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Product Development Performance in the Auto Industry: 1990s Update

by

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Abstract

Over the past decade, firms in the auto industry have focused much of their attention on new product development performance. This paper reports on a follow-up study to Clark and Fujimoto's research on product development performance in the 1980s. We find that U.S. and European firms have made significant strides in meeting Japanese levels of product development performance. Driving this improvement have been changes in the use of suppliers, in overlapping phases of the development process, and in the type of project management system used. We also find that Korean auto makers are relatively efficient in terms of lead time and engineering productivity, although final design quality is lower. The narrowing of the competitive gap in the management of individual projects may point to product line performance as a future driver of competitive advantage.

Introduction

The purpose of this paper is to present the initial data developed in our research on new product development in the world auto industry in the 1990s. This work updates research initially begun by Clark and Fujimoto in the 1980s; since that time, there has been a great deal of activity in the industry as firms respond to increasing market pressures, and evidence of significant changes in the way product development is organized and managed throughout the world is emerging. The central question at this stage of our research is whether new product development performance has converged among firms in the auto industry. In subsequent stages of research we plan to address additional issues such as the management of project portfolios, advanced development efforts, and strategies for learning across projects.

The main findings from the first stage of our research are:

1. Significant gains by U.S. and European firms in terms of lead time and productivity.
2. Greater use of suppliers in the development process by U.S. firms.
3. Broad adoption of "simultaneous engineering" principles by U.S. firms.
4. An overall shift in the U.S. and Europe towards "heavier" project management systems.
5. The continuation of "heavy" project management systems in Japanese firms in conjunction with a movement toward multiple project management.

The body of the paper will describe our findings in greater detail.

Methods and Data

To augment our database of development projects, we contacted automobile companies in Europe, Japan, and the United States and asked each firm to provide data from one or two major development projects completed sometime in the early 1990s. As in the previous study, we defined a major development project as one in which over 50% of the car's parts were new, and we eliminated projects that were simple model year updates or restylings.[1]

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[1] One of the projects actually had only 40% new parts, slightly violating our 50% decision rule.

Nearly all firms in the auto industry agreed to participate in our current round of research. To date, our sample includes 25 projects from 19 companies.[2] The number of design organizations represented is 22, because some auto makers have more than one product development center.[3]

For each project, we administered a lengthy questionnaire to gather data about project complexity, project performance, team organization, and the project manager. During subsequent one to two day visits at each company, we interviewed key members of the project team to gather supplemental information about the project's background and the organization of the team. Where possible, we gathered additional documentation about the project and schedule. In most cases we have returned to the companies to present preliminary results and to check the accuracy of the data gathered in the questionnaire. Throughout the analysis, we followed the procedures used in our previous study.

Table 1 highlights differences in the composition of the sample from the 1980s to the 1990s in terms of body size, price, and unit sales.

Body size. The current sample did not include any micro-mini vehicle projects (very small vehicles with engine sizes of 1.0 liter or less); these vehicles are produced largely for the Japanese market, and typically account for only a small percentage of market sales. The current sample did include more mid to large size cars in Japan, and smaller cars in the United States and in Europe.

Average selling price. Overall, the average selling price of cars in our sample rose. In Japan, this trend was driven by the shift to larger cars with higher selling prices. The U.S. sample had more cars from the luxury segment, pushing up the average selling price despite the smaller size of the vehicles. The lower selling price in Europe was driven by smaller models from high-end manufacturers that competed with high end models from the volume manufacturers, rather than the most expensive models. As a consequence, for the purposes of this report we have not separated the European companies into high-end and volume manufacturers as was done in the earlier study.

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[2] We consider Ford of Europe distinct from Ford in the United States; similarly, we would treat Opel/Vauxhall (GM Europe) as distinct from General Motors in the United States.

[3] For example, General Motors in the United States has three major car development centers and one major truck center.

Table 1: Summary of data

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Number of projects:						
1980s	12	6	11	0	29	29
1990s	8	5	12	3	28	25
Total	20	11	23	3	57	54
Year of introduction:						
1980s	1981-85	1984-87	1980-87		1980-87	1980-87
1990s	1991-93	1991-93	1990-95	1990-93	1990-95	1990-95
Total	1981-93	1984-93	1980-95	1990-93	1980-95	1980-95
Body size:						
1980s						
Micro-mini	25	0	0		10	10
Small	67	17	64		56	56
Medium to large	8	83	36		34	34
1990s						
Micro-mini	0	0	0	0	5	0
Small	63	40	83	100	63	68
Medium to large	37	60	17	0	32	32
Total						
Micro-mini	15	0	0	5	5	6
Small	65	27	74	63	63	61
Medium to large	20	73	26	32	32	33
Price (1987 dollars):						
1980s	9238	13193	19720		14032	14032
	(4945)	(4557)	(12705)		(9679)	(9679)
1990s	15609	18968	15088	8833	15260	16031
	(5289)	(8512)	(5666)	(2021)	(6209)	(6103)
Total	11786	15818	17303	8833	14635	14957
	(5892)	(6961)	(9748)	(2021)	(8112)	(8208)
Units:						
1980s	112	217	285		200	200
	(86)	(195)	(280)		(209)	(209)
1990s	98	178	360	78	222	240
	(62)	(154)	(280)	(48)	(229)	(236)
Total	107	199	324	78	211	218
	(76)	(170)	(276)	(48)	(217)	(221)

Definitions:

Year of introduction – Calendar year when the first version of the model was introduced to the market.

Body size – Percent of projects in each of the categories. Micro-mini models are sold mostly in Japan and have 0.55 liter engines. Small models include sub-compact and compact models. Medium to large models have a wheelbase greater than 105.0 inches (267 mm).

Price – Average suggested retail price of major versions in each model. U.S. 1987 retail prices are used wherever possible. Prices of models not sold in the U.S. are estimated by applying the relative price of some global models to the global models' U.S. price. See Table 5 for definitions of units.

Table 2: Product Development Performance Measures (unadjusted)

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Engineering hours (EH):						
1980s	1155	3478	3418		2494	2494
	(544)	(2472)	(1437)		(1804)	(1804)
1990s	1321	2261	3229	1180	2328	2471
	(426)	(1272)	(1327)	(507)	(1362)	(1372)
Total	1216	2925	3319	1180	2414	2483
	(498)	(2026)	(1352)	(507)	(1594)	(1608)
Lead time (LT):						
1980s	43	62	61		53	53
	(6)	(11)	(9)		(12)	(12)
1990s	51	52	59	51	54	55
	(12)	(4)	(15)	(1)	(12)	(13)
Total	46	57	60	51	54	54
	(9)	(10)	(12)	(1)	(12)	(12)
Total Product Quality (TPQ):						
1980s	53	35	60		52	52
	(29)	(29)	(21)		(27)	(27)
1990s	61	42	59	21	52	56
	(16)	(18)	(17)	(1)	(20)	(18)
Total	56	38	60	21	52	54
	(25)	(24)	(19)	(1)	(24)	(23)

Definitions & Methods

Engineering hours – Hours spent directly on the project in question by the engineers, technicians, and other employees at the company. Suppliers' engineering hours are excluded, except when total vehicle-development works are subcontracted out under some consignment arrangement, as are engineering hours of overhead, process engineering, and pilot production. Concept generation, product planning, and product engineering are included. Figures include neither engine nor transmission development except modification work necessary to match them with the total vehicle.

Lead time – Time elapsed from start of the development project (initiation of organizational activities for product concept generation) to market introduction.

Total product quality (TPQ) – A weighted average of perceived total quality (0.2), conformance quality (0.1), design quality (0.4) and long-term market share change (0.1). Following Clark and Fujimoto, the quality data are collected at the firm level using several data sources: Consumer Reports' overall evaluations of models and percent of recommended models, and JD Powers' CSI data for perceived total quality; Consumer Reports' quality ratings and JD Powers' IQS survey for conformance quality; survey of auto industry expert panel for design quality; Wards Automotive Reports for home country market share data. Each measure (except the market share growth) was converted to a rank variable and assigned 0 points if in the bottom third, 50 points if in the middle third, and 100 points if in the top third. The market share indicator was assigned 50 points for the bottom third, 75 for the middle third and 100 points for the top third. Multiple measures were averaged and multiplied by the weighting factor presented above. Since many of our quality indicators come from sources in the U.S. market, we are missing data for organizations that do not sell to the U.S. market (e.g., FIAT, Peugeot, GM-Europe and Ford-Europe). In these cases we assume a quality score that reflects the mean of that indicator. There may also be some bias in our measures if companies export models to the U.S. that are not reflective of the quality of models they offer to the market as a whole. The analysis of the quality data is not yet complete. We are awaiting additional data from JD Powers and the expert panel survey. In the meantime we are relying on the Consumer Reports data and self-reported quality data at the project level for the design quality measure. In a few cases we have adjusted the design quality figure when the project quality did not seem reflective of the organization as a whole.

Units sales volume. Our sample of projects showed a wide variance in the average level of production volume, reflecting, in part, the mix of core and specialty products in our sample. The bulk of European projects we studied were core products with higher volume sales, while those in Japan and the

U.S. were more often specialty products, and from the 1980s to the 1990s, the average production volume of the U.S. and Japanese projects fell slightly.

A. Unadjusted Performance Measures

This section reports on lead time, engineering hours, and total product quality, unadjusted for differences in project complexity. Table 2 shows significant overall gains by the European and U.S. auto makers.

