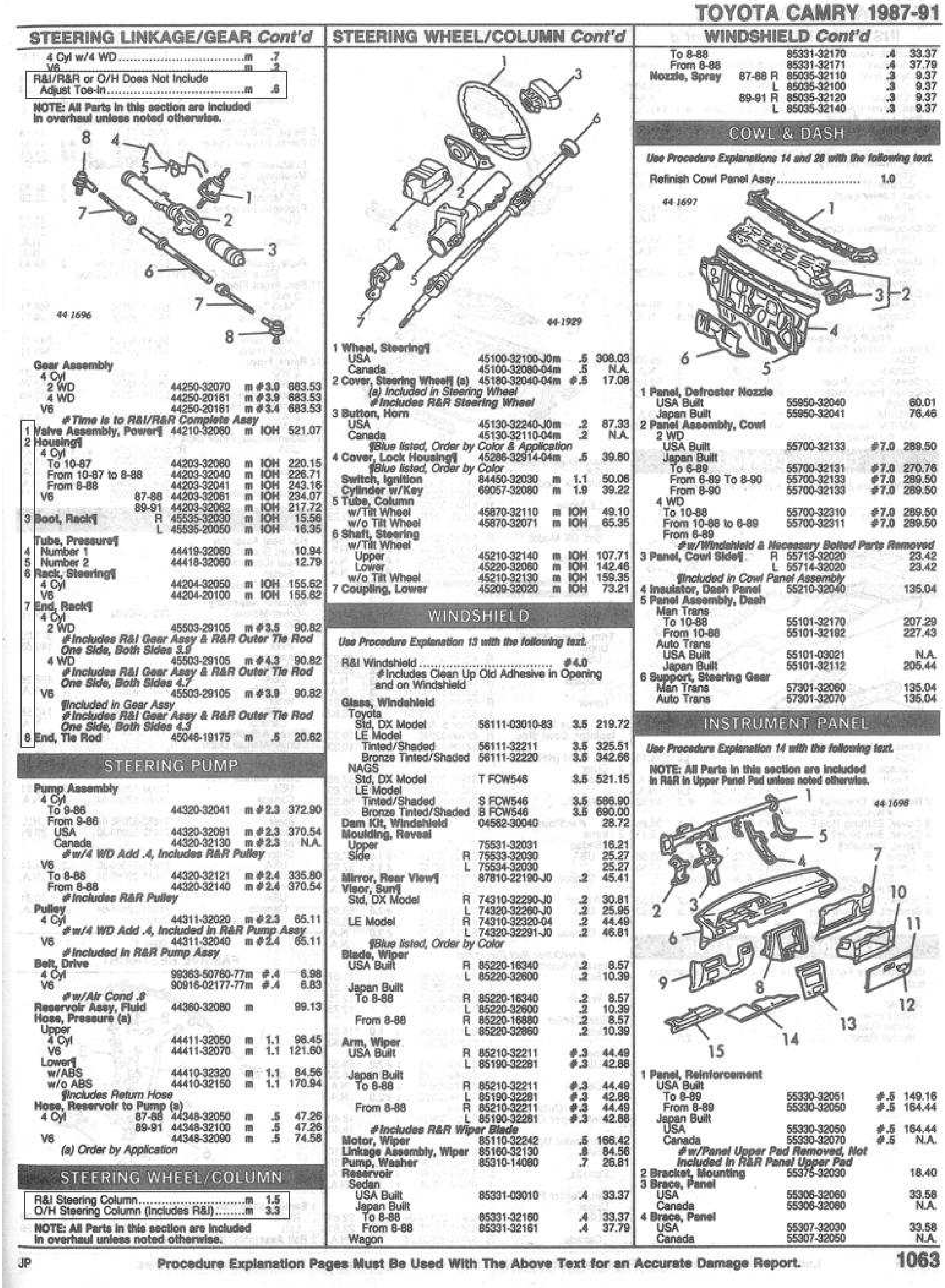


Figure 12. The timeline of Lean Production evolution (Holweg 2007: 434).



TOYOTA CAMRY 1987-91

STEERING LINKAGE/GEAR Cont'd

4 Cyl w/4 WD ....m .7
V6 ....m .2

R&I/R&R or O/H Does Not Include
Adjust Toe-In ....m .6

NOTE: All Parts in this section are included in overhaul unless noted otherwise.

44 1696

Gear Assembly					
4 Cyl					
2 WD		44250-32070	m	#3.0	683.53
4 WD		44250-20161	m	#3.9	683.53
V6		44250-20161	m	#3.4	683.53
#Time is to R&I/R&R Complete Assy					
1 **Valve Assembly, Power¶**		44210-32060	m	IOH	521.07
2 **Housing¶**					
4 Cyl					
To 10-87		44203-32060	m	IOH	220.15
From 10-87 to 8-88		44203-32040	m	IOH	226.71
From 8-88		44203-32041	m	IOH	243.16
V6	87-88	44203-32061	m	IOH	234.07
	89-91	44203-32062	m	IOH	217.72
3 **Boot, Rack¶**	R	45535-32030	m	IOH	15.56
	L	45535-20050	m	IOH	16.35
Tube, Pressure¶					
4 Number 1		44419-32060	m		10.94
5 Number 2		44418-32060	m		12.79
6 **Rack, Steering¶**					
4 Cyl		44204-32050	m	IOH	155.62
V6		44204-20100	m	IOH	155.62
7 **End, Rack¶**					
4 Cyl					
2 WD		45503-29105	m	#3.5	90.82
#Includes R&I Gear Assy & R&R Outer Tie Rod One Side, Both Sides 3.9					
4 WD		45503-29105	m	#4.3	90.82
#Includes R&I Gear Assy & R&R Outer Tie Rod One Side, Both Sides 4.7					
V6		45503-29105	m	#3.9	90.82
¶Included in Gear Assy					
#Includes R&I Gear Assy & R&R Outer Tie Rod One Side, Both Sides 4.3					
8 **End, Tie Rod**		45046-19175	m	.5	20.62

