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Thirty Years of Benchmarking Product Development Performance: A Research Note

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Abstract

This discussion paper presents some key descriptive results and gives historical context to the recently completed 4th Round of the Global Automotive Development Study at the Harvard Business School. The Study features a unique set of longitudinal data (from the mid-1980s to late-2000s) on 99 vehicle development projects from 26 distinct automakers (OEMs) in the world auto industry. The paper compares the historical trends of Asian (Japanese & Korean) and Western (U.S. & W. European) OEM averages for various product-development performance and organizational metrics to show how automotive product development has changed over the past three decades.

Data on Asian OEMs, which have consistently shown a high level of participation in this Study, show that for the past decade there has been an increasing trend in both the average number of engineering hours and the average ratio of newly developed parts in development projects. This finding is a reversal of the downward trend shown by both these metrics between the early 1990s and the late 1990s. Western data for the past decade also shows an increasing average number of engineering hours, although the ratio of newly developed parts has now begun to trend downward. In the 1990s, Western OEMs showed an increasing trend for both these metrics. The current trend toward rising engineering hours in both Asia and the West suggests that vehicle development is becoming increasingly more difficult in recent years. We suggest that the growth in engineering hours may be attributable to OEMs inability to fully overcome growing vehicle complexity.

The Study's data indicate that engineering lead-time has continued to decrease for Asian OEMs in the 2000s, but that it is now decreasing at a lesser rate than in the past. Western data from the most recent round also exhibit shortening lead-time, which reverses the trend toward lengthening lead-time that the data exhibited in the 1990s. The authors interpret this finding to suggest that reducing development lead-time remains a strategic focus of OEMs. However, in Asia at least, efforts to shorten average lead-time may not be as high a priority as it has been in the past. It would seem that the primary focus of management has shifted to containing the growing complexity referred to above, rather than continuing to push for greater reductions in lead-time.

Taken as a whole, the Study's data gathered over the past quarter of a century do not seem to indicate fundamental changes in either the overall orientation or the core activities of New Product Development for traditional powertrain vehicles. Thus, within such vehicle development projects there remain the difficult critical tasks of both *internal integration* (achieving consistency in the product structure and functions) and *external integration* (matching development activities with the customer experience). For the foreseeable future, OEMs that outperform rivals in these two types of integration will have a product development advantage in the industry.

Keywords

automobile industry, new product development (NPD), project management, engineering efficiency, development lead time, product complexity, longitudinal data analysis

Discussion Paper (Ver. 5.4)

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1. Introduction

A quarter of a century has passed since The Global Automotive Study at the Harvard Business School (Harvard Auto Study) was launched in the mid-1980s. During that time, the Study has directly led to various influential works in the management of product development within firms (e.g., Clark & Fujimoto, 1990, 1991; Thomke & Fujimoto, 2000; Thomke, 2003, 2006).

The Study's unit of analysis is a new product development project at an automaker through which an internal-combustion-engine-powered vehicle is developed. An automaker (OEM) is defined at the level of an R&D Center. This approach allows the world auto industry to be analyzed based on the number of "independent product-development organizations" (Heller, Mercer, and Fujimoto, 2006). In the auto industry, a product-development organization can be operationalized as an R&D Center that is able to develop a vehicle on its own from concept creation to production preparation.[1]

The research approach that has under girded the Study since its inception is that of following the flow of information within organizations, between organizations, and between a firm and consumers (Clark and Fujimoto, 1991; and Fujimoto, 2007). Development of a product is viewed as a simulation of consumption of that product.[2] Successful product development requires a correct understanding of customer needs and how to meet them through a newly designed product that, in the case of automobiles, will involve hundreds of engineers and many different organizational units at an OEM and its suppliers.[3] Better product development performance can be obtained by improving (1) the accuracy with which the consumption experience is simulated and (2) the transfer of information between people for more effective and efficient problem solving to ensure that the product actually delivers the functionality to its users that it was designed to deliver.

The paper is organized as follows. In Section 2, we present a brief overview of the research methodology used and data collected in the four rounds to date of the Harvard Auto

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1 Thus, for example, Ford's American R&D Center near Detroit and its European R&D Center in Cologne would be counted as two distinct OEMs. Even with the close coordination of their activities under same umbrella organization of Ford Motor Company since the late 1990s, each entity contains its own product and process engineering organizations that are fully capable of undertaking all of the activities from concept creation to production preparation. On the other hand, Peugeot and Citroen, for example, would be counted as one single OEM. Though there is a significant separation between these two brands in the areas of product planning and marketing, there is essentially only one product and process engineering entity at PSA that develops both Peugeots and Citroens.

2 For a graphical representation of this point, see pg. 23 of Clark and Fujimoto, 1991

3 For additional discussion of this point see, Fujimoto, 2007.

Study. Next, in Section 3, we review the body of findings that came out of the Study through the first three rounds of the Study, as well as give an overview of the most recently completed fourth round. In Section 4, a number of figures are shown to indicate trends over the past 25 years in key development performance and organizational processes metrics, such as: ratio of newly developed parts, total engineering hours, ratio of black-box parts, lead-time, use of prototypes, and the role of project managers. Finally, Section 5 presents some concluding remarks.

2. Overview of Data and Methods

Round 1 of the Harvard Auto Study benchmarked vehicle development projects that were launched in the mid-1980s, and its findings were principally contained in the 1991 seminal book by Clark and Fujimoto, *Product Development Performance*. The second round of the Study was launched in the early 1990s, and the third round was launched in the late 1990s. The fourth round of the Study was launched in 2006. Over the Study's four rounds, data on 99 vehicle development projects have been collected from OEMs located in the traditional automobile manufacturing regions of the West (U.S. and Western Europe) and Asia (Japan and Korea). Table 1 contains an overview of the four rounds.

Table 1: Overview of the Study's Four Rounds

Round	When launched	# OEMs participating by Region	# Projects	Projects from:
One	Mid-1980s	Asian = 8	12	1981 to 1985
		Western = 12	17	1980 to 1987
Two	Early-1990s	Asian = 11	12	1990 to 1993
		Western = 12	19	1990 to 1995
Three	Late-1990s	Asian = 11	13	1995 to 1999
		Western = 6	8	1997 to 1998
Four	Mid-2000s	Asian = 8	13	2001 to 2007
		Western = 4	5	2007 to 2008

Total = 99 projects (1980 to 2008)

As can be noted in Table 1, the Study has consistently obtained a high level of participation by OEMs from around the world, particularly in Asia. When a new round is about to be launched OEMs around the world are invited to participate in the Study. Each OEM then decides whether or not it will participate. Participating OEMs decide how many projects will be studied, and following discussion with researchers, OEMs decide which projects will be studied.

While self-selection may bias the data, we do not find major systematic differences in how OEMs selected projects across the rounds.[4] In order increase the uniformity of the data, OEMs were not allowed to select micro-mini car projects (e.g., engine displacement under 660cc) after Round 1.

Specifying the exact population of automotive OEMs in any given period that are capable of independently undertaking a vehicle development project is a non-trivial endeavor that is beyond the scope of this paper. Nevertheless, it is generally accepted in the industry that since the mid-1980s despite the various waves of financial mergers, acquisitions, tie-ups and break-ups, there have consistently been approximately 25 to 30 such OEMs around the world (Fujimoto, Takeishi, Nobeoka, 1999; Heller, Mercer, Fujimoto, 2006), with slightly more than half of the population being headquartered in the West. Assuming a population of 25 OEMs, the first three rounds of the Study consistently had participation by 60% or more of the population of OEMs around the world. Participation in the current fourth round stands at slightly under 50%.

Assuming a population of approximately 12 to 14 OEMs in Asia and 13 to 15 in the West, participation in Asia has been relatively steady at two thirds or more of the Asian population of OEMs. A similar participation rate held for the West in Rounds 1 and 2. However, in Round 3 Western OEM participation fell just below 50%. In Round 4, Western participation was around 25% of the population. Thus, it must be noted that *caution should be used when generalizing findings drawn from Western averages generated in the later rounds of the Study* when there were relatively few participating Western OEMs.

Over the four rounds, a total of 26 distinct OEMs have provided data to the Study. At present, the Study consists of data on a total of 99 vehicle development projects. In a round, generally an OEM will provide data on one or two projects. On average, the Study has data on

[4] However, it is re-emphasize that that the relatively small sample size of Western projects in the Rounds 3 and 4 makes these findings less robust for the late 1990s and 2000s than in other periods.

three to four projects per OEM. Approximately two thirds of OEMs participated in three or more rounds, with nearly a quarter of the OEMs participating in all four rounds. Table 2 contains a breakdown of the level of participation by the number of rounds in which an OEM supplied data. Table 2 contains a breakdown of the level of participation by the number of projects for which an OEM supplied data. This table indicates that there has been a relatively low level of turnover of participating OEMs, with two thirds of the OEMs participating in three or more rounds. As shown in Table 3, the typical participating OEM has supplied data for three to five projects.

Table 2: Breakdown of the number of *rounds* in which an OEM participated

Number of OEM s that participated in:	
1 Round	3
2 Rounds	6
3 Rounds	11
4 Rounds	6

Table 3: Breakdown of the number of *projects* supplied by participating OEMs

	Over the life of the study, the number of OEMs that provided data on:						
	1 Project	2 Projects	3 Projects	4 Projects	5 Projects	6 Projects	7 Projects
Number of OEMs	3	2	7	5	5	2	2

Data collection process

Since the first round, project data has consistently been collected in close cooperation with participating OEMs. Typically multiple visits to each OEM are needed to explain the data collection process, facilitate data collection, provide interim feedback, verify & revise collected data, and provide final feedback. Harvard Business School (HBS) has generously provided funding for data analysis and visits to participating OEMs for Rounds 1 to 4. The University of Tokyo has provided similar funding for Rounds 2 to 4.[5]

The initial project data collected in Round 1 was gathered through case studies and structured interviews. The structured interview notes were then made into a 20-page questionnaire that was used to collect data on additional projects in Round 1. This questionnaire was subsequently revised into the one that was used for data collection in Round 2. Again, revisions were made and a 30-page questionnaire resulted for Round 3. A 2-page follow-up questionnaire was subsequently added to Round 3 providing more detailed coverage of vehicle production ramp-up in the plant. For Round 4, the questionnaire was again revised and expanded to 46 pages.