Lead time. Lead time (LT) is defined as the number of months required to develop a new vehicle, from the initiation of concept development to market introduction.[4] Firms in the United States reduced overall lead time by nearly a year (from 62 months to 52 months), firms in Europe reduced average lead time by 2 months (from 61 to 59), and lead time for Japanese projects increased by 8 months (from 43 to 51).

Engineering hours.[5] Not accounting for differences in project complexity, U.S. firms reduced the number of product engineering hours from 3.5 to 2.3 million. European projects used .2 million hours less, from 3.4 to 3.2 million engineering hours, and Japanese projects had a slight increase from 1.2 to 1.3 million hours.

Quality. The analysis of total product quality (TPQ) incorporates several indicators of product quality. We arrived at an index of TPQ by weighting four factors: perceived total quality, conformance quality, design quality, and long-term market share change. It is important to note that our quality measures are based on a rating of the design organization as a whole, not of an individual development project. The quality level in the United States has increased from 35 to 45, and in Japan from 53 to 61, while the European quality level has stayed fairly constant. Korean quality lags that of the auto producers in Japan, the U.S., and Europe.

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[4] Note that our measure of lead time is longer than program approval to start of production, a common measure sometimes used in the industry and in press reports.

[5] The number of hours does not include the time required to develop the manufacturing process. The reported measure is for product engineering hours, which includes hours for designers, product engineers, project managers, prototype assembly, and vehicle testing. It includes hours for engineers, managers, technicians and support staff, but does not include overhead for engineering administration. The measure also excludes process engineering hours and time required for pilot production. It was not possible to obtain these data in a consistent fashion in Clark and Fujimoto's original study.

Table 3: Project Strategy Variables

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Common parts ratio (C):						
1980s	.19	.38	.30		.27	.27
	(.08)	(.26)	(.15)		(.17)	(.17)
1990s	.28	.25	.32	.13	.28	.29
	(.20)	(.16)	(.19)	(.08)	(.18)	(.18)
Total	.22	.32	.31	.13	.27	.28
	(.15)	(.22)	(.17)	(.08)	(.17)	(.18)
Supplier participation ratio (S):						
1980s	.52	.15	.26		.34	.34
	(.10)	(.12)	(.14)		(.19)	(.19)
Supplier proprietary (SP)	.08	.03	.06		.06	.06
Black box (BB)	.62	.16	.29		.40	.40
Detail control (DC)	.30	.81	.65		.54	.54
1990s	.44	.33	.29	.38	.35	.35
	(.15)	(.14)	(.13)	(.07)	(.15)	(.15)
Supplier proprietary (SP)	.06	.12	.12	.13	.10	.10
Black box (BB)	.55	.30	.24	.36	.35	.35
Detail control (DC)	.39	.58	.64	.51	.55	.55
Total	.49	.23	.27	.38	.35	.34
	(.12)	(.15)	(.13)	(.07)	(.17)	(.17)
Supplier proprietary (SP)	.07	.07	.09	.13	.08	.08
Black box (BB)	.59	.22	.26	.36	.38	.38
Detail control (DC)	.34	.71	.65	.51	.54	.54
Scope (NH):						
1980s	.58	.66	.66		.63	.63
	(.06)	(.14)	(.11)		(.11)	(.11)
1990s	.58	.64	.64	.68	.63	.62
	(.11)	(.03)	(.12)	(.07)	(.10)	(.11)
Total	.58	.65	.65	.68	.63	.62
	(.08)	(.11)	(.11)	(.07)	(.10)	(.11)

Definitions:
Common parts ratio (C) – Fraction of parts in common with other existing models at the company, based on number of part drawings.
Supplier proprietary parts (SP) – Fraction of parts developed entirely by part suppliers as their standard products.
Black box parts (BB) – Fraction of parts whose basic engineering is done by auto makers, while detailed engineering is done by parts suppliers.
Detail-controlled parts (DC) – Fraction of parts developed entirely by car makers from basic to detailed engineering.
Supplier participation ratio (S) – Overall fraction of parts developed by the supplier, calculated as 1.0*SP + 0.7*BB.
Scope (NH) – Fraction of engineering effort done by car makers, calculated as 0.3+0.7*(1-C)*(1-S). The calculation assumes that 30% of the total engineering workload is for systems engineering.

B. Project Scope

A crucial adjustment to the raw performance numbers is to measure the level of common parts usage and supplier participation. Table 3 presents data on these factors.

Common parts. In our current sample of projects, we found an overall convergence in the use of common parts (C) in the U.S., Japan, and Europe. U.S. projects used more newly designed parts, with common parts decreasing from 38% to 28%. In Japan, the use of common parts increased from 18% to 28% – a change that seems to reflect a shift toward minimizing investment costs by reusing existing parts. The European level of common parts changed only slightly, from 30% to 32%. Korean projects used a lower percentage of common parts, reflecting early efforts to develop in-house designs.

Supplier participation. The level of supplier content (S) has also seen significant convergence since the 1980s. In particular, U.S. firms greatly increased their reliance on suppliers in the development process, from 15% to 33%. This difference can be explained by an increase in the use of both supplier proprietary parts (from 3% to 12%) and black box parts (from 16% to 30%). In Japan, supplier participation decreased from 52% to 44%. However, our discussions with Japanese manufacturers did not reveal a conscious strategy to bring parts design in house. Black box parts decreased from 62% to 55%, while supplier proprietary parts decreased from 8% to 6%. In Europe, supplier participation increased slightly from 26% to 29%. Black box parts decreased from 29% to 24%, but supplier proprietary parts increased from 6% to 12%. Our discussions with European firms indicated that they would increase their reliance on suppliers during the development process in the future.

Project scope. The calculation for project scope assumes that 30% of the design task is devoted to systems work; the remaining 70% of the work is assumed to be composed of time devoted to developing components. Project scope is thus the total amount of effort on the project not done by suppliers or in previous projects. The project scope figures are quite stable across regions and across the two time periods.

C. Project Complexity

The size of the design task varies dramatically across projects depending on the complexity of the project undertaken. Clark and Fujimoto initially examined many possible drivers of project complexity, including product and process innovativeness, body size, number of body styles, feature complexity (using average selling price as a proxy), and powertrain complexity (using body/engine combinations as a proxy). In our current study we have added expected volume and a complexity index.

Table 4: Degree of Component and Process Innovation

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Component innovation dummy:						
1980s	0.67	0.67	0.55		0.62	0.62
	(0.49)	(0.52)	(0.52)		(0.49)	(0.49)
1990s	0.25	0.40	0.42	0.00	0.32	0.36
	(0.46)	(0.55)	(0.51)	(0.00)	(0.48)	(0.49)
Total	0.50	0.55	0.48	0.00	0.47	0.50
	(0.51)	(0.52)	(0.51)	(0.00)	(0.50)	(0.50)
Process innovation dummy:						
1980s	0.50	0.83	0.45		0.55	0.55
	(0.52)	(0.41)	(0.52)		(0.51)	(0.51)
1990s	0.13	0.60	0.25	0.33	0.29	0.28
	(0.35)	(0.55)	(0.45)	(0.58)	(0.46)	(0.46)
Total	0.35	0.73	0.35	0.33	0.42	0.43
	(0.49)	(0.47)	(0.49)	(0.58)	(0.50)	(0.50)
Degree of innovation:						
1980s	3.01	2.53	2.96		2.89	2.89
	(0.53)	(0.38)	(0.58)		(0.54)	(0.54)
1990s	2.35	2.20	2.35	2.52	2.34	2.32
	(0.20)	(0.70)	(0.39)	(0.46)	(0.41)	(0.41)
Total	2.75	2.38	2.64	2.52	2.62	2.63
	(0.54)	(0.55)	(0.57)	(0.46)	(0.55)	(0.56)
Process change:						
1980s	2.52	3.23	2.88		2.80	2.80
	(0.69)	(0.32)	(0.52)		(0.61)	(0.61)
1990s	2.15	2.48	2.39	2.27	2.32	2.33
	(0.34)	(0.58)	(0.49)	(0.24)	(0.44)	(0.47)
Total	2.37	2.89	2.63	2.27	2.57	2.59
	(0.59)	(0.58)	(0.55)	(0.24)	(0.59)	(0.60)

Definitions:
Component innovation dummy – Equal to one if at least one of the components was judged to be pioneering.
Process innovation dummy – Equal to one if at least one of the manufacturing process technologies used for the projects was pioneering.
Degree of innovation – Average level of component innovation on a scale from 1 (low) to 4 (high).
Process change – Average level of manufacturing process innovation on a scale from 1 (low) to 4 (high).

Product and process innovation. The percent of projects using a pioneering component or process technology decreased in all regions from the 1980s to the 1990s; similarly, the average measure of component and process innovation decreased in all regions (see Table 4). Across regions, the level of product innovation was highest in Japan and Europe, as measured by the average level, although U.S. projects listed the highest use of at least one pioneering component. U.S. projects reported the highest level of process innovation along both measures, followed by Europe and Japan. Korean projects had the lowest level of product and process innovation along most measures.