STEERING PUMP

Pump Assembly					
4 Cyl					
To 9-86		44320-32041	m	#2.3	372.90
From 9-86					
USA		44320-32091	m	#2.3	370.54
Canada		44320-32130	m	#2.3	N.A.
#w/4 WD Add .4, Includes R&R Pulley					
V6					
To 8-88		44320-32121	m	#2.4	335.80
From 8-88		44320-32140	m	#2.4	370.54
#Includes R&R Pulley					
Pulley					
4 Cyl		44311-32020	m	#2.3	65.11
#w/4 WD Add .4, Included in R&R Pump Assy					
V6		44311-32040	m	#2.4	65.11
#Included in R&R Pump Assy					
Belt, Drive					
4 Cyl		99363-50760-77	m	#.4	6.98
V6		90916-02177-77	m	#.4	6.83
#w/Air Cond .8					
Reservoir Assy, Fluid		44360-32080	m		99.13
Hose, Pressure (a)					
Upper					
4 Cyl		44411-32050	m	1.1	98.45
V6		44411-32070	m	1.1	121.60
Lower¶					
w/ABS		44410-32320	m	1.1	84.56
w/o ABS		44410-32150	m	1.1	170.94
¶Includes Return Hose					
Hose, Reservoir to Pump (a)					
4 Cyl	87-88	44348-32050	m	.5	47.26
	89-91	44348-32100	m	.5	47.26
V6		44348-32090	m	.5	74.58
(a) Order by Application					

STEERING WHEEL/COLUMN

R&I Steering Column ....m 1.5
O/H Steering Column (Includes R&I) ....m 3.3

NOTE: All Parts in this section are included in overhaul unless noted otherwise.

STEERING WHEEL/COLUMN Cont'd

44-1929

1 **Wheel, Steering¶**					
USA		45100-32100-J0	m	.5	308.03
Canada		45100-32080-04	m	.5	N.A.
2 **Cover, Steering Wheel¶ (a)**		45180-32040-04	m	#.5	17.08
(a) Included in Steering Wheel					
#Includes R&R Steering Wheel					
3 **Button, Horn**					
USA		45130-32240-J0	m	.2	87.33
Canada		45130-32110-04	m	.2	N.A.
¶Blue listed, Order by Color & Application					
4 **Cover, Lock Housing¶**		45286-32914-04	m	.5	39.80
¶Blue listed, Order by Color					
Switch, Ignition		84450-32030	m	1.1	50.06
Cylinder w/Key		69057-32080	m	1.9	39.22
5 **Tube, Column**					
w/Tilt Wheel		45870-32110	m	IOH	49.10
w/o Tilt Wheel		45870-32071	m	IOH	65.35
6 **Shaft, Steering**					
w/Tilt Wheel					
Upper		45210-32140	m	IOH	107.71
Lower		45220-32060	m	IOH	142.46
w/o Tilt Wheel		45210-32130	m	IOH	159.35
7 **Coupling, Lower**		45209-32020	m	IOH	73.21

WINDSHIELD

Use Procedure Explanation 13 with the following text.

R&I Windshield .... #4.0
#Includes Clean Up Old Adhesive in Opening and on Windshield

Glass, Windshield				
Toyota				
Std, DX Model		56111-03010-83	3.5	219.72
LE Model				
Tinted/Shaded		56111-32211	3.5	325.51
Bronze Tinted/Shaded		56111-32220	3.5	342.66
NAGS				
Std, DX Model		T FCW546	3.5	521.15
LE Model				
Tinted/Shaded		S FCW546	3.5	586.90
Bronze Tinted/Shaded		B FCW546	3.5	690.00
Dam Kit, Windshield		04562-30040		28.72
Moulding, Reveal				
Upper		75531-32031		16.21
Side	R	75533-32030		25.27
	L	75534-32030		25.27
Mirror, Rear View¶		87810-22190-J0	.2	45.41
Visor, Sun¶				
Std, DX Model	R	74310-32290-J0	.2	30.81
	L	74320-32260-J0	.2	25.95
LE Model	R	74310-32320-04	.2	44.49
	L	74320-32291-J0	.2	46.81
¶Blue listed, Order by Color				
Blade, Wiper				
USA Built	R	85220-16340	.2	8.57
	L	85220-32600	.2	10.39
Japan Built				
To 8-88	R	85220-16340	.2	8.57
	L	85220-32600	.2	10.39
From 8-88	R	85220-16880	.2	8.57
	L	85220-32860	.2	10.39
Arm, Wiper				
USA Built	R	85210-32211	#.3	44.49
	L	85190-32281	#.3	42.88
Japan Built				
To 8-88	R	85210-32211	#.3	44.49
	L	85190-32281	#.3	42.88
From 8-88	R	85210-32211	#.3	44.49
	L	85190-32281	#.3	42.88
#Includes R&R Wiper Blade				
Motor, Wiper		85110-32242	.5	166.42
Linkage Assembly, Wiper		85160-32130	.8	84.56
Pump, Washer		85310-14080	.7	26.81
Reservoir				
Sedan				
USA Built		85331-03010	.4	33.37
Japan Built				
To 8-88		85331-32160	.4	33.37
From 8-88		85331-32161	.4	37.79
Wagon				

WINDSHIELD Cont'd

To 8-88		85331-32170	.4	33.37
From 8-88		85331-32171	.4	37.79
Nozzle, Spray	87-88 R	85035-32110	.3	9.37
	L	85035-32100	.3	9.37
	89-91 R	85035-32120	.3	9.37
	L	85035-32140	.3	9.37

COWL & DASH

Use Procedure Explanations 14 and 28 with the following text.