In the West, data collection and feedback has primarily been done in English, with the native language of the OEM used on occasion. In Asia, data collection and feedback has been done in Japanese and Korean.

Data Adjustment

In order to allow for fair inter-project comparisons, Clark and Fujimoto (1990), Ellison (1996), Nobeoka and Fujimoto (2004), Thomke (2006) and other works written using data from the Harvard Auto Study have used a comprehensive series of calculations to adjust for differences in project strategy and vehicle complexity. Although there is some variation in methods used by the particular works, data adjustments have been made for: vehicle size, degree of re-use of platforms[6], number of body types (e.g., two-door, three-door, five-door models), newly developed parts ratio, in-house development ratio, price, the innovativeness of components and the innovativeness of production processes. In this way, the researchers sought to control for those major inter-project differences that are more related strategic managerial decisions, rather than operational managerial efficiency (i.e., intra-project management methods.)

By controlling for various forms of project strategy and vehicle complexity, the project data can be normalized to a common baseline to allow for “apple-to-apple” comparisons. However, as an intial look at the Study’s updated data set that includes projects from the 2000s, *this paper presents data that has not been adjusted to normalize for strategy and complexity*.

[5] Kobe University and Hitsotsubashi University have funded the research visits and data analysis conducted by Kentaro Nobeoka in Rounds 3 and 4.

[6] Degree of re-use of an existing platform indicates is measured by how much change is made to an existing vehicle’s wheelbase, track, and suspension.

3. Main Findings of Each Round

Round One[7]

Clark and Fujimoto (1991) was the principal work published based on data gathered in the first round of the Harvard Auto Study.[8] The widespread impact among both academics and practitioners of the results of the first round of the Study may be attributed to the research having (1) statistically documented the gap in automotive development performance (i.e., development productivity, lead-time, and quality) between Japan and the West[9] and (2) clearly showed how this performance variation could be explained by differences in project management, including differences in the management of outsourcing.

Since the automobile is a product that is highly complex in both its internal product structure and its product-user interface, there is great importance and difficulty in achieving product integrity (Fujimoto, 1990). For such a product, an OEM achieves product integrity by performing well in both *external integration* (i.e., making sure that a new product concept meets the latent needs of consumers) and *internal integration* (i.e., effectively coordinating the work of internal specialists, functional divisions, and external suppliers to realize a particular product concept).[10]

Clark and Fujimoto (1991) highlighted the heavyweight product (or project) manager (HWPM) system as an efficient and effective way to coordinate simultaneously both the external and internal linkages needed to develop a vehicle. In Round 1, Japanese product managers tended to be heavier (i.e., have a stronger voice and more responsibility in decision making) than their Western counterparts. The Japanese product managers had both more

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[7] Round 1 contains data from 29 projects (Asia=12; West=17); the initial market launches of the vehicles covered span the period of 1980 to 1987.

[8] Lenfle and Baldwin (2007) gives a detailed overview of the contributions of Clark and Fujimoto's seminal work to product development management. There are various related works that were written based on data from Round 1 (e.g., Clark and Fujimoto, 1987; Clark, Chew, and Fujimoto, 1988; Fujimoto, 1989; Clark and Fujimoto, 1989; Clark and Fujimoto, 1990; Clark, Chew, Fujimoto, 1992; Clark and Fujimoto, 1994; Fujimoto, Iansiti, and Clark, 1996).

[9] In Round 1, European OEMs were divided into volume and high-end manufacturers. While Japanese OEMs tended to have an advantage over European volume manufacturers in both total product quality, development productivity, and lead-time, their advantage over high-end European manufacturers was only in development productivity and lead-time. That is, the total quality of high-end European OEMs generally tended to exceed that of the Japanese.

[10] See Fujimoto (1990) and Clark & Fujimoto (1991) for further discussion of product integrity. Fujimoto et al., (1996) contains a detailed discussion of external integration.

influence over engineers (i.e., higher internal integration) and were more influential over concept development including being more directly linked to markets (i.e., higher external integration) vis-à-vis their American and European counterparts. Differences in project management performance were coupled with striking differences in the average number of long-term participants in vehicle development projects between Asia and the West.[11] Much larger project teams in the West was viewed as an indicator of greater specialization of labor among engineers.

Results from the first round also described the efficacy of overlapping product and process engineering to reduce total engineering hours and development lead-time.[12] Overlapping engineering stages when coupled with intensive communication can facilitate the early identification of potential downstream problems. By starting the problem-solving cycle earlier in the development process, costly late design changes can be reduced. Early and frequent coordination with suppliers was also noted as an important aspect of the intensive communication found in Japan.

Round 1 also looked at development-project strategy (i.e., the percentage of newly developed parts, the vehicle's target price range, and the involvement of suppliers), and found that strategic decisions could explain some, but not all, inter-regional differences in performance. A finding that attracted much attention was the much larger ratio of design work outsourced by Japanese OEMs to suppliers. On average, suppliers performed 30% of the total engineering effort (measured as number of engineering hours) of a Japanese vehicle project, which was nearly double the European level and more than four times the level of supplier participation in design for American OEMs.

All three regions purchased similar average percentages (under 10%) of supplier proprietary parts, for which suppliers do all of the design work and OEMs buy the parts "off-the-shelf". The difference in supplier participation in development was due to the Japanese OEMs spending an average of 62% of their procurement budget on *black-box parts*, whereas the similar figure was 16% for American OEMs and 39% was European OEMs.[13] For black-box

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[11] The average number of long-term participants for Japanese projects was 523 people, whereas the comparable figure for American OEMs was 1,190, for European volume-OEMs was 863, and for European high-end OEMs was 817 people.

[12] Such overlapping is also commonly termed concurrent engineering or simultaneous engineering.

[13] At the opposite extreme of the *supplier proprietary parts* category lies the *detail-controlled parts* category, which was by far the method of part design most commonly used by American OEMs through the 1980s. For detail-controlled parts, the OEM does

parts, suppliers do all of the detailed part design work based on general guidance and specifications supplied by the OEM. Since there is typically a need for ongoing close coordination between a black-box part supplier and the OEM that outsourced the part, in many cases the supplier will be asked to dispatch one or more engineers to the OEM as a "guest engineer" who will work inside the OEM's development center for an extended period of time.

In retrospect, Clark and Fujimoto (1991) use of the term "black-box" seems to have caused some degree of confusion. Though an OEM may provide only general guidance (e.g., functional targets, physical dimensions) to a supplier for a particular part and out-sources the detailed design work, this behavior does not necessarily mean that the work done by the supplier will be completely opaque to the OEM. There is a key difference between an OEM being dependant on a supplier due to limited engineering or production capacity and being dependant on a supplier for knowledge (Fine and Whitney, 1999). OEMs that are keenly aware of this distinction strive to purchase "gray" rather than "black" box parts.

The following quotation summarizes the findings of the first round. "What seems to set apart the outstanding companies in product development… is the overall pattern of consistency in their total development system… (that is, consistency can be found) not only in the broad principles and architecture of the system, but also in its working-level details. Consistency in performance results from consistency in total organization and management" (Clark and Fujimoto, 1991, p. 7).

Round Two[14]

Results from the Round 2 of the Harvard Study and comparisons with Round 1 can be found primarily in Ellison (1996), Ellison et al. (1995), and Fujimoto (2000).[15] Round 2 data showed partial catch-up of Western OEMs with Asia, with an overall narrowing of the development performance gap between Asia and the West. While the inter-region gap narrowed on most key

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essentially all of the part design work, with the supplier responsible only for the actual manufacturing of the part and in some cases, all or some of the production process engineering.

[14] Round 2 contains data from 31 projects (Asia=12; West=19); the initial market launches of the vehicles covered span the period of 1990 to 1995.

[15] In retrospect, Fujimoto (2005) notes that the limited number of published works following Round 2 might be due to inherent limitations associated with the second round of research such as the Harvard Auto Study (i.e., relatively small sample size and not enough elapsed time for rich time-series data analysis).

metrics (e.g., total engineering hours and development lead-time), at the same time for some other metrics (e.g., prototype lead-time) the East/West gap showed little change from Round 1.

Between Round 1 and Round 2, Western OEMs largely incorporated the HWPM approach, which empowers project managers to pursue the internal and external integration needed to deliver to the market a vehicle with high product integrity. However, in the West the influence of project managers in creating the vehicle concept on average only rose to as high as middleweight. In the West, it was apparently difficult in most OEMs to change the traditional strong organizational role plated by dedicated product planners in setting vehicle concepts.

Round Three[16]

Results from Round 3 can be found primarily in Thomke and Fujimoto (2000), Thomke (2003, 2006), and Nobeoka and Fujimoto (2004) and Fujimoto and Nobeoka (2006). Thomke (2006) gives a concise overview of the main findings of Round 3, some of which are discussed below.

The ongoing longitudinal data collected in Round 3 on the main project performance metrics (e.g, lead time and engineering hours) used in earlier rounds generally showed a renewed widening of the gap between Asian and Western OEMs. A reversal of the trend that had been observed in Round 2 was a surprising finding, as it was largely expected that there would be ongoing convergence of performance and organizational processes. What can explain this renewed performance gap?

The principal answer can be found in the analysis of the primary aim of Round 3, which was to ascertain how usage of CAD/CAE systems in development differed among OEMs and regions. Detailed analysis of organizational variables and in-depth interviews with participating OEMs permitted the researchers to understand how the careful use of CAD can be an enabler for front-loading problem solving in the design process (Thomke & Fujimoto, 2000).[17] Thomke (2003) describes this and other potential benefits of the "smart" use of digital tools. Thomke (2006) clearly shows that while the Western OEMs led their Japanese counterparts in the introduction of the most advanced innovation tools, they clearly did not lead in project performances metrics. Thomke (2006, pp.26-27) argues that the poor project performance of the Western OEMs can be attributed to their failure to change sufficiently

[16] Round 3 contains data from 21 projects (Asia=13; West=8); the initial market launches of the vehicles covered span the period of 1995 to 1999.