Table 5: Project Complexity

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Price (1987 dollars):						
1980s	9238	13193	19720		14032	14032
	(4945)	(4557)	(12705)		(9679)	(9679)
1990s	15609	18968	15088	8833	15260	16031
	(5289)	(8512)	(5666)	(2021)	(6209)	(6103)
Total	11786	15818	17303	8833	14635	14957
	(5892)	(6961)	(9748)	(2021)	(8112)	(8208)
Units:						
1980s	112	217	285		200	200
	(86)	(195)	(280)		(209)	(209)
1990s	98	178	360	78	222	240
	(62)	(154)	(280)	(48)	(229)	(236)
Total	107	199	324	78	211	218
	(76)	(170)	(276)	(48)	(217)	(221)
Body styles (Clark & Fujimoto):						
1980s	2.2	1.8	2.2		2.1	2.1
	(1.1)	(0.7)	(1.3)		(1.1)	(1.1)
1990s	2.0	1.6	2.4	1.3	2.0	2.1
	(0.5)	(0.5)	(1.1)	(0.6)	(0.9)	(0.9)
Total	2.1	1.7	2.3	1.3	2.1	2.1
	(0.9)	(0.6)	(1.2)	(0.6)	(1.0)	(1.0)
Complexity index:						
1980s	95	92	83		90	90
	(32)	(72)	(34)		(42)	(42)
1990s	68	76	100	72	83	85
	(44)	(34)	(46)	(22)	(42)	(44)
Total	84	85	92	72	87	87
	(38)	(56)	(41)	(22)	(42)	(43)

Definitions:
Body styles – The body style count defined by Fujimoto counted the number of body styles with a unique silhouette. Under this definition, a 2-door and 4-door sedan with the same silhouette would be considered 1 body style. In addition, different badge versions (such as the Ford Tempo/Mercury Topaz) were not counted as additional body styles.
Complexity index – A calculated complexity index based on the platform complexity, body type complexity, badge complexity, and powertrain complexity. See Appendix I for further details on this measure.

Average selling price. The average selling price is a proxy for the feature level of a vehicle. In general, products with a higher sticker price include features which are more time consuming and difficult to engineer. Higher sticker prices may also reflect features that are difficult to measure such as lower road noise, better fit, higher build quality, and better materials. In the total sample, European projects had the highest average price, followed by those from the U.S., Japan, and Korea. Across the two time periods, the U.S. and Japan saw rising price levels, while the European average price level fell.

Units sales volume. The expected unit sales volume is a proxy for the willingness of firms to spend additional time to reduce a product's cost. For example, a project team is much more likely to spend time engineering the cost out of parts for a vehicle that will sell 700,000 units annually than it will for a vehicle that sells 70,000 units. Additionally, unit sales may incorporate some difficult to capture elements of body style or market complexity. An important driver of sales volume is the number of markets in which the product is sold and the number of body variations and trim styles offered. European vehicles sold in the highest volumes, on average, followed by those from the U.S. and Japan.

Number of body styles. More body styles create additional work for body engineers and the project team. As highlighted in Table 5, European and Japanese projects in general had more body styles than their U.S. counterparts. However, the number of body styles for Japanese and U.S. projects decreased slightly, as did unit sales volume, reflecting a mix of projects containing more specialty products, while the increased European average number of body styles (and unit sales volume) suggests a mix containing more core products.

Complexity index. In our current research we developed a new measure that incorporates platform, body style, and powertrain complexity into an overall index, as detailed in Appendix I (see Table 5). European projects had the highest complexity index overall, with Korean projects having the lowest complexity. In the past decade, Japanese and U.S. projects decreased while European projects increased in complexity.

D. Adjusted Performance Measures

Using a regression model described in Appendix II, we adjusted each of the projects for the level of complexity.

Table 6: Adjusted Lead Time and Engineering Hours

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Adjusted engineering hours (EHADJ):						
1980s	1703	3366	2915		2507	2507
	(843)	(642)	(950)		(1084)	(1084)
1990s	2093	2297	2777	2127	2438	2477
	(500)	(947)	(723)	(926)	(739)	(755)
Total	1847	2880	2843	2127	2474	2493
	(745)	(936)	(822)	(926)	(926)	941)
Adjusted lead time (LTADJ):						
1980s	44.6	60.9	59.2		53.5	53.5
	(7.4)	(5.6)	(6.1)		(9.9)	(9.9)
1990s	54.5	51.6	56.1	54.5	54.7	54.7
	(12.6)	(3.8)	(12.2)	(3.6)	(10.3)	(10.9)
Total	48.6	56.7	57.6	54.5	54.1	54.1
	(10.7)	(6.7)	(9.7)	(3.6)	(10.1)	(10.3)
Total Product Quality (TPQ):						
1980s	53	35	60		52	52
	(29)	(29)	(21)		(27)	(27)
1990s	61	42	59	21	52	56
	(16)	(18)	(17)	(1)	(20)	(18)
Total	56	38	60	21	52	54
	(25)	(24)	(19)	(1)	(24)	(23)

Definitions:
Adjusted engineering hours – The number of hours required to develop a project of average project complexity. See Appendix II for further details on the adjustment method, which is based on a multiple regression model.
Adjusted lead time – The number of months required to develop a project of average project complexity. See Appendix II for further details on the adjustment method, which is based on a multiple regression model.
Total product quality (TPQ) – The TPQ index presented in Table 2 makes quality comparisons relative to other vehicles in the same class. As a consequence, the TPQ index has already been adjusted for project quality and is presented here to allow comparisons across the three measures of development performance.

Adjusted lead time. Table 6 shows the adjusted lead time for projects in the 1980s and 1990s. A comparison to Table 2 reveals that complexity does not have a large impact on lead time. The data reveal that Japanese projects increased lead time by 10 months, while U.S. firms lowered lead time by 9 months and European firms lowered lead time by 3 months. As a consequence, product development performance in terms of lead time converged significantly.

Adjusted engineering hours. Table 6 also demonstrates convergence in adjusted engineering hours from the 1980s to the 1990s. A comparison to the unadjusted numbers in Table 2 shows that differences in complexity account for a significant portion of the variance in unadjusted engineering hours. In both time periods, the U.S. projects were of average complexity while the Japanese projects were less complex and the European projects were more complex.

The U.S. projects reduced adjusted engineering hours by nearly one third. Over this same period, adjusted hours in Europe decreased by 5% while adjusted hours in Japan increased by over 10%.

Total product quality. The TPQ index presented in Table 2 is derived from quality comparisons relative to other vehicles in the same price class; hence, the index has already been adjusted for the relevant measures of project complexity. The TPQ figures are reproduced in Table 6 to allow comparison with adjusted engineering hours and lead time.

Table 7: Project Management Structure

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Project management type:						
1980s						
Heavyweight	17%	0%	0%		7%	7%
Light-heavyweight	25	0	0		10	10
Middleweight	41	17	36		35	35
Lightweight	17	83	46		41	41
Functional	0	0	18		7	7
1990s						
Heavyweight	25%	20%	0%	0%	11%	12%
Light-heavyweight	50	40	25	33	36	36
Middleweight	25	40	58	33	43	44
Lightweight	0	0	17	0	7	8
Functional	0	0	0	33	3	0
Total						
Heavyweight	20%	9%	0%	0%	9%	9%
Light-heavyweight	35	18	13	33	23	22
Middleweight	35	27	48	33	39	39
Lightweight	10	46	30	0	24	26
Functional	0	0	9	33	5	4
Overall integration index:						
1980s	17.6	10.2	10.3		13.3	13.3
	(5.9)	(2.6)	(2.0)		(5.5)	(5.5)
1990s	18.9	19.2	17.7	13.3	17.8	18.4
	(2.4)	(3.6)	(2.7)	(3.5)	(3.2)	(2.8)
Total	18.1	14.3	14.1	13.3	15.5	15.6
	(4.7)	(5.6)	(4.4)	(3.5)	(5.0)	(5.1)

Definitions:
Overall integration index – Sum of 29 dummy variables for characteristics of effective volume manufacturers listed in Table 15 of Appendix III. See Appendix III for details of the classification scheme.

Overall patterns in development performance. Tables 6 and 7 highlight striking changes in new product development performance from the 1980s to the 1990s that differed significantly by region.

- U.S. projects reflect improved performance in terms of quality, lead time, and productivity as a result of fundamental changes in the way development projects were managed.
- European projects reflect improved performance along all dimensions, but at a much smaller rate. The European experience seems to reflect the strength of the traditional functional development paradigm. Some companies were slow to make adjustments to their development process, thus slowing improvement; in other cases, firms invested in new processes, but at the cost of short-term improvements.
- Japanese firms continued to increase product quality, but at the expense of lead time and development productivity. The Japanese experience may reveal an underlying emphasis on total product quality in the development process during the early 1990s. We have noted that some Japanese firms have fallen into the trap of "fat design," where auto makers provide more quality than consumers are willing to pay. This "fat design" may have crept into the development process in terms of the resources that firms have been willing to devote to projects.
- In Korea, no improvement data is available because the industry has just begun the development of indigenous models. The current research reveals that the Korean industry is very competitive with the rest of the world in terms of development productivity and lead time, but the overall quality level of Korean models currently lags other regions. This pattern seems to be consistent with an industry that lacks a large base of engineering talent and is only beginning to develop in-house capabilities in new product development.

Another theme in the pattern of development performance has been the positive correlation between adjusted engineering hours and lead time. While we cannot attribute causality to this relationship, many auto makers believe that lead time is a critical driver of development productivity. A number of the firms that have improved development productivity have done so by simultaneously reducing project lead time and the size of their development teams.