Refinish Cowl Panel Assy 1.0

44 1697

1 **Panel, Defroster Nozzle**				
USA Built		55950-32040		60.01
Japan Built		55950-32041		76.46
2 **Panel Assembly, Cowl**				
2 WD				
USA Built		55700-32133	#7.0	289.50
Japan Built				
To 6-89		55700-32131	#7.0	270.76
From 6-89 To 8-90		55700-32133	#7.0	289.50
From 8-90		55700-32133	#7.0	289.50
4 WD				
To 10-88		55700-32310	#7.0	289.50
From 10-88 to 6-89		55700-32311	#7.0	289.50
From 6-89				
#w/Windshield & Necessary Bolted Parts Removed				
3 **Panel, Cowl Side¶**	R	55713-32020		23.42
	L	55714-32020		23.42
¶Included in Cowl Panel Assembly				
4 **Insulator, Dash Panel**		55210-32040		135.04
5 **Panel Assembly, Dash**				
Man Trans				
To 10-88		55101-32170		207.29
From 10-88		55101-32182		227.43
Auto Trans				
USA Built		55101-03021		N.A.
Japan Built		55101-32112		205.44
6 **Support, Steering Gear**				
Man Trans		57301-32060		135.04
Auto Trans		57301-32070		135.04

INSTRUMENT PANEL

Use Procedure Explanation 14 with the following text.

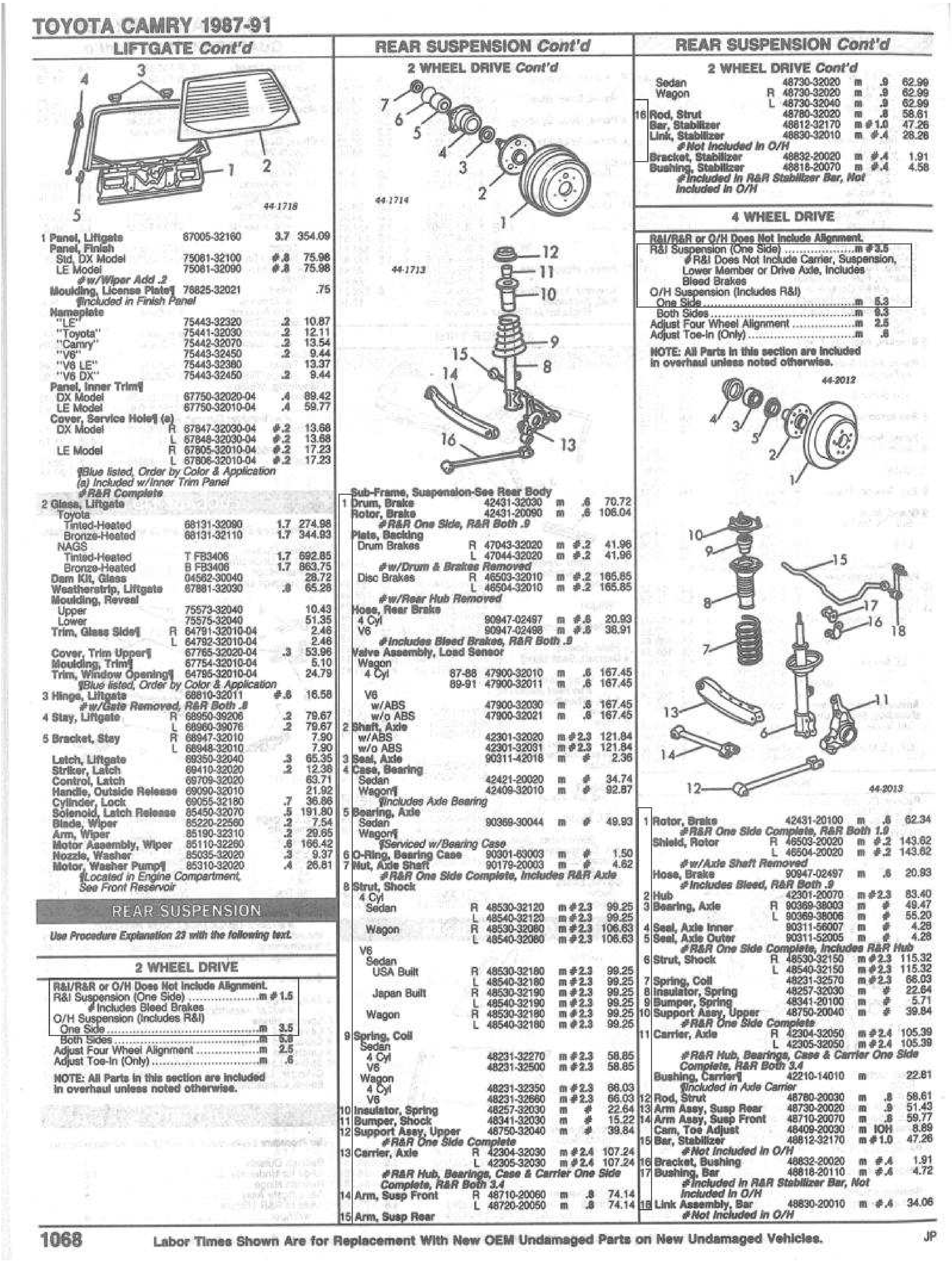
NOTE: All Parts in this section are included in R&R in Upper Panel Pad unless noted otherwise.

44 1698

1 **Panel, Reinforcement**			
USA Built			
To 8-89	55330-32051	#.5	149.16
From 8-89	55330-32050	#.5	164.44
Japan Built			
USA	55330-32050	#.5	164.44
Canada	55330-32070	#.5	N.A.
#w/Panel Upper Pad Removed, Not Included in R&R Panel Upper Pad			
2 **Bracket, Mounting**	55375-32030		18.40
3 **Brace, Panel**			
USA	55306-32060		33.58
Canada	55306-32080		N.A.
4 **Brace, Panel**			
USA	55307-32030		33.58
Canada	55307-32050		N.A.