[17] Based on a comparison of Round 1 and 2 data, Fujimoto (2000) elaborates the role of partitioning and overlapping in early problem solving.

"existing processes, organizational structure, management and culture" to allow the potential of the new tools to be realized.[18]

Thomke (2006) also suggests that the comparatively poor project performance of Western OEMs shown in Round 3 may in fact be attributable, at least in part, to their generally favorable profitability exhibited by some of them in the early and mid-1990s (when the Round 3 vehicles were being developed), due in part to such OEMs being the primary beneficiaries of the booming SUV and light truck segments in the United States. The financial strength of these OEMs may have lessened their motivation to continue to pursue development-performance improvements through continued changes to organizational processes and culture. Likewise, the relatively strong project performance of Japanese OEMs shown in Round 3 may be attributable, at least in part, to their generally poor profitability in the early and mid-1990s, which was largely due to severe yen appreciation and post-Bubble economic stagnation in Japan.

Round Four[19]

A central issue taken up in the Round 4 questionnaire was investigating the continued increase in the number of electronic-control units (ECUs) and related embedded software within vehicles. ECUs first began to appear in mass-market vehicles in the 1970s, when technologies such as fuel injectors were introduced to decrease the environmental impact of exhaust emissions.

In the ensuing thirty years, regulations in developed countries imposing ever-stricter performance requirements (e.g., for exhaust emissions, fuel efficiency, and safety), along with more electronic components (e.g., for engine control, various "by-wire" controls, electronic stability control, and convenience features), have led to a rise in the number of ECUs in vehicles and the increases in the required software coding, testing, and debugging. In the vehicles of Asian OEMs surveyed in Round 4, there was an average of 19.8 ECUs per vehicle (n=10).[20]

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[18] As an example from this paper, Figures 15 and 16, show that the HWPM systems remained only partially introduced in the West, with product managers still having relatively week influence in concept definition. In addition, Nobeoka and Fujimoto (2004) note that the specialization ratio gap remains – there tends to be more specialization (i.e., larger project teams) in Western OEMs vis-à-vis Asian OEMs.

[19] Round 4 contains data from 18 projects (Asia=13; West=5); the initial market launches of the vehicles covered span the period of 2001 to 2008.

[20] In order to be able to calculate an average and still maintain confidentiality, we must obtain data for at least three projects (from different OEMs). Since we were able to obtain ECUs and embedded software data on only two of the five vehicle development projects provided by Western OEMs, we are unable to provide quantitative results for Western OEMs for this part of the questionnaire.

As the increase in the number of ECUs and lines of software code has accelerated over the past ten or so years, in many OEMs around the world there appears to be a growing amount of friction between mechanical engineers, electronic engineers, and software engineers. This friction may be a manifestation of the struggles of OEMs to find the best way to tackle the apparent ongoing increase in the complexity of vehicle development (Higashi & Fukuzawa, 2009; Fujimoto, 2010).

Another issue that was carefully examined in the Round 4 questionnaire was the interaction between advanced engineering and vehicle development. Advanced engineering was discussed in Clark and Fujimoto (1991), but given the longer development lead-times of the 1980s there was typically enough time for new technologies to be sufficiently developed within the vehicle project. In recent years, due to (1) growing complexity of new features and materials and (2) the difficulty to fit many new-technology development initiatives within shorter vehicle development lead-times, Fujimoto (2006) argues that it is now increasingly important to actively manage the interplay of advanced engineering and vehicle development.

Increased managerial complexity can be found not only in coordinating the advanced engineering phases, or front end, of vehicle projects, but also in managing the back end of projects. With vehicles being produced in many countries, on many different lines, and sometimes without much time lag between production starts in the various plants, growing complexity in process engineering also must be managed within vehicle projects.

Qualitative findings from visits to OEMs indicate that some ways in which leading OEMs are seeking to overcome growing vehicle complexity include: shifting the emphasis from reusing actual physical components to reusing knowledge, re-balancing the ratio of virtual vs. physical testing, and not overusing difficult digital tools. Management of the interface between advanced engineering and vehicle engineering appears to be an increasingly important competitive battleground.

Another apparent approach to tackling the issue of growing complexity that can be seen among Asian OEMs is to make a clearer distinction between the development of lower-volume vehicles that will be sold in only a few national markets and higher-volume vehicles that will be sold in many markets around the world. **Figure 1** shows such a polarization trend in the Asian sample. For the twelve vehicle projects for which we have an answer for planned cumulative volume, seven vehicles are under 1 millions units and 5 are over 1.5 million units. **Figure 2** shows that the lower cumulative volume projects are tend to be sold in a fewer number of countries.

Figure 1: Cumulative planned production volumes of Round 4 projects

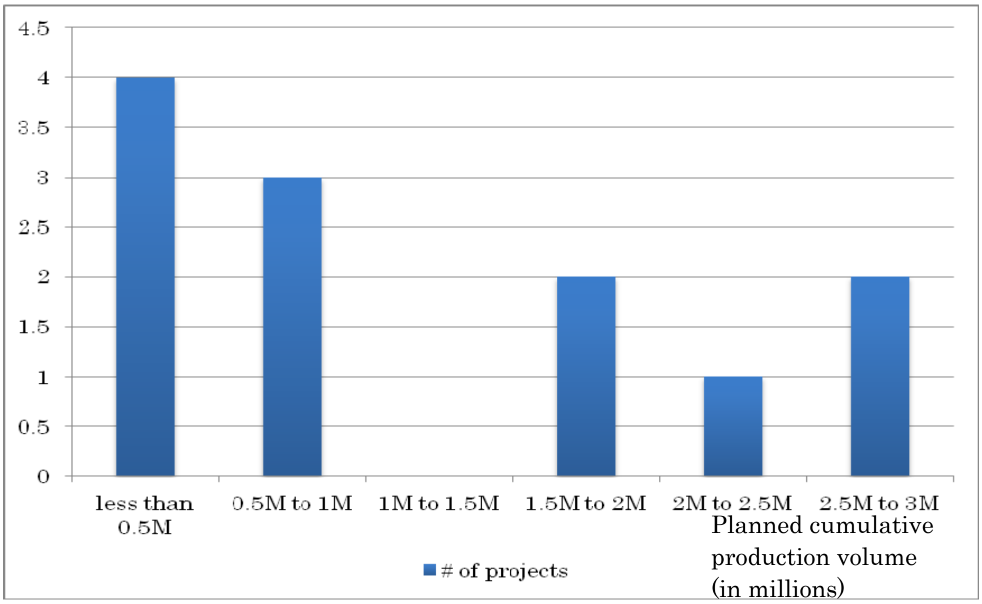
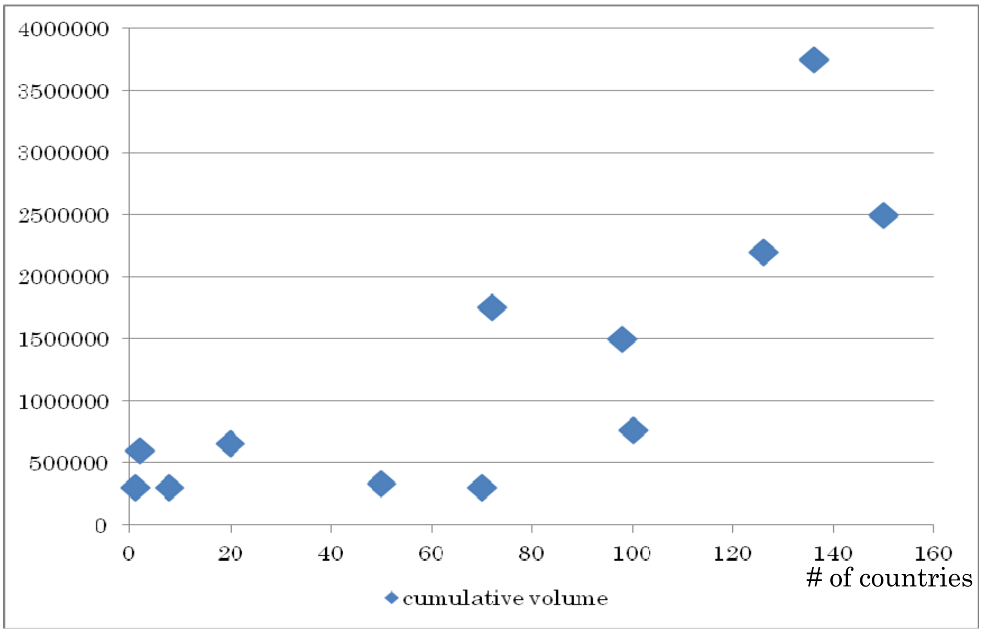


Figure 2: Cumulative Planned Production Volume and Number of Countries Where Vehicle Intended to be Sold



4. Longitudinal Trends in Automotive Development and Project Management

For this present paper, we have not yet adjusted Round 4 data to control for differences in vehicle and project complexity, as described previously. Thus, the following figures we show longitudinal trends using only unadjusted data.

The results shown here are subject to change after the project data has been adjusted for complexity. It is worth nothing that in past rounds data adjustment has not greatly altered the data trends. Thus, we expect the following trends shown by the "raw data" are likely to hold even after the project data has been adjusted to normalize project complexity across the data samples in each round.

We also would like to note that up through Round 3, Western data was presented separately for the U.S. and Europe. In Round 4, however, insufficient participation from American OEMs (at least 3 projects from 3 separate OEMs are needed to calculate an anonymous average) forced us to merge the U.S. and European data samples and create one "Western" average. We have calculated this American and European combined Western average for past rounds. The Western average is compared with an "Asian" average that is a combination of Japanese and Korean OEMs, as insufficient participation from Korean OEMs also did not allow us to calculate separate averages for Korean and Japanese OEMs. As with the Western data, we have calculated the combined Asian data for Rounds 2 and 3. Round 1 did not have data from Korean OEMs.

Comparing Round 1 to Round 4, the was a *lengthening* of planned product lifecycles in Asia, from 4.6 years to 5.5 years. Over the same period, in the West there was a *shortening* of planned product lifecycles, from 10.8 years[21] to 6.5 years. Data on cumulative planned production volume was not collected in Rounds 1 and 2. From Round 3 to Round 4, there was an expanding average cumulative planned production volume from 1.09 to 1.25 million units for Asian projects. Over the same period, Western projects showed a great reduction in the cumulative planned production volume in the sample (3.46 to 0.83 million units). However, we attribute much of this large reduction in the West to sampling bias.