E. Factors Underlying the Performance Changes

Clark and Fujimoto's work identified several possible drivers of successful new product development processes.

1. Overlapping cycles

One important driver of improvements in lead time, productivity, and total product quality appears to be overlap in problem solving cycles. Figures 1 and 2 show the lengths of stages in the development process in the 1980s and 1990s, adjusted for differences in project complexity. Close examination of the figures reveals significant changes in both the overlap among stages and the length of individual stages.

For example, Figure 3 examines regional changes in product and process development stages. In Japan, the increase in overall engineering hours is the result of less overlap (despite a decrease in individual stage lengths). In contrast, because of greater overlap, the total duration of product and process engineering remains constant in the U.S. despite an increase in individual stage lengths. The U.S. projects reflect the use of simultaneous engineering principles, with much earlier involvement from process engineers. In Europe, projects show an increase in engineering hours – increased overlap is insufficient to outweigh an increase in the individual stages. The Korean projects have very short product and process engineering stages, with virtually no overlap.

Figure 4 groups individual stages into *planning lead time* (concept development and product planning) and *engineering lead time* (product development, process engineering, pilot production, and ramp-up). As was the case with engineering hours, increased lead time for Japanese projects was driven by increases in the planning and engineering stages as a decrease in overlap between the two stages. While some of this increase may be a statistical anomaly, we discovered that Japanese firms found excellent concepts more difficult to develop following periods of market leadership. There was also some evidence that Japanese firms had made a conscious effort to spend more time on the concept development phase. In the U.S. projects, decreased lead time is the result of shorter planning cycles and greater overlap between the two stages, which appears to reflect greater control over the vehicle concept by the team and project manager. European lead time decreased as a result of greater overlap between the planning and engineering stages.

Table 8: Lead Time for Prototypes (months)

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Total prototype lead time:						
1980s	6.5	11.8	10.9		9.2	9.2
	(2.1)	(2.9)	(3.0)		(3.5)	(3.5)
1990s	5.6	12.4	8.9	na	7.5	8.6
	(1.5)	(3.8)	(2.1)	na	(4.4)	(3.6)
Total	6.2	12.1	9.9	na	8.4	8.9
	(1.9)	(3.2)	(2.8)	na	(4.0)	(3.5)
Drawing release time:						
1980s	3.8	8.3	6.3		5.7	5.7
	(1.9)	(3.0)	(2.3)		(2.9)	(2.9)
1990s	2.9	7.8	5.4	na	5.4	5.1
	(1.2)	(2.3)	(1.9)	na	(2.6)	(2.6)
Total	3.4	8.1	5.9	na	5.5	5.4
	(1.7)	(2.6)	(2.1)	na	(2.7)	(2.8)
Prototype construction time:						
1980s	2.7	3.5	4.6		3.5	3.5
	(0.6)	(1.0)	(1.9)		(1.5)	(1.5)
1990s	2.7	4.6	3.4	na	2.2	3.5
	(1.3)	(2.2)	(1.0)	na	(3.6)	(1.6)
Total	2.7	4.0	4.1	na	2.9	3.5
	(0.9)	(1.7)	(1.6)	na	(2.8)	(1.5)

Definition: *Total prototype lead time* – The number of months from the release of the first parts drawings until the first prototype is completed. Total prototype lead time can be broken into two components: drawing release time and prototype construction time.
Drawing release time – The number of months from the first parts drawings are released to suppliers until the final parts drawings are delivered to suppliers of prototype parts.
Prototype construction time – The number of months from the final release of all prototype parts drawings until the completion of the first prototype.

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2. Manufacturing capabilities in the development process

a. Prototypes

As seen in Table 8, there have been no significant changes in prototype lead time from the 1980s to the 1990s. However, our interviews uncovered substantial changes in the U.S. and Europe with respect to the quality of initial prototypes. U.S. and European firms are emphasizing the degree to which first prototypes represent the actual production process. In many cases, prototype parts are now sourced from the production supplier rather than from specialty firms. In addition, some firms are beginning to make prototype body panels from hard rather than soft tools. Thus, while Japanese firms have maintained an advantage in prototype lead time, our interviews suggest that U.S. and European firms have closed the competitive gap somewhat in terms of prototype quality.

Table 9: Number of Prototypes and Pilot Vehicles

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Number of prototypes:						
1980s	82	44	69		70	70
	(50)	(23)	(42)		(44)	(44)
1990s	103	67	71	69	80	81
	(61)	(50)	(51)	(55)	(53)	(54)
Total	90	56	70	69	74	75
	(54)	(39)	(45)	(55)	(48)	(48)
Prototypes per body style:						
1980s	38	31	43		39	39
	(18)	(27)	(31)		(25)	(25)
1990s	57	41	36	42	45	45
	(31)	(23)	(17)	(17)	(24)	(24)
Total	45	36	40	42	41	41
	(24)	(24)	(26)	(17)	(24)	(25)
Pilot vehicles:						
1980s	120	192	228		177	177
	(93)	(140)	(321)		(221)	(221)
1990s	120	110	190	76	141	148
	(81)	(65)	(105)	(37)	(92)	(93)
Total	120	151	211	76	161	164
	(86)	(112)	(244)	(37)	(173)	(176)
Pilots per body style:						
1980s	53	122	144		103	103
	(36)	(79)	(225)		(151)	(151)
1990s	66	77	116	51	87	90
	(41)	(70)	(100)	(1)	(75)	(78)
Total	58	100	132	51	96	98
	(38)	(74)	(176)	(1)	(121)	(123)

Definitions:
Prototypes – Total number of functional, complete-vehicle engineering prototypes produced over the life of the program.
Prototypes per body style – The number of prototypes divided by the number of body styles as defined in Table 5.
Pilot vehicles – The total number of pilot vehicles built during the pilot production process.
Pilots per body style – The number of pilot vehicles divided by the number of body styles as defined in Table 5.

The total number of prototypes built per project has risen in Japan and the U.S., but remained flat in Europe (see Table 9). Measured on a per body style basis, the number of prototypes has actually decreased in Europe, while rising in the U.S. and Japan.

Table 10: Die Lead Time (months)

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Total die lead time:						
1980s	14.0	25.2	28.4		21.6	21.6
	(1.1)	(2.6)	(6.8)		(7.8)	(7.8)
1990s	14.9	20.0	22.7	na	19.4	19.5
	(4.4)	(3.2)	(13.7)	na	(9.9)	(10.1)
Total	14.4	22.8	25.1	na	20.4	20.6
	(3.0)	(3.8)	(11.4)	na	(8.9)	(9.0)
Drawing release time:						
1980s	3.2	6.3	6.8		5.2	5.2
	(1.4)	(3.7)	(2.5)		(2.9)	(2.9)
1990s	3.6	7.0	7.2	na	5.9	6.0
	(1.2)	(4.9)	(10.3)	na	(7.2)	(7.3)
Total	3.4	6.6	7.0	na	5.6	5.6
	(1.3)	(4.1)	(7.9)	na	(5.5)	(5.5)
Die construction time:						
1980s	6.2	14.3	15.6		11.4	11.4
	(2.3)	(5.2)	(3.8)		(5.7)	(5.7)
1990s	5.5	8.6	11.3	na	8.8	8.8
	(2.4)	(1.8)	(3.5)	na	(3.7)	(3.8)
Total	5.9	11.7	13.1	na	10.1	10.1
	(2.3)	(4.9)	(4.2)	na	(4.9)	(5.0)
Die tryout time:						
1980s	4.4	4.5	6.0		4.9	4.9
	(1.7)	(2.7)	(3.1)		(2.5)	(2.5)
1990s	5.8	4.4	4.3	na	4.6	4.8
	(3.7)	(3.0)	(3.2)	na	(3.3)	(3.3)
Total	4.9	4.5	5.0	na	4.8	4.9
	(2.7)	(2.7)	(3.2)	na	(2.9)	(2.9)

Definitions:
Total die lead time – The number of months from the release of the first drawings for the die set until the completion of the tryout for the die set. Total die lead time can be broken into three components: drawing release time, die construction time, and die tryout time.
Drawing release time – The number of months from the release of the first drawings for the die set until the final drawings are released to the die supplier.
Die construction time – The number of months from the final release of drawings for the die set until the dies are delivered to the auto manufacturer.
Die tryout time – The number of months between die delivery and the completion of tryout for the die set.

b. Die lead time

U.S. and European firms have significantly reduced the lead time required to build die sets for newly designed body panels (see Table 10). While Japanese projects maintained an advantage in die construction time, U.S. firms cut 6 months and European firms 4 months from their respective processes. Our statistical analysis reveals that die construction lead time continues to be an important driver of overall project lead time and engineering productivity.

c. Pilot production

The number of pilot vehicles built has dropped in the U.S. and Europe, while it has remained fairly constant in Japan, as shown by the data presented in Table 9. There is a high degree of variance in the number of pilot vehicles required for projects within regions, as indicated by the high standard deviations for many of these observations. This high degree of variance may be indicative of different strategies in pilot production. It may also highlight differences in the quality of designs with respect to manufacturability.

3. Organizational changes

Perhaps the most notable change in our study of development projects in the 1990s has been the increase in the weight of project management structures. Figure 5 illustrates our typology of organizational forms. The functional organization, which is distinguished from other forms by the lack of a project manager and a reliance on the functional organizations to coordinate among project tasks, was found in a few European organizations in the 1980s, but disappeared from the auto industry in all but one Korean company in the 1990s.