JP **Procedure Explanation Pages Must Be Used With The Above Text for an Accurate Damage Report.** **1063**

Figure 13. Excerpt from a Collision estimating guide (1) (Collision Estimating Guide – Imported 1991: 1063).



TOYOTA CAMRY 1987-91

LIFTGATE *Cont'd*

1	**Panel, Liftgate**		67005-32160	3.7	354.09
	Panel, Finish				
	Std, DX Model		75081-32100	#.8	75.98
	LE Model		75081-32090	#.8	75.98
	#w/Wiper Add .2				
	Moulding, License Plate¶		76825-32021		.75
	¶Included in Finish Panel				
	Nameplate				
	"LE"		75443-32320	.2	10.87
	"Toyota"		75441-32030	.2	12.11
	"Camry"		75442-32070	.2	13.54
	"V6"		75443-32450	.2	9.44
	"V6 LE"		75443-32380		13.37
	"V6 DX"		75443-32450	.2	9.44
	Panel, Inner Trim¶				
	DX Model		67750-32020-04	.4	89.42
	LE Model		67750-32010-04	.4	59.77
	Cover, Service Hole¶ (a)				
	DX Model	R	67847-32030-04	#.2	13.68
		L	67848-32030-04	#.2	13.68
	LE Model	R	67805-32010-04	#.2	17.23
		L	67806-32010-04	#.2	17.23
	¶Blue listed, Order by Color & Application				
	(a) Included w/Inner Trim Panel				
	#R&R Complete				
2	**Glass, Liftgate**				
	Toyota				
	Tinted-Heated		68131-32090	1.7	274.98
	Bronze-Heated		68131-32110	1.7	344.93
	NAGS				
	Tinted-Heated		T FB3406	1.7	692.85
	Bronze-Heated		B FB3406	1.7	863.75
	Dam Kit, Glass		04562-30040		28.72
	Weatherstrip, Liftgate		67881-32030	.8	65.28
	Moulding, Reveal				
	Upper		75573-32040		10.43
	Lower		75575-32040		51.35
	Trim, Glass Side¶	R	64791-32010-04		2.46
		L	64792-32010-04		2.46
	Cover, Trim Upper¶		67765-32020-04	.3	53.96
	Moulding, Trim¶		67754-32010-04		5.10
	Trim, Window Opening¶		64795-32010-04		24.79
	¶Blue listed, Order by Color & Application				
3	**Hinge, Liftgate**		68810-32011	#.6	16.58
	#w/Gate Removed, R&R Both .8				
4	**Stay, Liftgate**	R	68950-39206	.2	79.67
		L	68960-39076	.2	79.67
5	**Bracket, Stay**	R	68947-32010		7.90
		L	68948-32010		7.90
	Latch, Liftgate		69350-32040	.3	65.35
	Striker, Latch		69410-32020	.2	12.38
	Control, Latch		69709-32020		63.71
	Handle, Outside Release		69090-32010		21.92
	Cylinder, Lock		69055-32180	.7	36.86
	Solenoid, Latch Release		85450-32070	.5	191.80
	Blade, Wiper		85220-22560	.2	7.54
	Arm, Wiper		85190-32310	.2	29.65
	Motor Assembly, Wiper		85110-32260	.6	166.42
	Nozzle, Washer		85035-32020	.3	9.37
	Motor, Washer Pump¶		85310-32020	.4	26.81
	¶Located in Engine Compartment, See Front Reservoir				

REAR SUSPENSION

Use Procedure Explanation 23 with the following text.

2 WHEEL DRIVE

R&I/R&R or O/H Does Not Include Alignment.
R&I Suspension (One Side) ....m #1.5
Includes Bleed Brakes
O/H Suspension (Includes R&I)
One Side ....m 3.5
Both Sides ....m 5.8
Adjust Four Wheel Alignment ....m 2.5
Adjust Toe-In (Only) ....m .6

NOTE: All Parts in this section are included in overhaul unless noted otherwise.