Total engineering hours

The measure used by the Harvard Study for development projects that has attracted the most widespread attention over the years is total engineering hours. It is a measure that includes

[21] In Round 1, the planned product lifecycles was 8.1 year in the U.S. and 12.2 year in Europe, for a weighted average of 10.8 years.

essentially all direct investments into the development of a vehicle, except for capital expenditures for tooling (including dies) and outlays for product testing (e.g., prototypes). Compared to a strictly monetary measure, engineering hours are less directly affected by differing wage rates among countries, short-term fluctuations in exchange rates, or longer-term currency appreciation or depreciation trends. Thus, engineering hours may be considered a good productivity measure for international comparisons and benchmarking both within and especially across time periods.

Since Asian and Western OEMs showed productivity improvements in Rounds 2 and 3 respectively, the data in **Figure 3** is striking in showing an overall increase in the average number of engineering hours for both Asian and Western OEMs when comparing Round 4 with Round 1. While the Western average has grown markedly more than the Asian average, we expect this gap to be reduced after the data has been adjusted for vehicle and project complexity.

Figure 3: Total number of engineering hours

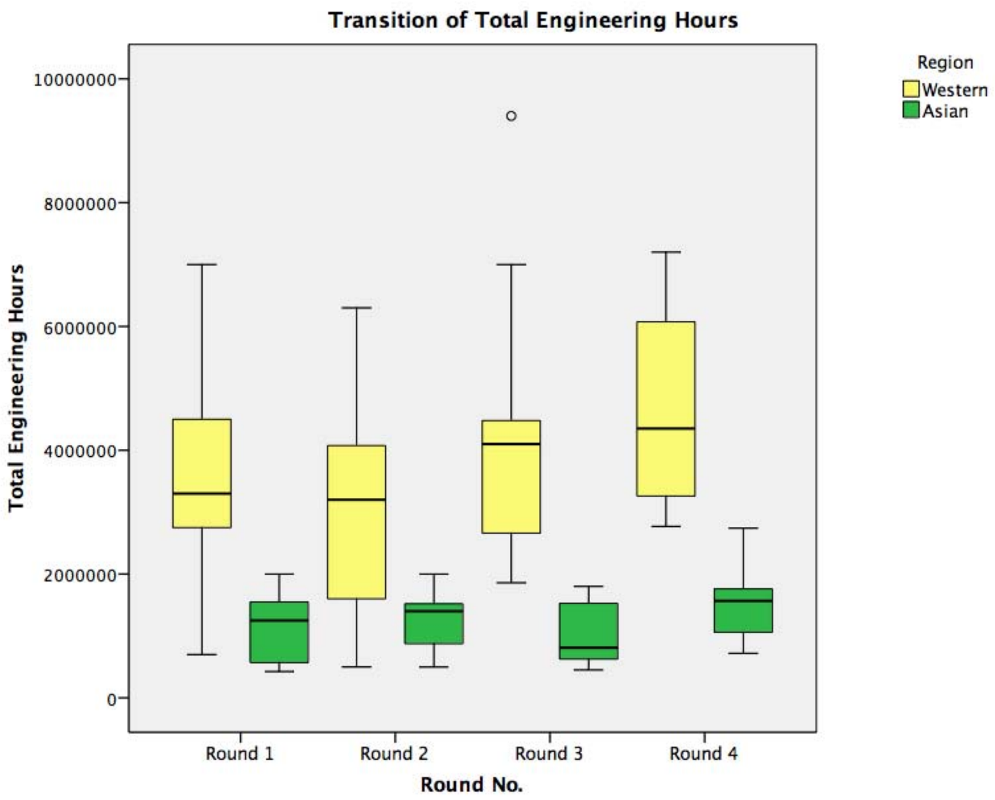


Figure 3 highlights one of the main themes of the Round 4: that the growing complexity of automotive development seems to be canceling out much of the efforts of OEMs to continue to improve their product development efficiency. As discussed above, the main

drivers of growing complexity stems from the increased number of electronically controlled components and ECUs in vehicles, increased difficulty in managing the advanced engineering's interaction with development projects, and the ongoing globalization of production.

Ratio of newly developed parts

The ratio of parts and components that are newly developed for a project is a measure of the scope of a project.[22] For automobiles, minor model-changes (or facelifts) will typically have well under 50% of newly developed parts. Derivative vehicles of an existing platform will typically have between about 40 and 60% newly developed parts. Full model-changes will typically have well over 50% newly developed parts. Since this Study has consistently sought to exclude minor model-changes, project data has generally been for projects with newly developed parts in excess or around 50%.

While comparative data on the ratio of newly developed parts is not available for Round 1, the data for Rounds 2 to 4 (**Figure 4)** is striking. The data trends for Asian and Western OEMs are nearly mirror images. From the early to late 1990s, Western OEMs increased the average ratio of newly developed parts to the level of Asian OEMs in the 1980s. However, at the same time less carry-over parts were being used in the West, Asian OEMs drastically increased the average ratio of newly developed parts. Then, from the late 1990s into the 2000s, Western OEMs changed course and reduced the number of newly-developed parts. Asian OEMs also changed course and dramatically increased the average ratio of newly developed parts to close to the level of Western OEMs in the late 1990s.

These inverse data trends could be interpreted as Asian and Western OEMs chasing each other only to find that their target has moved when they go there. What can explain this apparent game of cat and mouse?

The apparent emphasis Western OEMs between Round 2 and Round 3 was on improving *vehicle performance* through using more newly parts. Western OEMs may have been emboldened to increase the ratio of newly developed parts, following the narrowing of their average productivity and lead-time gaps vis-・-vis Asian OEMs from the 1980s to early 1990s, as

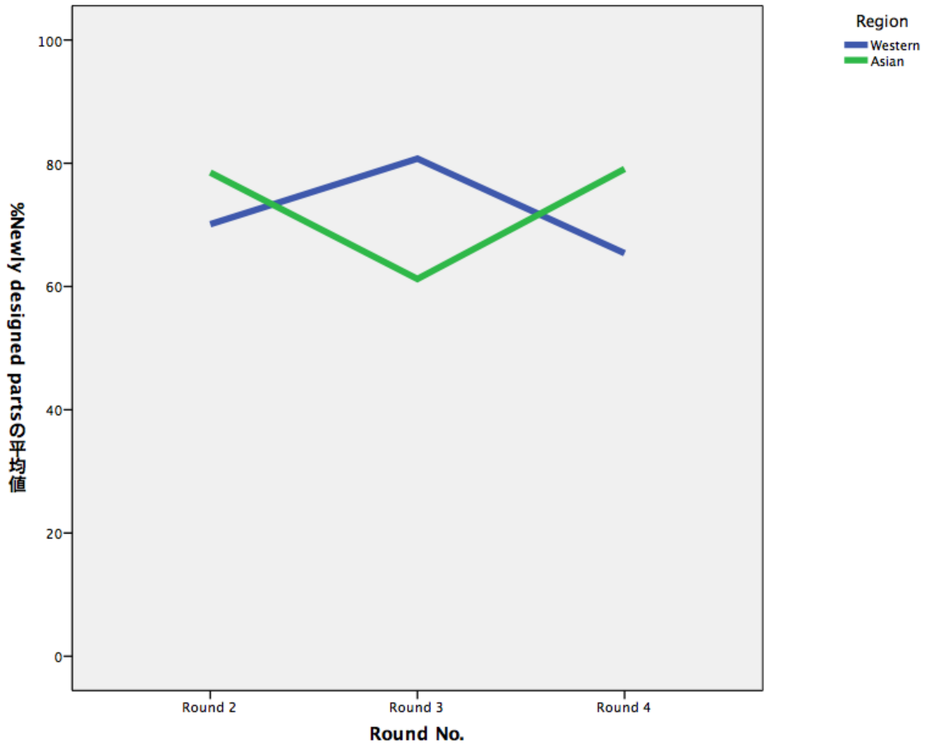
[22] In the Study the term "newly developed parts" includes both structural and functional modifications of existing parts, since any such changes would require new engineering and testing hours for that part. The opposite of newly developed parts is "carryover parts", which indicates the percentage of existing parts that are re-used in a new vehicle project. These existing parts may come from a focal model, such as the previous generation of a vehicle, or from other models in an OEM's line-up of vehicles.

shown by data from Rounds 1 to 2. On the other hand, the apparent emphasis in Asia between Round 2 and Round 3 was on using more carry-over parts for *cost reduction*, which was due at least in part to the economic decline and yen appreciation experienced by Japan in the 1990s.

In the subsequent period, the apparent emphasis of Western OEMs between Rounds 3 and 4 was on improving the *cost structure* for vehicles by decreasing the number of newly developed parts. This shift in strategy may have been triggered by exchange rate changes, such as an appreciating euro, and possibly a growing productivity gap with Asian OEMs. However, again the opposite apparent emphasis was shown by Asian OEMs between Rounds 3 and 4. Asian OEMs from the late 1990s to the 2000s were apparently focused on improving *vehicle performance*, by increasing the ratio of newly developed parts, which we think was have as this triggered by increasingly strict environmental and safety regulations.

The longitudinal data on the average ratio of newly developed parts suggests that there is a close relationship between this measure and the general vehicle and vehicle-platform strategies of OEMs in a region. Related to this point, qualitative Round 4 findings from Asian OEMs indicates that a new form of “newly developed parts” may be emerging. That is, rather than focusing on carrying-over tangible existing parts when developing an all-new vehicle, some Asian OEMs seem to be increasingly turning their attention to carrying-over intangible accumulated knowledge abut part development, including re-using existing tooling to make new parts.