The other three forms of project management structure all utilize a project manager in some form. The lightweight project manager system was the predominant organizational form in the auto industry in the 1980s, while heavier project management forms have emerged in the 1990s. The heaviness of project managers is largely determined by their level of control over working members of the project team and over relevant functional areas (including marketing, manufacturing, and the vehicle concept). An extreme form of the heavyweight project manager system is the autonomous project team, where the team is set up as a separate organization for the life of the project.

The "heaviness" of the project manager can be considered as a spectrum from light to heavy depending on these factors. We have developed an index to categorize the heaviness of the project manager, the details of which can be found in Appendix III. Table 7 presents the prevalence of organizational types in the 1980s and the 1990s as well as the average level of the integration index that helps determine the "heaviness" of the project management organization. The U.S. organizations dramatically increased the use of heavyweight project managers.

Conclusion

The basic data on product development performance from projects in the 1990s reveal the beginnings of an overall convergence in the management of individual projects. U.S. firms have dramatically decreased lead time and engineering hours while increasing overall product quality. European firms have also made gains in terms of lead time, engineering hours, and overall product quality, although our interviews suggest that many of these firms are in the middle of the change process. Japanese projects had lead time and engineering hours rise in parallel with product quality, suggesting the Japanese firms have hit the product development frontier or that they are focusing attention elsewhere. Korean firms are working hard to develop expertise in the development process. Their early experience is quite promising, with competitive lead time and productivity, although total product quality lags the rest of the world.

Our research with firms over the past two years has uncovered several other issues for us to explore in the near future. First, we have observed interesting patterns in the way change has occurred within firms. In particular, it appears that systematic change to the development process is initially costly, but is then followed by a period of rapid incremental improvement. Our interviews have revealed several different strategies for managing change in the development process. Second, many firms, particularly in Japan, are beginning to focus more attention on the management of portfolios of development projects. We are observing in the industry a tension between the development of excellent individual projects and the ability to coordinate and share costs across a coherent portfolio of projects. Finally, increased reliance on suppliers for component technologies has caused firms to examine what makes up their set of core competencies.

Appendix I: Project Complexity Adjustment

The task of controlling for differences across projects is inherently difficult. This appendix describes the project complexity index used as an alternative to the simple measure of the number of body styles. Interviews with engineers revealed that project complexity was driven by several factors, including: platform complexity, body style complexity, powertrain complexity, and market complexity. In the following sections, we describe each type of project complexity in more detail. Table 11 details the specific methodology used to create each variable. Table 12 provides a summary of the values of each variable by region and time period.

Table 11: Complexity Index Calculation

Platform complexity (BASECOMP): the degree of change to the underlying platform. Following Sheriff (1987), the index assigns 30 points for a new wheelbase, 30 points for a new track, 30 points for a new suspension, 15 points for a revised suspension, and 100 points if the entire platform is new. In addition, we assign 10 points if a new all wheel drive system is developed with the vehicle.

Body style complexity (BSCOMP): body style complexity calculates the level of complexity due to body types and badge types. The index is calculated as (1+BTCOMP)*(1+BACOMP)*BTBAOL.

Body type complexity (BTCOMP): the sum of the workload required to produce more than one version of the vehicle. The extra workload is divided into several categories: simple door conversions (4-door to 2-door with no change to silhouette), complex door conversions (4-door sedan to 2-door coupe with silhouette change), rear end conversion (sedan to hatch), wagon conversion (sedan/hatch to wagon), or convertible conversion (2-door to convertible). Starting with the 4-door version as base, where possible, each incremental model is compared to the set of previously considered body types to avoid double counting of workload. For example, a project with 2-, 3-, 4-, and 5-door versions requires one simple door conversion and one rear end conversion. Each conversion type is weighted as follows based on engineering estimates of difficulty: simple doors (0.75), complex doors (2.0), rear ends (1.0), wagon (1.5), and convertible (1.5).

Badge complexity (BACOMP): measures the workload required to badge a vehicle for another marketing division. The extra workload is divided into three categories: trim conversion (trim differences only), partial conversions (front & rear 10" plus hood panel adjustments), full conversion (all visible exterior panels). Each conversion type is weighted as follows based on engineering estimates: trim (0.2), partial (0.4), and full (1.0).

Body type/badge overlap ratio (BTBAOL): the overlap of models covered by the body type and badge indices. For example, it may be the case that only one of three body types is offered in badge versions, resulting in a factor of 0.33.

Powertrain complexity (PTCOMP): the number of unique engines fitted to the vehicle, not including minor adjustments for different emissions standards, but including engines of same displacement with additional valves or turbocharging.

Complexity index (CMPIND): a composite index calculated from the other indices. Specifically, the index is calculated as (BASECOMP)*(1+BSCOMP*.15)*(1+PTCOMP*.025). The weights for the body style complexity and powertrain complexity were derived from engineering estimates.

Platform complexity. Platform complexity measures the engineering workload required to design the underlying platform and chassis components. While the measure of newly designed parts should be higher for vehicles based on new platforms, in some cases "new" parts are really revisions to existing part drawings. Hence, platform complexity measures the degree to which the vehicle is different from its predecessor. Our measure of platform complexity examines changes to the vehicle's wheelbase, track, and suspension. In addition, we include a factor to allow for additional engineering effort for vehicles with all-wheel drive capability.

Table 12: Components of Complexity Index

	Japan	U.S.	Europe	Korea	Total	(w/o Korea) Total
Platform complexity (BASECOMP):						
1980s	70	64	60		65	65
1990s	55	63	70	67	64	64
Total	64	64	65	67	65	64
Body style complexity (BSCOMP):						
1980s	2.7	2.9	2.3			2.6
1990s	1.9	2.0	2.7	1.3	2.2	2.3
Total	2.4	2.5	2.5	1.3	2.4	2.4
Body type complexity (BTCOMP):						
1980s	1.7	1.2	1.3		1.4	1.4
1990s	0.7	0.7	1.7	0.3	1.1	1.2
Total	1.3	1.0	1.5	0.3	1.3	1.3
Badge complexity (BACOMP):						
1980s	0.17	0.57	0.00		0.19	0.19
1990s	0.07	0.32	0.17	0.00	0.15	0.17
Total	0.13	0.45	0.08	0.00	0.17	0.18
Body type/badge overlap (BTBAOL):						
1980s	.94	.92	1.0		.96	.96
1990s	1.00	.90	.94	1.00	.96	.95
Total	.96	.91	.97	1.00	.96	.95
Powertrain complexity (PTCOMP):						
1980s	4.2	2.3	6.0		4.5	4.5
1990s	3.9	1.8	5.4	2.3	4.0	4.2
Total	4.1	2.1	5.7	2.3	4.3	4.4
Complexity index (CMPIND):						
1980s	95	92	83		90	90
1990s	68	76	100	72	83	85
Total	84	85	92	72	87	87

Note from Table 12 that the average level of platform complexity remained constant from the 1980s to the 1990s, and the overall average was similar across regions. The complexity of Japanese projects diminished over the time period, while European platform complexity increased. The Korean projects were slightly more complex than the average, reflecting the fact that these projects were among the first developed domestically.

Body style complexity. Body style complexity captures differences in fundamental body types (2-door coupe, 3-door hatchback, 4-door sedan, 5-door hatchback, wagon, and convertible) as well as the number of versions created for different marketing divisions (e.g., Ford/Mercury and Pontiac/Oldsmobile/Buick). In many cases the total number of body styles can be calculated by multiplying the number of body types by the number of badge types. In some instances, however, only a few of the basic body types are rebadged for different marketing divisions. As a consequence, we also have to control for the level of overlap between the body types and badge variations.

Body type complexity: We analyzed body type complexity according to the effort required to develop a body type in addition to the base model, generally the 4-door version of the vehicle. For example, adding a wagon to a 4-door project requires the redesign of the rear end of the vehicle, but generally does not affect the design from the rear doors forward. Interviews with engineers indicated that adding a wagon model was more complex than changing from a sedan to a hatchback. We also distinguished among simple 2-door conversions that left the vehicle's silhouette unchanged and 2-door coupe conversions that changed the vehicle's roofline. Table 11 details the weightings used in the body type complexity index.

Badge complexity: We also examined body styles that were developed to adapt the vehicle to additional marketing channels or regional markets. Badge proliferation has been particularly prevalent in the U.S., where the historical independence of the auto company's divisions has created a strong desire on the part of dealers to have differentiated products. As a consequence, GM, Ford, and Chrysler are all likely to develop more than one version of a particular body style for more than one marketing division.

Badge proliferation typically entails less additional workload than does an increase in the number of basic body styles. Most changes are largely cosmetic and affect the details in the front and rear 10" of the vehicle, in addition to trim along the side panels. In some cases the pattern stamped in the hood or the apertures for lamps may change slightly. In extreme cases, badge versions of the same vehicle may share no external body styles. We classified additional badge versions of vehicles as major, minor, or trim-only, depending on the level of change required to major body panels. We applied the weights reported in Table 11 to calculate the badge complexity index.

Body type/badge overlap: In practice, most automobile development projects consist of a mix of these two proliferation strategies. For example, Chrysler's LH project consists of four basic models: Dodge Intrepid, Eagle Vision, Chrysler Concorde, and the Chrysler LHS/New Yorker. These models consist of two basic body types (a regular wheelbase and long wheelbase 4-door sedan) and three badged versions of the regular wheelbase model (Intrepid, Vision, and Concorde).