REAR SUSPENSION *Cont'd*

2 WHEEL DRIVE *Cont'd*

	Sub-Frame, Suspension-See Rear Body					
1	**Drum, Brake**		42431-32030	m	.6	70.72
	Rotor, Brake		42431-20090	m	.6	106.04
	#R&R One Side, R&R Both .9					
	Plate, Backing					
	Drum Brakes	R	47043-32020	m	#.2	41.96
		L	47044-32020	m	#.2	41.96
	#w/Drum & Brakes Removed					
	Disc Brakes	R	46503-32010	m	#.2	165.85
		L	46504-32010	m	#.2	165.85
	#w/Rear Hub Removed					
	Hose, Rear Brake					
	4 Cyl		90947-02497	m	#.6	20.93
	V6		90947-02498	m	#.6	38.91
	#Includes Bleed Brakes, R&R Both .9					
	Valve Assembly, Load Sensor					
	Wagon					
	4 Cyl	87-88	47900-32010	m	.6	167.45
		89-91	47900-32011	m	.6	167.45
	V6					
	w/ABS		47900-32030	m	.6	167.45
	w/o ABS		47900-32021	m	.6	167.45
2	**Shaft, Axle**					
	w/ABS		42301-32020	m	#2.3	121.84
	w/o ABS		42301-32031	m	#2.3	121.84
3	**Seal, Axle**		90311-42018	m	#	2.36
4	**Case, Bearing**					
	Sedan		42421-20020	m	#	34.74
	Wagon¶		42409-32010	m	#	92.87
	¶Includes Axle Bearing					
5	**Bearing, Axle**					
	Sedan		90369-30044	m	#	49.93
	Wagon¶					
	¶Serviced w/Bearing Case					
6	**O-Ring, Bearing Case**		90301-63003	m	#	1.50
7	**Nut, Axle Shaft**		90179-20003	m	#	4.62
	#R&R One Side Complete, Includes R&R Axle					
8	**Strut, Shock**					
	4 Cyl					
	Sedan	R	48530-32120	m	#2.3	99.25
		L	48540-32120	m	#2.3	99.25
	Wagon	R	48530-32080	m	#2.3	106.63
		L	48540-32080	m	#2.3	106.63
	V6					
	Sedan					
	USA Built	R	48530-32180	m	#2.3	99.25
		L	48540-32180	m	#2.3	99.25
	Japan Built	R	48530-32190	m	#2.3	99.25
		L	48540-32190	m	#2.3	99.25
	Wagon	R	48530-32180	m	#2.3	99.25
		L	48540-32180	m	#2.3	99.25
9	**Spring, Coil**					
	Sedan					
	4 Cyl		48231-32270	m	#2.3	58.85
	V6		48231-32500	m	#2.3	58.85
	Wagon					
	4 Cyl		48231-32350	m	#2.3	66.03
	V6		48231-32660	m	#2.3	66.03
10	**Insulator, Spring**		48257-32030	m	#	22.64
11	**Bumper, Shock**		48341-32030	m	#	15.22
12	**Support Assy, Upper**		48750-32040	m	#	39.84
	#R&R One Side Complete					
13	**Carrier, Axle**	R	42304-32030	m	#2.4	107.24
		L	42305-32030	m	#2.4	107.24
	#R&R Hub, Bearings, Case & Carrier One Side Complete, R&R Both 3.4					
14	**Arm, Susp Front**	R	48710-20060	m	.8	74.14
		L	48720-20050	m	.8	74.14
15	**Arm, Susp Rear**					
	Sedan		48730-32020	m	.9	62.99
	Wagon	R	48730-32020	m	.9	62.99
		L	48730-32040	m	.9	62.99
16	**Rod, Strut**		48780-32020	m	.8	58.61
	Bar, Stabilizer		48812-32170	m	#1.0	47.26
	Link, Stabilizer		48830-32010	m	#.4	28.26
	#Not Included in O/H					
	Bracket, Stabilizer		48832-20020	m	#.4	1.91
	Bushing, Stabilizer		48818-20070	m	#.4	4.58
	#Included in R&R Stabilizer Bar, Not Included in O/H					

4 WHEEL DRIVE

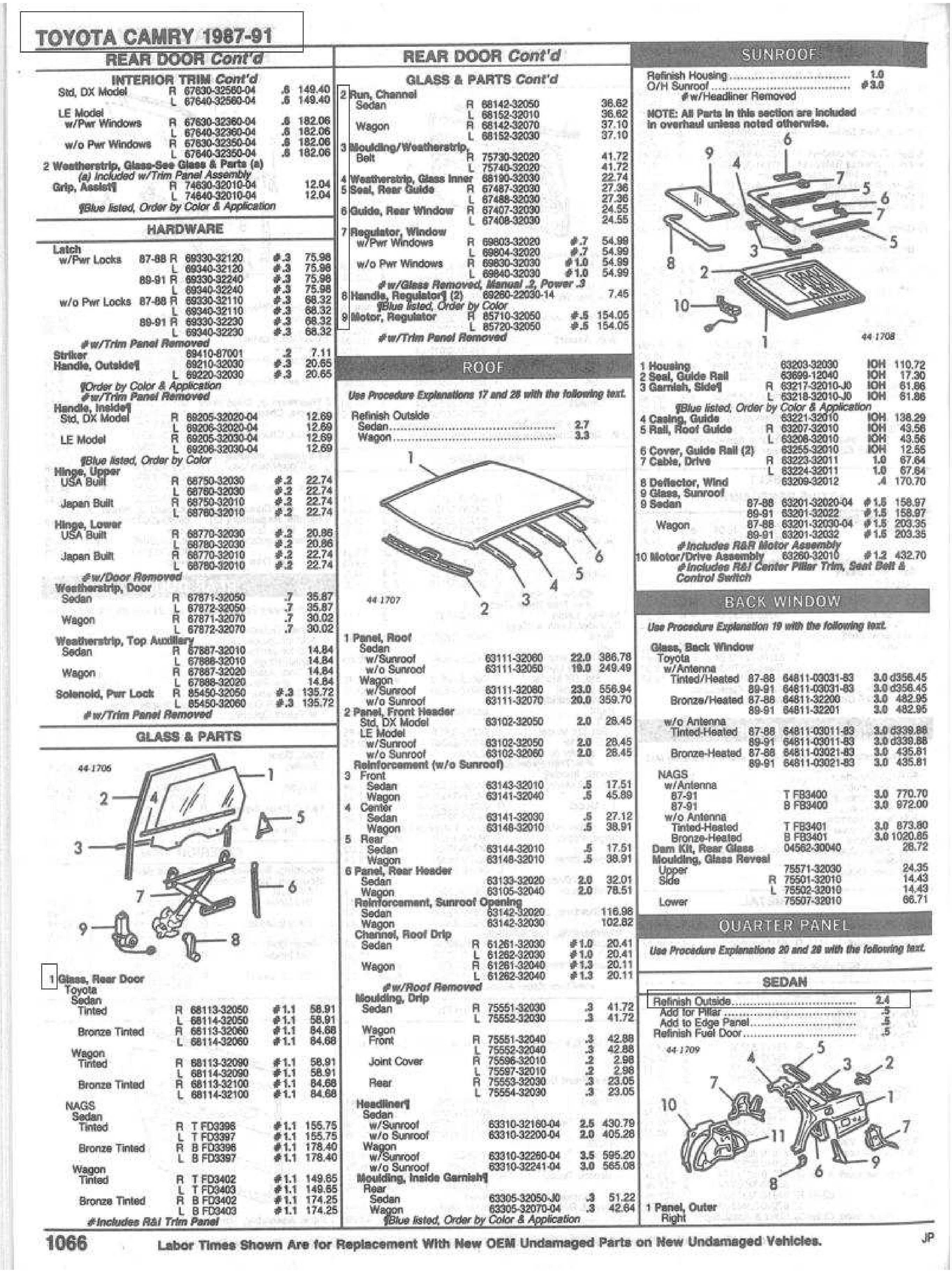
R&I/R&R or O/H Does Not Include Alignment.
R&I Suspension (One Side) ....m #3.5
#R&I Does Not Include Carrier, Suspension, Lower Member or Drive Axle, Includes Bleed Brakes
O/H Suspension (Includes R&I)
One Side ....m 5.3
Both Sides ....m 9.3
Adjust Four Wheel Alignment ....m 2.5
Adjust Toe-In (Only) ....m .6

NOTE: All Parts in this section are included in overhaul unless noted otherwise.