Figure 4: Average ratio of newly developed parts

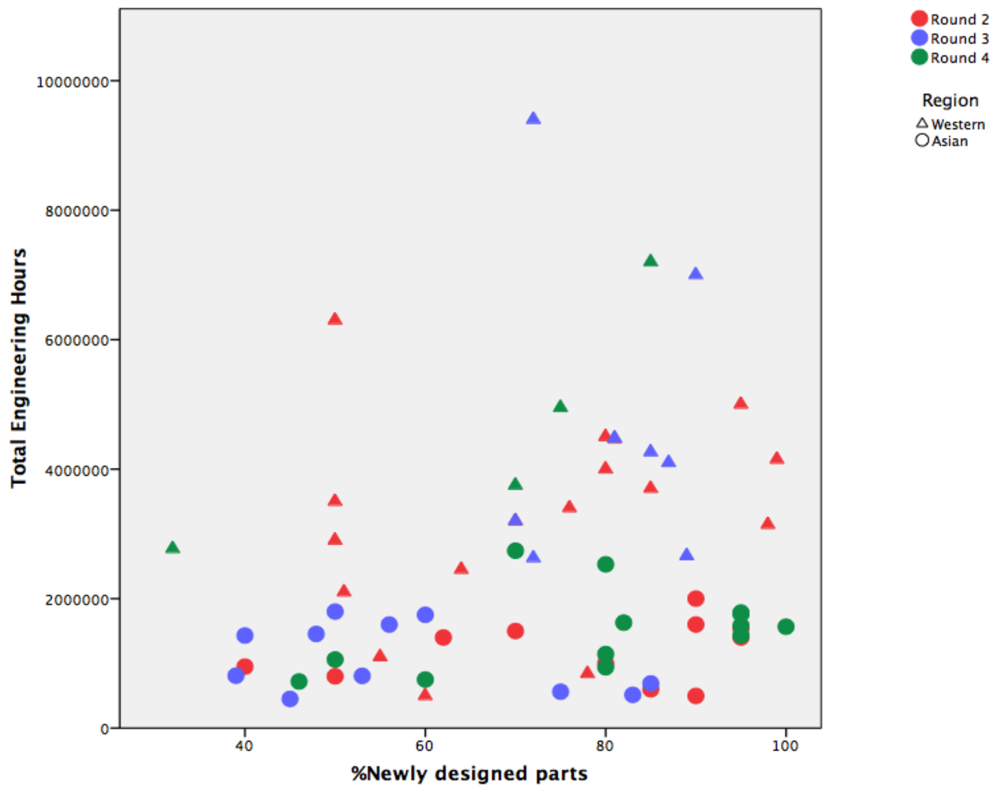


Less engineering-hour "penalty" for newly engineered parts for Asian OEMs

When taken together, the Asian project data shown in Figures 3 and 4 indicate that both the total number of engineering hours and the ratio of newly developed parts followed a downward trend from the early 1990s into the late 1990s. However, in the subsequent period, from the late 1990s into the 2000s, the trends in Asia reversed themselves for both of these measures, as both total engineering hours and newly developed parts have risen. For these two measures, Western data exhibited the opposite pattern than that seen in Asia in the 1990s. However, into the 2000s, while the ratio of newly developed parts has now begun to trend downward in the West, the average number of engineering hours has continued to increase.

The current rise engineering hours in both Asia and the West suggests that vehicle development is becoming increasingly difficult in recent years, which may be attributable to growing complexity, as discussed earlier. However, a growing average total engineering hours for Western OEMs in Round 4, despite a decreasing new-parts ratio, suggests that the "penalty" suffered by Western OEMs for more newly developed parts may actually be getting worse than in past years (**Figure 5**). However, this tentative implication must be tempered by the fact that is drawn from a very limited of number (only four) of Round 4 Western data points.

Figure 5: Engineering hours and ratio of newly designed parts

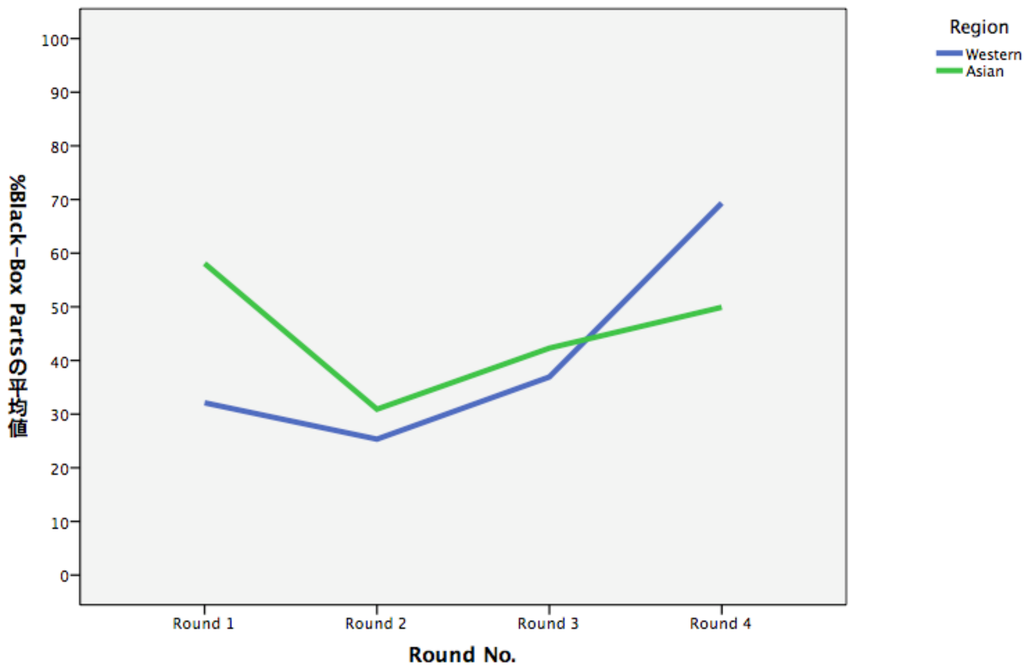


Increased Western OEM usage of "black-box" parts

Compared with the 1980s and 1990s, the average ratio of black-box parts used for projects in the West has increased dramatically, having risen all the way to 70% (**Figure 6**). This increase can be attributed to (1) the spin-off of parts divisions of some Western OEMs and (2) the increase in so-called "system suppliers". As a result, the average ratio of black-box parts in the West in Round 4 has now greatly surpassed the level seen in Asia.

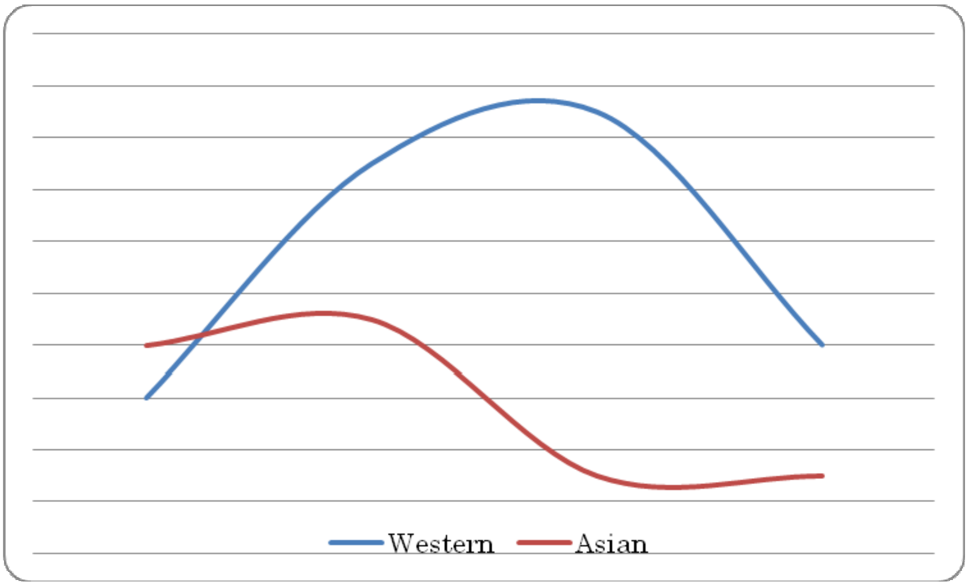
For the Asian data, the large decrease in the average ratio of black-box parts (from 58% to 31%) between Rounds 1 and 2 is surprising. One minor reason for this decrease in is addition of Korean OEMs to the Asian sample from Round 2. When the Round 2 data is limited to Japanese OEMs, the decrease in use of black-box parts becomes slightly less pronounced (falling to 33%). We speculate that the fall in Japanese black-box parts for Round 2 data (early 1990s) may be due to the lingering effects of the Japanese economic bubble. Further investigation of this point is needed. Nevertheless, with the exception of Round 2, the level of black-box parts used by Asian OEMs over the past 25 years has been somewhat consistent, ranging between 40% to 60%.

Asian OEMs not having increased their black-box purchases to the degree indicated by the Western average may be due to their wariness of possibly becoming too dependant on suppliers for knowledge of key components (cf., Fine & Whitney, 1999), especially given the ongoing increase in the percentage of electronic components in vehicles. By keeping design knowledge in-house, an OEM may be better able to understand how to achieve cost reduction for that part or for related parts.



The rise in black-box parts shown in **Figure 6** has mostly come at the expense of detail-controlled parts. There has only been a small reduction in the average ratio of supplier proprietary parts, which includes typically generic parts that can be ordered from a catalog. In Round 4, on average less than 10% of parts for both Asian and Western OEMs were supplier proprietary parts. As is shown in **Figure 7**, this ratio is roughly the same level as in Round 1.