As a consequence, it is difficult to use a simple count of the total number of body styles to get a real feel for the engineering workload required. In our analysis, we examined all the models to determine the engineering content of the body styles. We identified the number of fundamental body styles in addition to the number of different badges supported. We then developed a multiplier to account for the total number of body style varieties. For example, in the Chrysler LH example above, the multiplier would be 0.5 because only one of the two fundamental body styles was affected by the badge engineering.

Powertrain complexity. Although our data for engineering hours excludes the development time required for new engines and transmissions, powertrain complexity measures the workload required to fit and test different powertrains for the vehicle. Powertrain complexity may also capture additional costs required to develop a basic design flexible enough to accommodate multiple engine sizes. We measured the number of engines offered in the project as a proxy for powertrain complexity. Table 12 shows that European projects had the highest number of engines, followed by the Japanese projects. The U.S. and Korean projects used fewer engines on average. There was a slight decrease in the number of engines used in our 1990s sample of projects.

Market complexity. Market complexity measures the workload required to adjust a basic design to the regulatory and market requirements of different countries and regions. Some aspects of market complexity are subsumed in measures of body style complexity and powertrain complexity. For example, auto makers have found that different regions require different body styles. In addition, selling a vehicle in the U.S. and Europe requires the development of more powertrains, because the differential in gas prices across regions results in demands for different engine sizes. In the U.S. and Japan, some models that are only sold domestically require the development of a left-or right-hand drive version.

We measured market complexity by looking at the number of major markets (U.S., Japan, and Europe) in which the vehicle was sold. We also tracked if the vehicle was developed in right- and left-hand drive versions. In examining the effect of market complexity on engineering hours and lead time, we did not find a significant impact. For this reason we have left market complexity out of the current analysis.

Complexity index. An overall complexity index combines individual factors to arrive at a total index. The form of the index depends on assumptions about the degree to which the factors interact additively or in multiplicative fashion. Based on engineering estimates, we used the multiplicative form. Table 11 describes the specific formula for the calculation.

Appendix II: Adjusted Engineering Hours and Lead Time

In order to compare engineering hours and lead time across regions, we needed to adjust for differences in project complexity. We did so by using multiple regression analysis to control for different aspects of project complexity. Tables 13 and 14 report the results of the regression models on engineering hours and total lead time. We kept the data separated into 1980s and 1990s samples in order to allow the coefficients of the controls to vary across the two time periods. The first regression model tests for regional differences in the two samples before adding any controls. The second model adds the control variables used most frequently by Clark and Fujimoto in their analysis of 1980s projects reported in *Product Development Performance*. The third regression model substitutes the complexity index described in Appendix I for the more simple measure of body styles. This model also adds the annual sales volume of each vehicle as a control variable for the reasons cited earlier in the report. We find that the new model explains a higher percent of the variation in engineering hours across projects. The new model also explains a higher percent of the variance for lead time in the 1980s, although neither of the two sets of controls does well at explaining the variance in the 1990s sample.

Because the data set has a limited number of observations, we limited the number of control variables. We eliminated product and process innovation control variables because the coefficients on them were not significant, and they did not help to explain additional variance.

In order to report adjusted engineering hours and lead times, we took the coefficients from the third regression model and applied them to the average values of the control variables from the 1980s and 1990s projects. The resulting calculation gives us an estimate for the number of hours/months it would take for the average firm in Japan to develop the average project for the entire sample. To calculate an adjusted figure for each project, we added that project's residual from the third model and the value of the regional dummy for European and U.S. projects. Hence, the final interpretation of adjusted engineering hours/lead time is the estimate of the time it would have taken that project team to have developed a project of average complexity as determined by the control variables that were used. The average adjusted Japanese engineering hours is higher than the raw figure because the projects had a lower than average level of complexity. Similarly, the European projects have a lower adjusted than raw engineering hours because they were higher complexity projects on average.

Table 13: Engineering Hours Regressions

Engineering Hours

Model:	1		2		3	
Sample:	90s	80s	90s	80s	90s	80s
Independent variables:						
Constant	1321†	1155†	-2119	-6236†	-1457	-2905*
	(428)	(418)	(1737)	(1696)	(1279)	(1201)
U.S.	939	2323†	770	1459*	204	1663†
	(663)	(723)	(676)	(613)	(534)	(526)
Europe	1980†	2263†	1376*	819	684	1212*
	(538)	(604)	(560)	(627)	(486)	(580)
Scope			3336	9697†	1224	2327
			(2446)	(2311)	(1983)	(2323)
Price ($1987)			.027	.062*	.066#	.057*
			(.038)	(.030)	(.035)	(.025)
Body styles			592*	550*		
			(273)	(227)		
Complexity index					13.9†	19.8†
					(4.9)	(4.9)
Units					2.3#	2.8*
					(1.1)	(1.2)
Summary statistics:						
Adjusted R^2	0.319	0.357	.412	.612	.661	.736
Degrees of freedom	22	27	19	24	18	23

Note: Standard errors in parentheses.
† Statistically significant at the 1% level
* Statistically significant at the 5% level
# Statistically significant at the 10% level

Table 14: Lead Time Regressions

Lead Time

Model	1		2		3	
Sample	90s	80s	90s	80s	90s	80s
Independent variables:						
Constant	51.0†	42.6†	26.4	17.7	27.2	17.9#
	(4.4)	(2.3)	(20.1)	(11.1)	(19.1)	(9.3)
U.S.	0.8	19.2†	-1.1	14.7†	-2.9	16.3†
	(7.1)	(4.0)	(7.7)	(4.0)	(7.9)	(4.1)
Europe	7.5	18.0†	4.9	11.1*	1.6	14.6†
	(5.7)	(3.4)	(6.2)	(4.1)	(7.1)	(4.5)
Scope			35.0	36.8*	22.4	34.9#
			(25.7)	(15.2)	(28.0)	(18.0)
Price ('87 $)			.091	.365#	.300	.247
			(.464)	(.198)	(.547)	(.195)
Body styles			1.43	0.16		
			(3.32)	(1.49)		
Complexity index					.077	.036
					(.076)	(.038)
Units					8.8	-9.9
					(17.7)	(9.2)
Summary statistics:						
Adjusted R^2	0.003	0.554	.008	.629	.008	.648
Degrees of freedom	23	27	20	24	19	23

Note: Standard errors in parentheses. Price and Units coefficients have been multiplied by 1000.
† Statistically significant at the 1% level
* Statistically significant at the 5% level
# Statistically significant at the 10% level

Appendix III: "Heaviness" of Project Manager

Fujimoto (1987)[6] developed a classification scheme for project management types based on an ideal project management index for volume auto producers. Each project was coded against the criteria presented in Table 15, with "yes" responses receiving a value of one and "no" responses receiving a value of zero. One measure of the heaviness of the project manager is the overall integration index, defined as the sum of the 29 items in the index. Fujimoto also used the following hierarchical sorting structure to classify the projects:

Level 1: Existence of project manager (PM) (Item 1)

Yes: Move to Level 2

No: Organization is functional

Level 2: Was the project manager responsible for the vehicle concept? (Items 2-6 and 22)

Yes: Organization is heavyweight to middleweight; go to Level 3A

No: Organization is lightweight to middleweight; go to Level 3B

Level 3: Strength and influence of project manager

Level 3A: Strength as PM and concept creator (Items 2, 7-10, 13-16, 18-20, and 26)

If total is 11-13: Organization is heavyweight

If total is 8-10: Organization is light-heavyweight

If total is 0-9: Organization is middleweight

Level 3B: Strength as PM (Items 2,7, 15, 16, 18-20, 26)

If total is 5-8: Organization is middleweight

If total is 0-4: Organization is lightweight

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[6] See Fujimoto (page 458a) and Clark and Fujimoto (page 382) for further information on the classification of project managers.