1	**Rotor, Brake**		42431-20100	m	.6	62.34
	#R&R One Side Complete, R&R Both 1.9					
	Shield, Rotor	R	46503-20020	m	#.2	143.62
		L	46504-20020	m	#.2	143.62
	#w/Axle Shaft Removed					
	Hose, Brake		90947-02497	m	.6	20.93
	#Includes Bleed, R&R Both .9					
2	**Hub**		42301-20070	m	#2.3	83.40
3	**Bearing, Axle**	R	90369-38003	m	#	49.47
		L	90369-38006	m	#	55.20
4	**Seal, Axle Inner**		90311-56007	m	#	4.28
5	**Seal, Axle Outer**		90311-52005	m	#	4.28
	#R&R One Side Complete, Includes R&R Hub					
6	**Strut, Shock**	R	48530-32150	m	#2.3	115.32
		L	48540-32150	m	#2.3	115.32
7	**Spring, Coil**		48231-32570	m	#2.3	66.03
8	**Insulator, Spring**		48257-32030	m	#	22.64
9	**Bumper, Spring**		48341-20100	m	#	5.71
10	**Support Assy, Upper**		48750-20040	m	#	39.84
	#R&R One Side Complete					
11	**Carrier, Axle**	R	42304-32050	m	#2.4	105.39
		L	42305-32050	m	#2.4	105.39
	#R&R Hub, Bearings, Case & Carrier One Side Complete, R&R Both 3.4					
	Bushing, Carrier¶		42210-14010	m		22.81
	¶Included in Axle Carrier					
12	**Rod, Strut**		48780-20030	m	.8	58.61
13	**Arm Assy, Susp Rear**		48730-20020	m	.9	51.43
14	**Arm Assy, Susp Front**		48710-20070	m	.8	59.77
	Cam, Toe Adjust		48409-20030	m	IOH	8.89
15	**Bar, Stabilizer**		48812-32170	m	#1.0	47.26
	#Not Included in O/H					
16	**Bracket, Bushing**		48832-20020	m	#.4	1.91
17	**Bushing, Bar**		48818-20110	m	#.4	4.72
	#Included in R&R Stabilizer Bar, Not Included in O/H					
18	**Link Assembly, Bar**		48830-20010	m	#.4	34.06
	#Not Included in O/H					

1068 **Labor Times Shown Are for Replacement With New OEM Undamaged Parts on New Undamaged Vehicles.** JP

Figure 14. Excerpt from a Collision estimating guide (2) (Collision Estimating Guide – Imported 1991: 1068).



TOYOTA CAMRY 1987-91

REAR DOOR *Cont'd*

INTERIOR TRIM *Cont'd*

Std, DX Model		R	67630-32560-04	.6	149.40
		L	67640-32560-04	.6	149.40
LE Model					
w/Pwr Windows		R	67630-32360-04	.6	182.06
		L	67640-32360-04	.6	182.06
w/o Pwr Windows		R	67630-32350-04	.6	182.06
		L	67640-32350-04	.6	182.06
2 Weatherstrip, Glass-See Glass & Parts (a)					
(a) Included w/Trim Panel Assembly					
Grip, Assist¶		R	74630-32010-04		12.04
		L	74640-32010-04		12.04
¶Blue listed, Order by Color & Application					

HARDWARE

Latch					
w/Pwr Locks	87-88	R	69330-32120	#.3	75.98
		L	69340-32120	#.3	75.98
	89-91	R	69330-32240	#.3	75.98
		L	69340-32240	#.3	75.98
w/o Pwr Locks	87-88	R	69330-32110	#.3	68.32
		L	69340-32110	#.3	68.32
	89-91	R	69330-32230	#.3	68.32
		L	69340-32230	#.3	68.32
#w/Trim Panel Removed					
Striker			69410-87001	.2	7.11
Handle, Outside¶			69210-32030	#.3	20.65
		L	69220-32030	#.3	20.65
¶Order by Color & Application					
#w/Trim Panel Removed					
Handle, Inside¶					
Std, DX Model		R	69205-32020-04		12.69
		L	69206-32020-04		12.69
LE Model		R	69205-32030-04		12.69
		L	69206-32030-04		12.69
¶Blue listed, Order by Color					
Hinge, Upper					
USA Built		R	68750-32030	#.2	22.74
		L	68760-32030	#.2	22.74
Japan Built		R	68750-32010	#.2	22.74
		L	68760-32010	#.2	22.74
Hinge, Lower					
USA Built		R	68770-32030	#.2	20.86
		L	68780-32030	#.2	20.86
Japan Built		R	68770-32010	#.2	22.74
		L	68780-32010	#.2	22.74
#w/Door Removed					
Weatherstrip, Door					
Sedan		R	67871-32050	.7	35.87
		L	67872-32050	.7	35.87
Wagon		R	67871-32070	.7	30.02
		L	67872-32070	.7	30.02
Weatherstrip, Top Auxiliary					
Sedan		R	67887-32010		14.84
		L	67888-32010		14.84
Wagon		R	67887-32020		14.84
		L	67888-32020		14.84
Solenoid, Pwr Lock		R	85450-32050	#.3	135.72
		L	85450-32060	#.3	135.72
#w/Trim Panel Removed					