Figure 7: Trend in usage of "supplier-proprietary" parts (%)



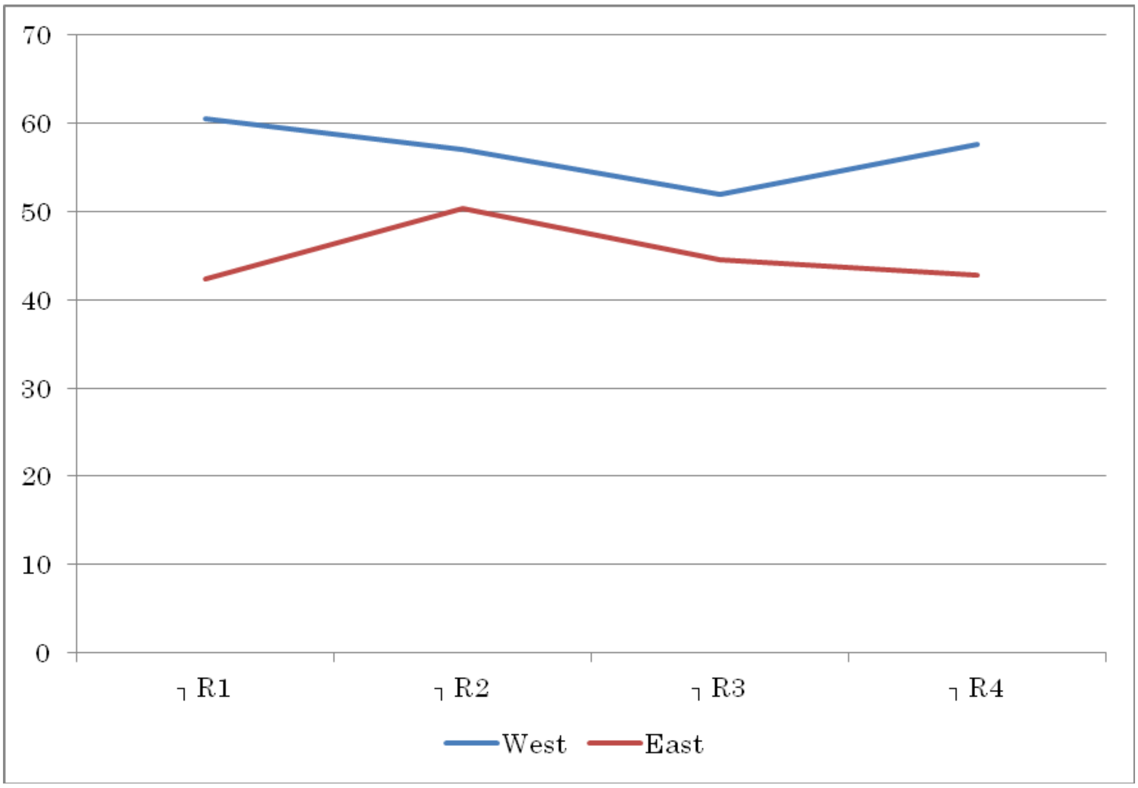
Development lead-time

As is shown in **Figure 8**, the development lead-time is nearly the same in Round 1 and Round 4. On average, it has taken Western OEMs 5 years and Asian OEMs 4 years to develop a vehicle from the start of concept generation (or project kick-off) to the start of sales. In the intervening twenty years, however, the two averages initially began to converge dramatically between Rounds 1 and 2. The two averages then moved in parallel between Rounds 2 and 3. In Rounds 3 and 4, however, the averages began to diverge dramatically.

As mentioned earlier, the average planned product lifecycles for Asian projects in Round 4 is 5.5 years, and for Western projects it is 6.5 years. Interestingly, the Asian-Western difference in lead-time from concept generation is about the same as the difference in planned product lifecycles. Thus in the average case, both Asian and Western OEMs are able to watch a new vehicle's sales for about a year and a half before kicking off the project for the next generation of the vehicle.

The similarity in the length of time between the start of sales and the kick-off of the succeeding vehicle project shown by the Round 4 data starkly contrasts with what was found in Round 1. In the 1980s, the average lifecycle for Asian OEMs was 4.6 years, and for Western OEMs it was 10.8 years. At that time, Asian OEMs could on average only watch a new vehicle's sales for about a year before having to kick-off the next generation vehicle project. Whereas Western OEMs could spend on average as much as 5 years before having to kick-off the successor project.

Figure 8: Lead-time from Concept Generation

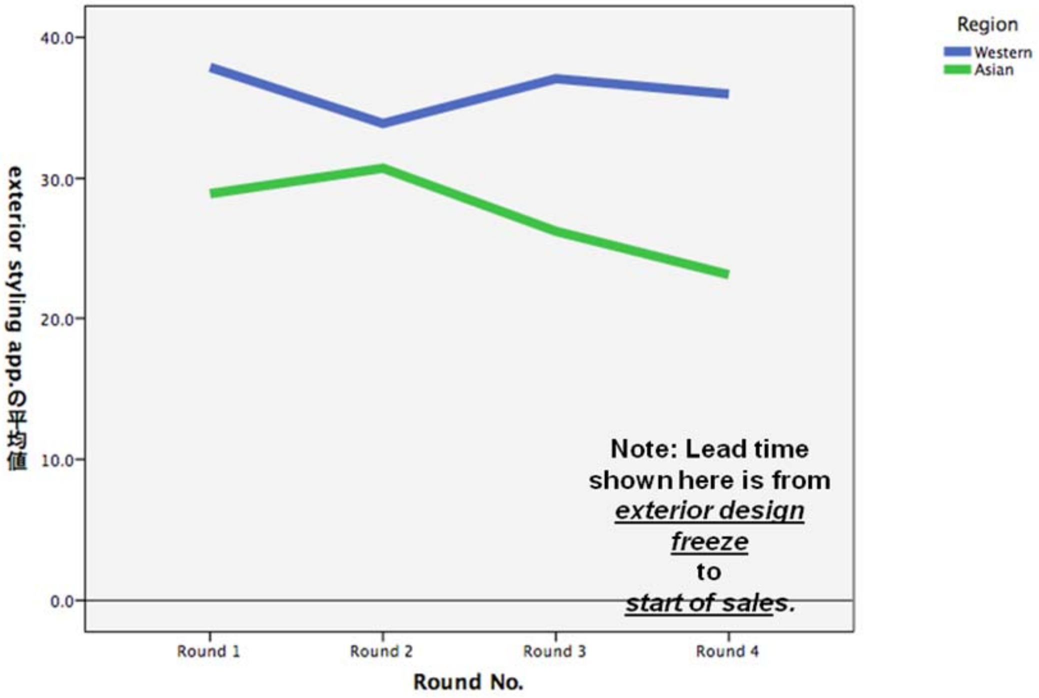


Another commonly used measure for development lead-time is the time required from design-freeze to start-of-sales. This engineering lead-time measure attracted much attention in past rounds. **Figure 9** gives the results of this measure for the four rounds of the Study. In Round 1, the measure showed the Japanese OEMs held an advantage of nearly a year over their Western counterparts. In Round 2, the narrowing of the engineering lead-time gap to a few months was emblematic of the catch-up of Western OEMs. In Round 3, the renewed large lead-time gap (of approximately one and a half years) was also striking.

Round 4 data on engineering lead-time shows that for Asian OEMs the average lead-time from exterior design freeze has not shrunk anywhere near the degree that is sometimes discussed in the popular automotive press. Reports of development in only 12-months (i.e., without any physical engineering prototypes) seem to be only rare cases (Higashi and Fukuzawa, 2009). The data suggests that some Asian OEMs seem willing to accept a slower reduction in engineering lead-time in order to maintain product quality. In Round 4, the Western average again changed course and showed a slight decrease from the

Round 3 level. Yet the large gap in Round 4 between the Asian and Western averages remains largely unchanged from Round 3.

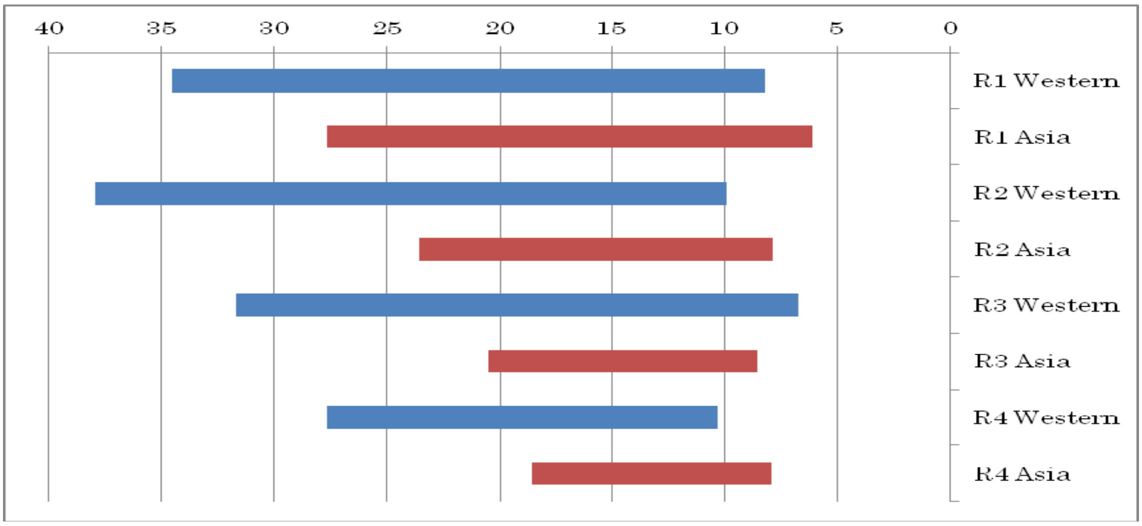
Figure 9: Lead-time from Styling Freeze



In the Study, lead-time data has also been gathered for the development of stamping dies. In order to increase the comparability of data, OEMs were asked to supply data on the lead-time for engineering and try-out of the stamping die for the vehicle's side body-panel. This body panel is typically the largest on a vehicle, and its die is generally the most difficult to engineer. An OEM was given the option of supplying data on another body panel if a more difficult one existed. However, data was collected for this side-body panel for nearly all of the projects over the four rounds.

Figure 10 shows the lead-time data for die development over the four rounds. The data shows that Western OEMs are gradually catching up to Asian OEMs in terms of die development lead-time. On the other hand, the timing when die engineering begins in Western OEMs remains much earlier than in Asian OEMs.