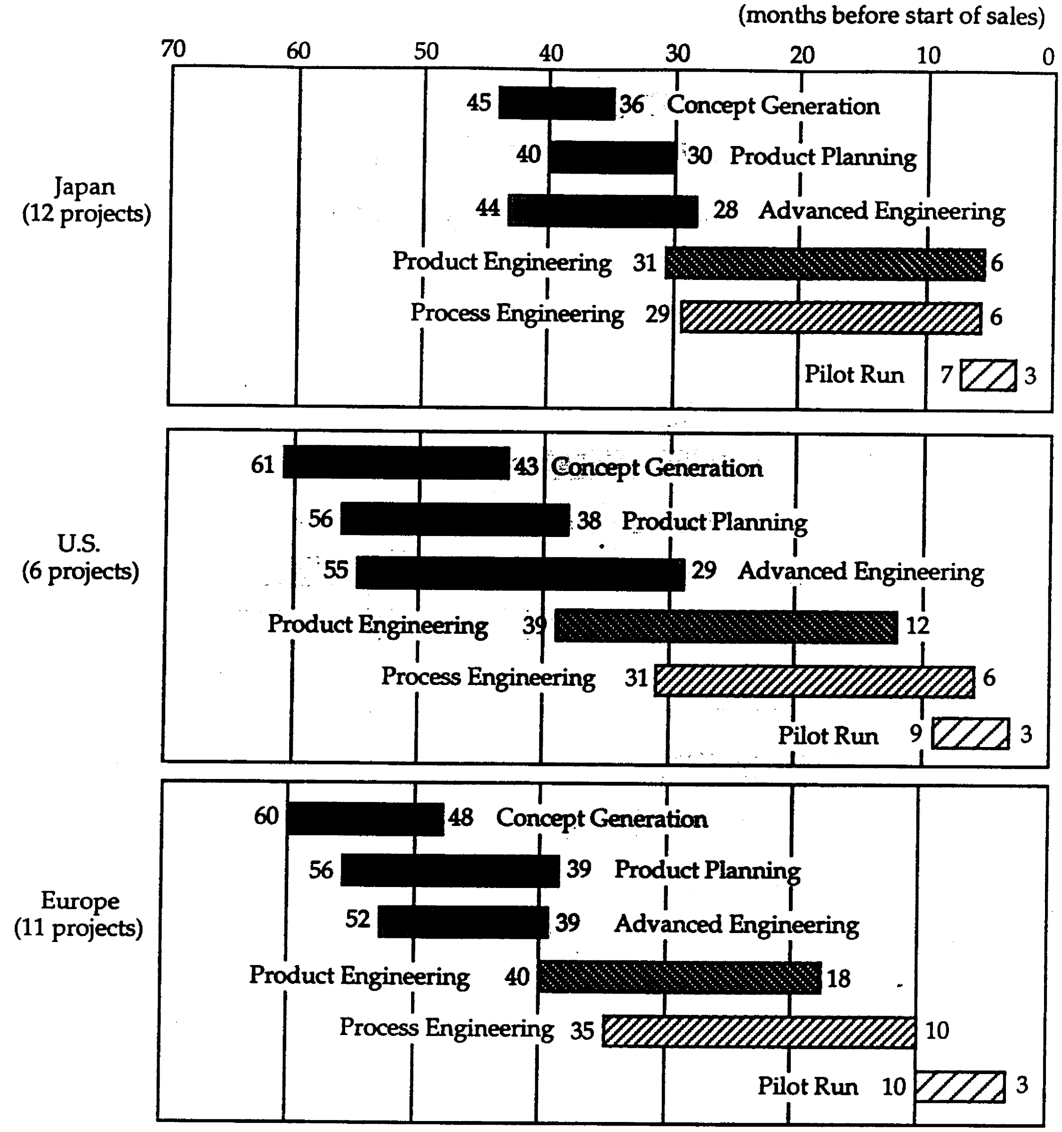
Table 15: Variables for Effective Volume Producers

1. Product managers exist
2. Product managers are responsible for wide development stages/areas
3. Project liaison teams or task forces exist
4. Liaison roles exist
5. Project team is composed of people from a broad range of functions
6. Project execution teams exist
7. Product managers maintain direct market contact
8. Concept creators have strong influence over marketing decisions
9. Concepts are created through cross-functional discussion under the leadership of concept creators
10. Concept generation and product planning stages are merged
11. Concept creators perform product planning
12. Concept creators perform layout
13. Simultaneous development of concept and styling
14. Simultaneous development of layout, styling and engine choice
15. Product managers perform product planning
16. Product managers are responsible for layout
17. Product managers perform concept generation
18. Product managers have significant influence (formally and informally) over product engineering
19. Product managers maintain direct contact with working engineers
20. Liaison persons have strong influence over working engineers
21. Many prototypes are developed and tested
22. Prototypes are built quickly
23. Test engineers cannot veto product designs
24. Early feedback from manufacturing
25. Project teams involve process engineering
26. Product managers have strong influence outside the engineering function
27. Manufacturing cannot veto product designs
28. High degree of overlap between product and process development
29. High perceived effectiveness of product-process communication

Appendix IV: Stages of the Product Development Process

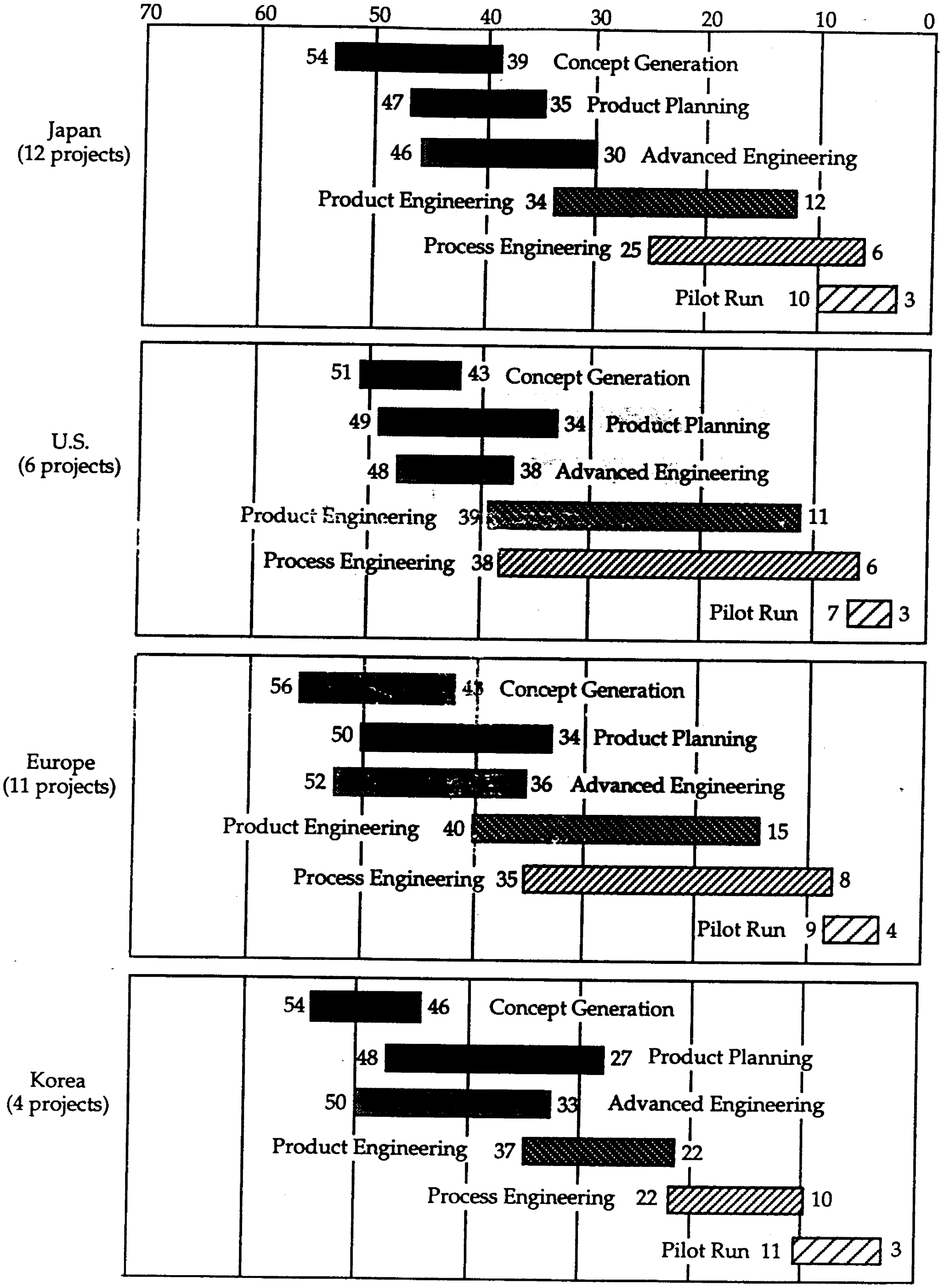
Concept development	The development of the overall concept for the vehicle in terms of market positioning. Stage ends with management approval of concept proposal.
Product planning	The development of the basic layout of the vehicle, external styling, performance targets and cost targets. Stage ends with the approval of external styling and other critical targets.
Advanced engineering	The development of main components such as engine, transmission and suspension before management approval of product planning.
Product engineering	The design of the vehicle itself, including prototype production and testing. Stage ends with management approval of engineering drawings.
Process engineering	Design of the manufacturing process for the vehicle including plant layout and tooling design. This stage ends with the installation of tooling equipment in the plant.
Pilot production	Test production at the volume production line for the vehicle. This stage ends with the start of volume production.