GLASS & PARTS

44-1706

1 Glass, Rear Door					
Toyota					
Sedan					
Tinted		R	68113-32050	#1.1	58.91
		L	68114-32050	#1.1	58.91
Bronze Tinted		R	68113-32060	#1.1	84.68
		L	68114-32060	#1.1	84.68
Wagon					
Tinted		R	68113-32090	#1.1	58.91
		L	68114-32090	#1.1	58.91
Bronze Tinted		R	68113-32100	#1.1	84.68
		L	68114-32100	#1.1	84.68
NAGS					
Sedan					
Tinted		R	T FD3396	#1.1	155.75
		L	T FD3397	#1.1	155.75
Bronze Tinted		R	B FD3396	#1.1	178.40
		L	B FD3397	#1.1	178.40
Wagon					
Tinted		R	T FD3402	#1.1	149.65
		L	T FD3403	#1.1	149.65
Bronze Tinted		R	B FD3402	#1.1	174.25
		L	B FD3403	#1.1	174.25
#Includes R&I Trim Panel					

REAR DOOR *Cont'd*

GLASS & PARTS *Cont'd*

2 Run, Channel					
Sedan		R	68142-32050		36.62
		L	68152-32010		36.62
Wagon		R	68142-32070		37.10
		L	68152-32030		37.10
3 Moulding/Weatherstrip,					
Belt		R	75730-32020		41.72
		L	75740-32020		41.72
4 Weatherstrip, Glass Inner			68190-32030		22.74
5 Seal, Rear Guide		R	67487-32030		27.36
		L	67488-32030		27.36
6 Guide, Rear Window		R	67407-32030		24.55
		L	67408-32030		24.55
7 Regulator, Window					
w/Pwr Windows		R	69803-32020	#.7	54.99
		L	69804-32020	#.7	54.99
w/o Pwr Windows		R	69830-32030	#1.0	54.99
		L	69840-32030	#1.0	54.99
#w/Glass Removed, Manual .2, Power .3					
8 Handle, Regulator¶ (2)			69260-22030-14		7.45
¶Blue listed, Order by Color					
9 Motor, Regulator		R	85710-32050	#.5	154.05
		L	85720-32050	#.5	154.05
#w/Trim Panel Removed					

ROOF

Use Procedure Explanations 17 and 28 with the following text.

Refinish Outside	
Sedan	2.7
Wagon	3.3

44 1707

1 Panel, Roof					
Sedan					
w/Sunroof			63111-32060	22.0	386.78
w/o Sunroof			63111-32050	19.0	249.49
Wagon					
w/Sunroof			63111-32080	23.0	556.94
w/o Sunroof			63111-32070	20.0	359.70
2 Panel, Front Header					
Std, DX Model			63102-32050	2.0	28.45
LE Model					
w/Sunroof			63102-32050	2.0	28.45
w/o Sunroof			63102-32060	2.0	28.45
Reinforcement (w/o Sunroof)					
3 Front					
Sedan			63143-32010	.5	17.51
Wagon			63141-32040	.5	45.89
4 Center					
Sedan			63141-32030	.5	27.12
Wagon			63148-32010	.5	38.91
5 Rear					
Sedan			63144-32010	.5	17.51
Wagon			63148-32010	.5	38.91
6 Panel, Rear Header					
Sedan			63133-32020	2.0	32.01
Wagon			63105-32040	2.0	78.51
Reinforcement, Sunroof Opening					
Sedan			63142-32020		116.98
Wagon			63142-32030		102.82
Channel, Roof Drip					
Sedan		R	61261-32030	#1.0	20.41
		L	61262-32030	#1.0	20.41
Wagon		R	61261-32040	#1.3	20.11
		L	61262-32040	#1.3	20.11
#w/Roof Removed					
Moulding, Drip					
Sedan		R	75551-32030	.3	41.72
		L	75552-32030	.3	41.72
Wagon					
Front		R	75551-32040	.3	42.88
		L	75552-32040	.3	42.88
Joint Cover		R	75596-32010	.2	2.98
		L	75597-32010	.2	2.98
Rear		R	75553-32030	.3	23.05
		L	75554-32030	.3	23.05
Headliner¶					
Sedan					
w/Sunroof			63310-32160-04	2.5	430.79
w/o Sunroof			63310-32200-04	2.0	405.28
Wagon					
w/Sunroof			63310-32260-04	3.5	595.20
w/o Sunroof			63310-32241-04	3.0	565.08
Moulding, Inside Garnish¶					
Rear					
Sedan			63305-32050-J0	.3	51.22
Wagon			63305-32070-04	.3	42.64
¶Blue listed, Order by Color & Application					

SUNROOF

Refinish Housing	1.0
O/H Sunroof	#3.0
#w/Headliner Removed	

NOTE: All Parts in this section are included in overhaul unless noted otherwise.

44 1708

1 Housing			63203-32030	IOH	110.72
2 Seal, Guide Rail			63699-12040	IOH	17.30
3 Garnish, Side¶		R	63217-32010-J0	IOH	61.86
		L	63218-32010-J0	IOH	61.86
¶Blue listed, Order by Color & Application					
4 Casing, Guide			63221-32010	IOH	138.29
5 Rail, Roof Guide		R	63207-32010	IOH	43.56
		L	63208-32010	IOH	43.56
6 Cover, Guide Rail (2)			63255-32010	IOH	12.55
7 Cable, Drive		R	63223-32011	1.0	67.64
		L	63224-32011	1.0	67.64
8 Deflector, Wind			63209-32012	.4	170.70
9 Glass, Sunroof					
9 Sedan	87-88		63201-32020-04	#1.5	158.97
	89-91		63201-32022	#1.5	158.97
Wagon	87-88		63201-32030-04	#1.5	203.35
	89-91		63201-32032	#1.5	203.35
#Includes R&R Motor Assembly					
10 Motor/Drive Assembly			63260-32010	#1.2	432.70
#Includes R&I Center Pillar Trim, Seat Belt & Control Switch					

BACK WINDOW

Use Procedure Explanation 19 with the following text.