Figure 10: Die Engineering Lead Time and Timing

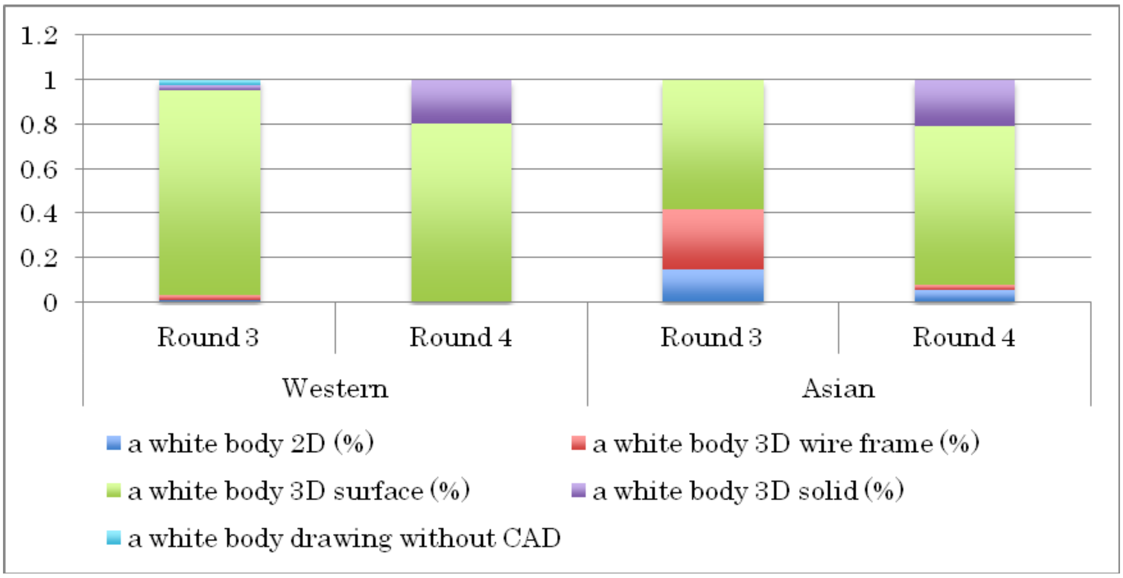


CAD Usage

Round 3 showed a gap in the introduction of the most advanced digital design tools, with Asian OEMs lagging their Western counterparts. However, Round 4 shows that the Asian data has nearly converged with Western data. **Figure 11** shows the data for how drawings were made for the fully welded inner and outer sheet metal of a vehicle (i.e, white-body). Round 4 data from both regions show similar levels of usage of 3D-solid and 3D-surface digital tools. The remaining usage of 2D drawings and 3D wire-frames by Asian OEMs can likely be attributed to a legacy effect. That is, Asian OEMs still use these less sophisticated tools when working with suppliers who have not yet switched to 3D CAD systems or for carry-over parts for which such 3D CAD data does not exist.

In Round 3, Western and Asian data also displayed a notable difference the number of CAD operators per engineer. Western projects (n=5) averaged 0.80 CAD specialists per engineer, which was much higher than Asian average of 0.26. While there are insufficient data points for us to present a Western average for Round 4, the Asian average (n=11) has risen to 1.1 CAD operator per engineer. More than one specialist per engineer would seem to indicate a possible over-specialization of labor in Asian OEMs. What can explain this dramatic rise in the Asian ratio? It seems that as CAD software has become increasingly sophisticated (e.g., CATIA 5), it has become too hard for many engineers in Asian OEMs to use on their own.

Figure 11: Type of CAD Usage for White-body Development

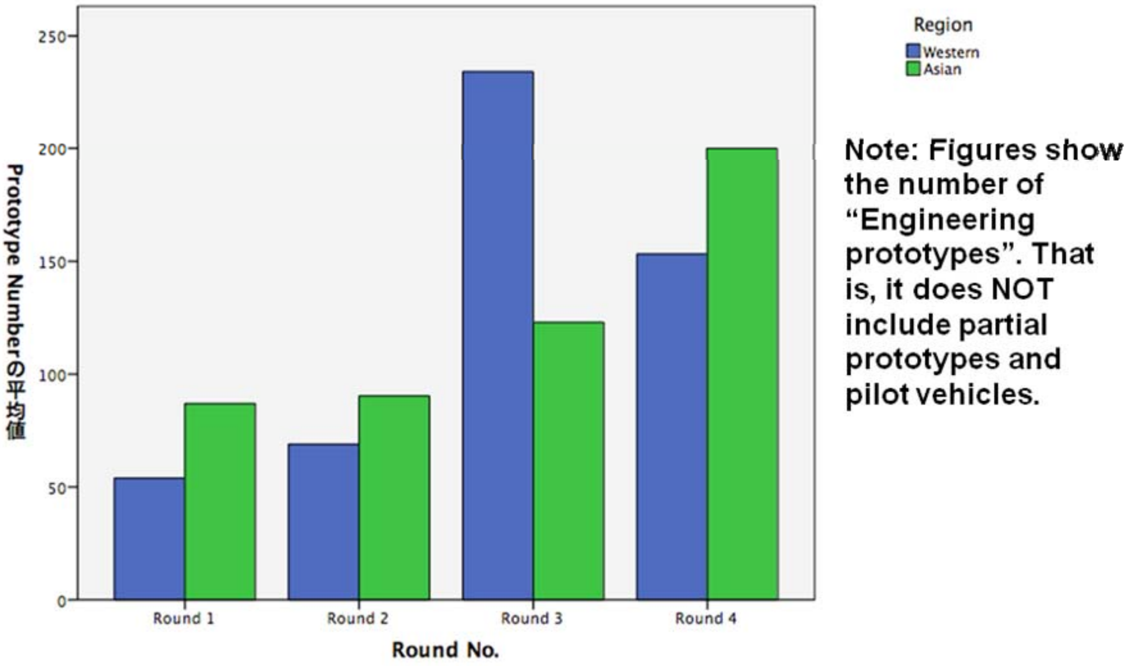


Prototyping

As shown in **Figure 12**, the average number of engineering prototypes used for a vehicle development project has been on an increasing trend through all of the rounds in both Asia and West. The spike in the usage of engineering prototypes in Round 3 for Western OEMs can be attributed to outliers that pulled up the Western average.

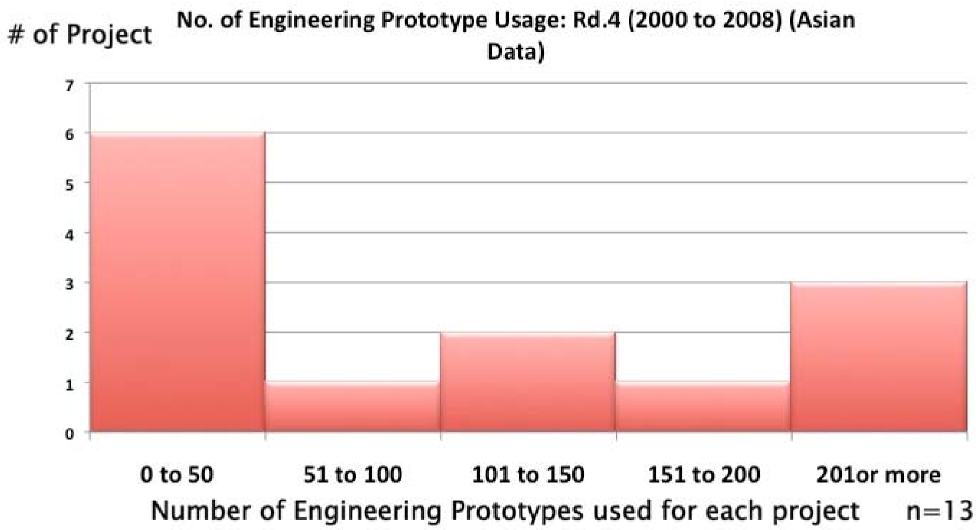
Thanks to digital engineering, OEMs have been able to reduce the number of prototypes for solving parts interference. At the same time, however, the Study's data indicates that there has also been an increase in the number of physical prototypes. The authors speculate that the increase in prototypes may be caused by an increasing number of features and functionalities that affect customer experience, which tend to be difficult to simulate virtually and thus require physical testing. Furthermore, it appears that stricter regulations for crash safety and discrepancies across regulatory regimes in regions around the world require that more physical prototypes be crashed for homologations. Without intense multilateral efforts to commonize safety regulations around the world, it would seem unreasonable to expect the *average* number of engineering prototypes to be greatly reduced.

Figure 12: Increase in number of engineering prototypes



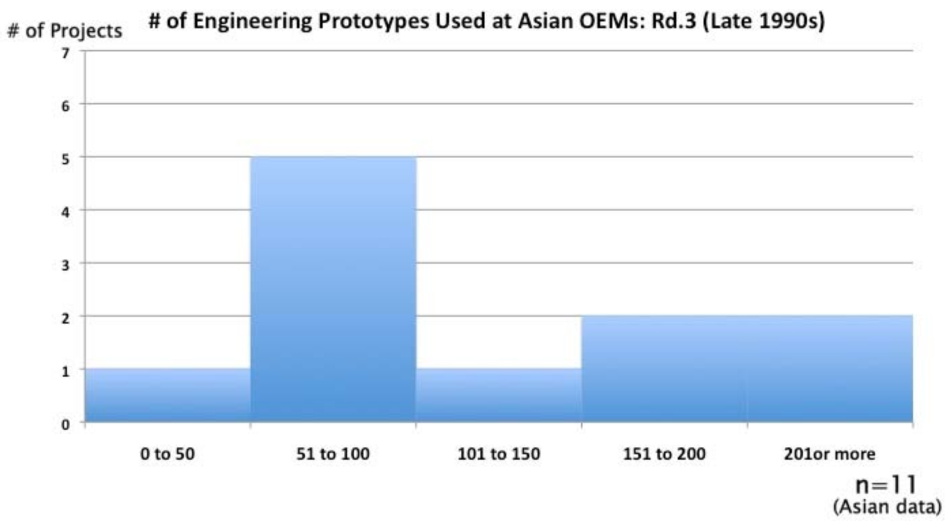
As for how OEMs are handling the increase in engineering prototypes, **Figure 13** shows what appears to be a "select and focus" policy at Asian OEMs in Round 4. We can see a somewhat polarized distribution of the number of engineering prototypes used. In six of the cases in the sample, the project used less than 50 engineering prototypes. On the other hand, six projects used more than 100 engineering prototypes. Projects that use relatively fewer engineering prototypes tend to be for so-called vehicle "derivatives" that are essentially new upper-bodies (i.e., a newly developed parts ratio of around 50%) On the other hand, projects that use relatively more engineering prototypes tend to be for new platform projects (i.e., newly developed parts ratio of well over 50%) that have new under- and upper-bodies. From the data of Round 4, the average number of engineering prototypes was 139.85 (n=7) for vehicle projects for which the OEM indicated it was a "new platform project". For projects that may be considered "derivatives" the average number of engineering prototypes was 89.16 (n=6).