Glass, Back Window					
Toyota					
w/Antenna					
Tinted/Heated	87-88		64811-03031-83	3.0	d356.45
	89-91		64811-03031-83	3.0	d356.45
Bronze/Heated	87-88		64811-32200	3.0	482.95
	89-91		64811-32201	3.0	482.95
w/o Antenna					
Tinted-Heated	87-88		64811-03011-83	3.0	d339.88
	89-91		64811-03011-83	3.0	d339.88
Bronze-Heated	87-88		64811-03021-83	3.0	435.81
	89-91		64811-03021-83	3.0	435.81
NAGS					
w/Antenna					
87-91			T FB3400	3.0	770.70
87-91			B FB3400	3.0	972.00
w/o Antenna					
Tinted-Heated			T FB3401	3.0	873.80
Bronze-Heated			B FB3401	3.0	1020.85
Dam Kit, Rear Glass			04562-30040		28.72
Moulding, Glass Reveal					
Upper			75571-32030		24.35
Side		R	75501-32010		14.43
		L	75502-32010		14.43
Lower			75507-32010		66.71

QUARTER PANEL

Use Procedure Explanations 20 and 28 with the following text.

SEDAN

Refinish Outside	2.4
Add for Pillar	.5
Add to Edge Panel	.5
Refinish Fuel Door	.5

44-1709

1 Panel, Outer
Right

1066 **Labor Times Shown Are for Replacement With New OEM Undamaged Parts on New Undamaged Vehicles.** JP

Figure 15. Excerpt from a Collision estimating guide (3) (Collision Estimating Guide – Imported 1991: 1066).

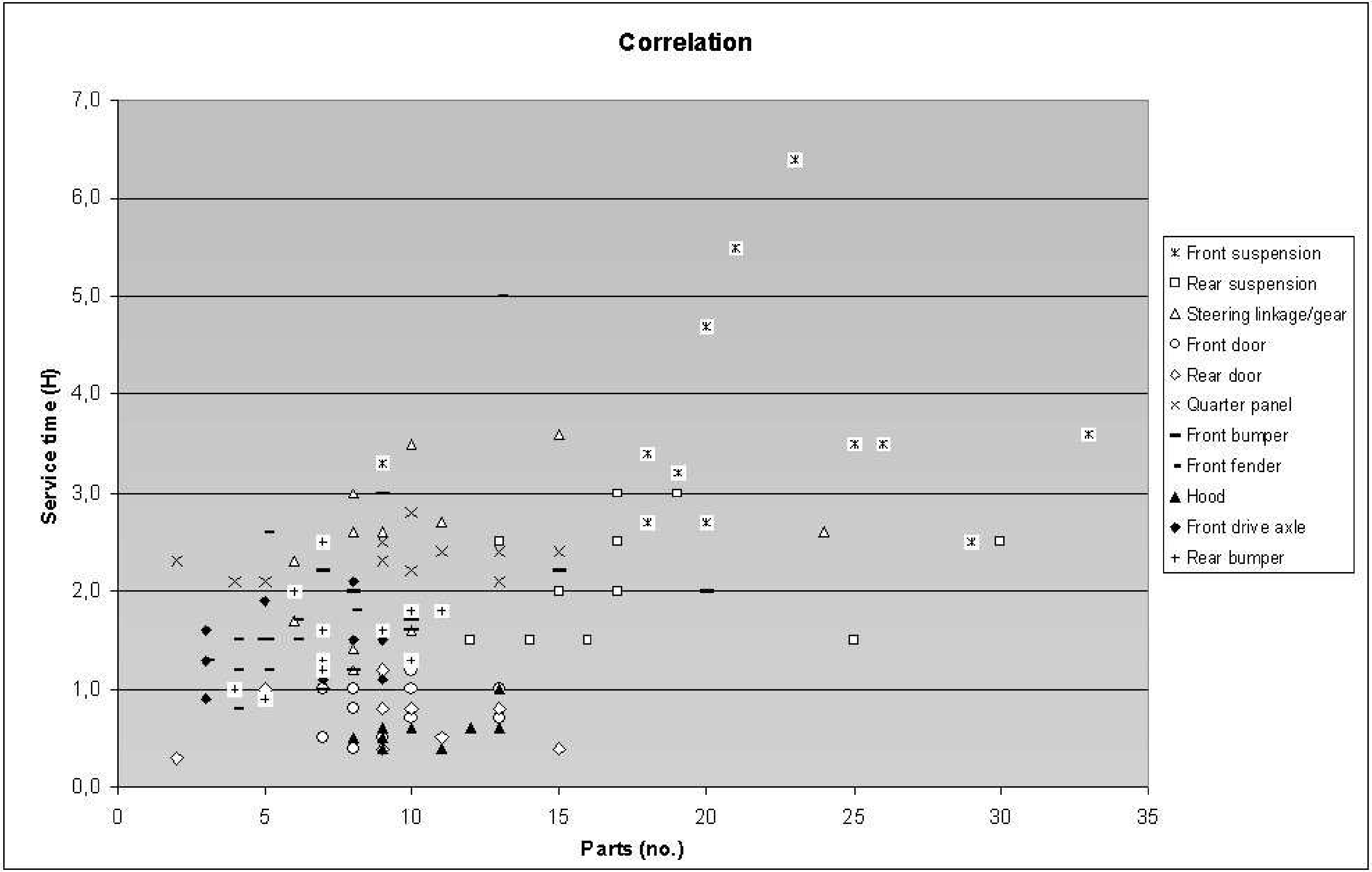


Figure 16. Correlation and cohesion of individual assemblies.