Figure 13: Use of Engineering prototypes in the 2000s (Asian data)



In contrast to the Round 4 finding, in Round 3 it is difficult to discern an overall pattern in the usage of physical engineering prototypes in Asian OEMs (**Figure 14**). In other words, the number of engineering prototypes used for development seem to be distributed rather uniformly in its across the sample, except for the spike at 51 to 100 prototypes. Thus, in the last ten or so years Asian OEMs have apparently become more competent at minimizing engineering prototypes for derivative vehicles.

0 **Figure 14: Use of Engineering prototypes in the 1990s (Asian data)**

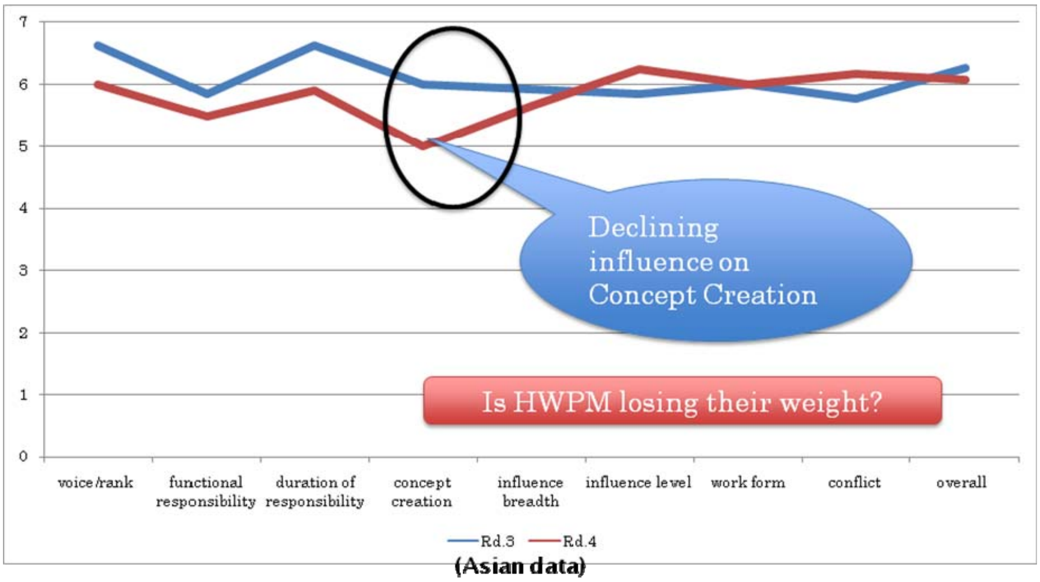


Change in "weight" of HWPM

The Study's Round 4 data shows some notable changes vis-à-vis Round 3 in the on the average results of each project leader's self-evaluation of his or her own degree of power over various aspects of project management and decision-making, what is termed in the Study the "weight" of the Product Manager. As is revealed in **Figure 15**, the recent data from Asian OEMs shows that they tended to give themselves a lower weight in six of the nine categories, including "overall" weight. The influence of the product manager over concept creation showed the greatest decrease, with it falling close to the level found in Western OEMs. Some of this decrease in the influence over concept creation may be attributable to the emergence or strengthening of alliances between Western OEMs and Asian OEMs that beginning in the mid-to-late 1990s (e.g., Mazda-Ford, Nissan-Renault, FujiHeavy/Subaru-GM, Suzuki-GM, Mitsubishi-DaimlerChrysler, Hyundai-DaimlerChrysler). Since some of these alliances featured Western OEMs that tended to have a voice in the product planning of their Japanese partner, product managers often had to cede some responsibility and influence over concept creation to product planners.

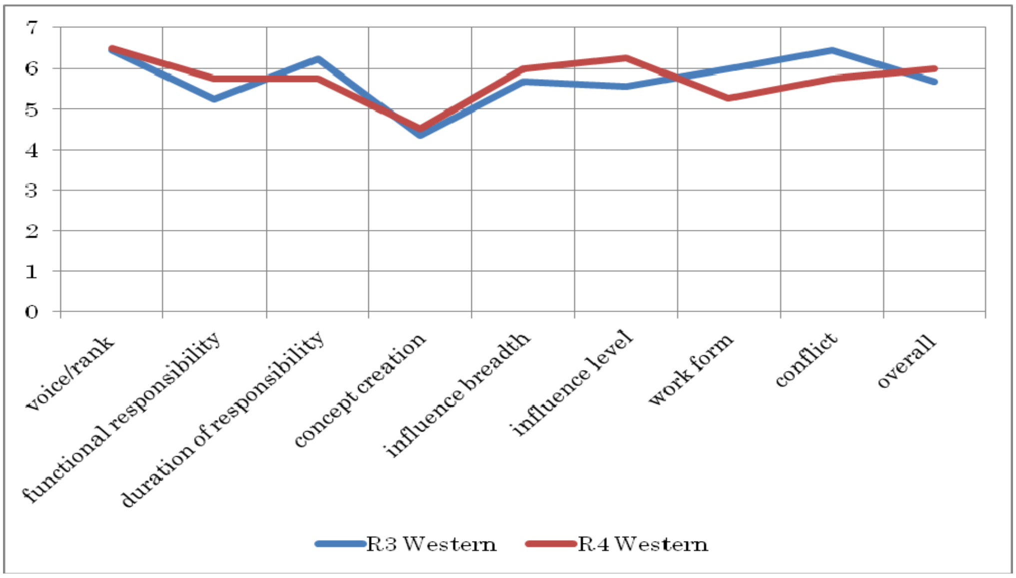
Yet even in the OEMs that remained independent of direct Western OEM influence, qualitative findings of Round 4 indicated that product managers in general exhibited less overall confidence than in past rounds. This lack of confidence may also explain the decrease in the average weight of Asian product managers. The apparent driver of the decrease in the confidence level of Asian product managers was ongoing increases in the complexity of vehicles due to the growing number of electrical components, ECUs, software, advanced technological features and new materials. Product managers seem to feel less certain of their ability to know each of these technological domains deeply enough to manage the integration of them into a vehicle.

Figure 15: Changes in HWPM in Asian OEMs



As shown in **Figure 16**, in general, product managers in Western OEMs appear to be on average about the same in Round 4 as in Round 3. They are becoming more heavyweight in terms of functional responsibility, influence breadth and level of influence over the project team. On the other hand, their weight has fallen in work style (i.e., more desk work) and role in conflict resolution. Product managers at Western OEMs continue to exhibit the same middleweight level of influence over concept creation as in past rounds.

Figure 16: Changes in HWPM in Western OEMs



5. Concluding remarks

The data collected in the Harvard Auto Study spans a quarter of a century. The Study's greatest academic value lies in its unique database of detailed time-series data that has been collected in a consistent manner. The data supplied by Asian OEMs is particularly valuable, given their consistently high participation rate and their having supplied data for each round for a relatively constant number of vehicle development projects. The Study's longitudinal data from a plurality of the industry players makes it possible to study the evolution of an industry from an internal perspective that is seldom available.

The Study's data indicate that while engineering lead-time has continued to decrease for Asian OEMs in the 2000s, it is now decreasing at a lesser rate than in the past. Western data from the most recent round also exhibit shortening lead-time, which reverses the trend toward lengthening lead-time that the data exhibited in the 1990s. The authors interpret this finding to suggest that reducing development lead-time remains a strategic focus of OEMs. However, in Asia at least, efforts to shorten average lead-time do not seem to be as high a priority as in the past. Rather, the primary focus of management in Asian OEMs seems to have shifted to dealing with the growing vehicle complexity referred to above, rather than continuing to push for greater reductions in lead-time.

Data on Asian OEMs show that for the past decade there has been an increasing trend in both the average number of engineering hours and the average ratio of newly developed parts in development projects. This finding is a reversal of the downward trend shown by both these metrics between the early 1990s and the late 1990s. Western data for the past decade also shows an increasing average number of engineering hours, although the ratio of newly developed parts has now begun to trend downward. In the 1990s, Western OEMs showed an increasing trend for both these metrics. The current trend toward rising engineering hours in both Asia and the West suggests that vehicle development is becoming increasingly more difficult in recent years. We suggest that the growth in engineering hours may be attributable to OEMs inability to fully overcome growing vehicle complexity.

Increased complexity is also suggested by the most recent Asian and Western data exhibiting similar trends towards an increased number of physical engineering prototypes used in development. Asian data on the total number of engineering prototypes indicates that OEMs may be following a “select and focus” strategy, whereby a larger number of engineering prototypes are used when so-called “new vehicle platforms” are created. On the other hand, for vehicles that are derivatives of existing vehicle platforms, fewer engineering prototypes are used.

The Harvard Auto Study does not specifically address the impact of the changes in the automobile’s product architecture (i.e., the design rules) that have been seen in some vehicles since the late 1990s, with the introduction of hybrid and all-electrical powertrains. Yet, the quantitative and qualitative changes observed over the four rounds of the Study do indicate that the product architecture of traditional internal-combustion-engine-powered vehicle has retained its persistent integrality. The difficultly OEMs around the world seem to be having overcoming the ongoing increase in vehicle complexity suggests we may be approaching the limits of the present business model. Whether or not the current alternative powertrain vehicles are a viable solution to the problem of growing complexity is an area in need of further research.

Taken as a whole, the Study’s data gathered over the past quarter of a century do not seem to indicate fundamental changes in either the overall orientation or the core activities of New Product Development for traditional powertrain vehicles. Thus, within such vehicle development projects there remain the difficult critical tasks of both *internal integration* (achieving consistency in the product structure and functions) and *external integration* (matching development activities with the customer experience). For the foreseeable future, OEMs that outperform rivals in these two types of integration will have a product development advantage in the industry.

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