Figure 1: Average Project Schedule – 1980s (Adjusted)



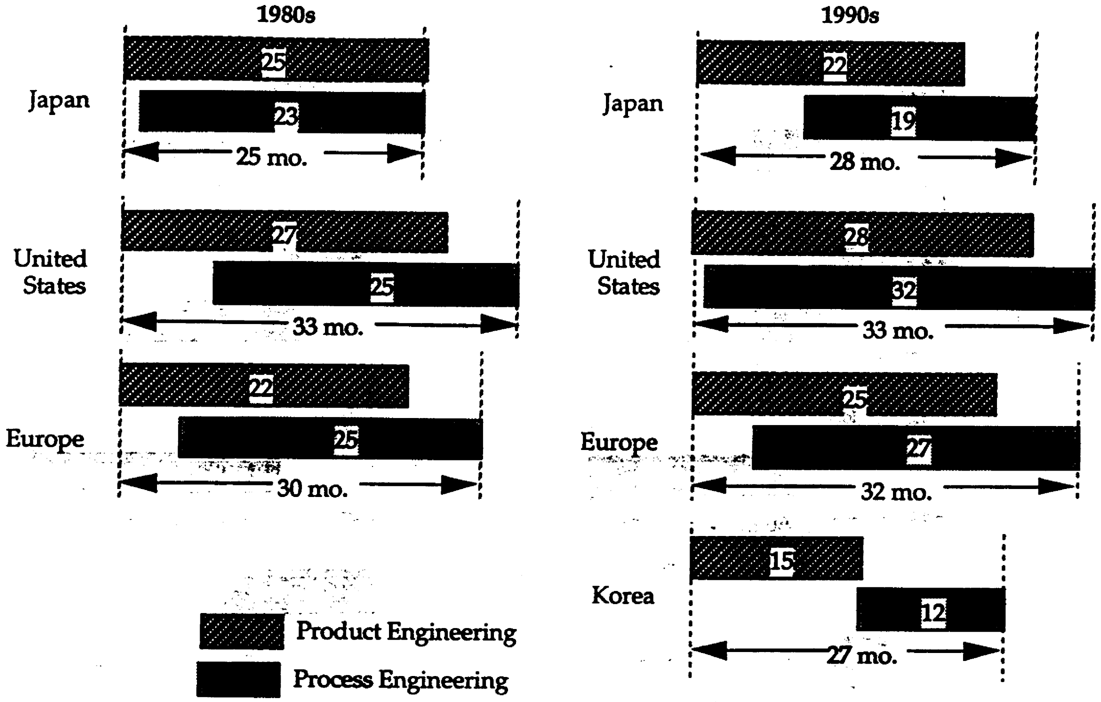
Definitions:
See Appendix IV for a definition of phases of the development process. Each phase of the process has been adjusted to account for differences in project complexity across regions.

Figure 2 Average Project Schedule - 1990s (Adjusted)



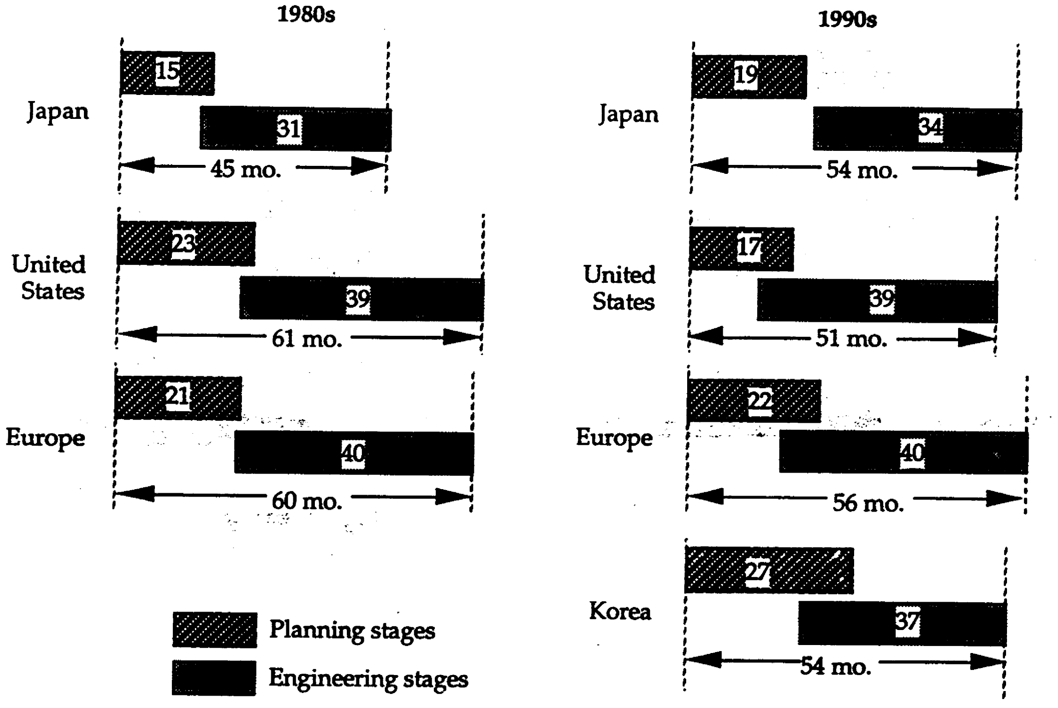
Definitions:
See Appendix IV for a definition of phases of the development process. Each phase of the process has been adjusted to account for differences in project complexity across regions.

Figure 3: Product vs. Process Engineering Phases (Adjusted)



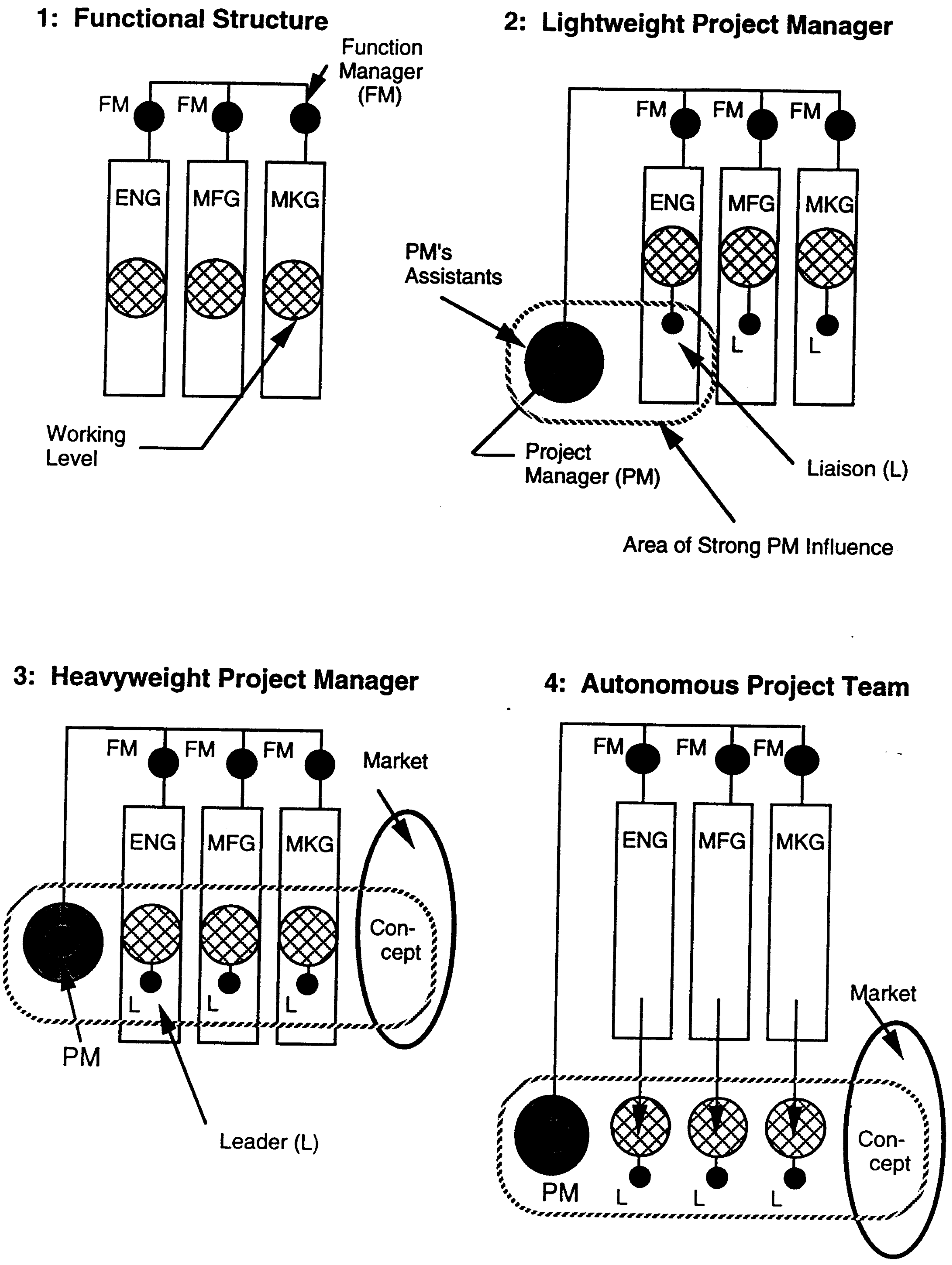
Definitions:
See Appendix IV for a definition of phases of the development process. Each phase of the process has been adjusted to account for differences in project complexity across regions.

Figure 4: Planning Lead Time vs. Engineering Lead Time (Adjusted)



Definitions:
Planning lead time – Number of months from the beginning to the end of the concept generation and product planning phases of the project.
Engineering lead time – Number of months from the beginning of product and process engineering until the first sales of the vehicle to the customer.
Note: The advanced engineering phase is not included in the above chart.

Figure 5: Types of development organizations



Glossary:

Wheelbase: the distance between the front and rear axles of the vehicle. Adjustments to the wheelbase are relatively less costly with front-engine, front-wheel drive cars, since the drive shaft does not have to run from the engine to the rear axle as it does in front-engine, rear-wheel drive configuration.

Track (front and rear): the width between the wheels (front and rear). Large adjustments to the track require either an adjustment to the floor pan or an adjustment to the geometry of the suspension.

Powertrain: The combination of an engine and transmission that provides power to the driving wheels of the vehicle. Powertrain development is generally done by a separate group from the vehicle development group, in part because powertrains are frequently shared among vehicles. However, an important part of the development process is to fit the powertrain to the specific vehicle, with engine mounts, engine dressings and an engine controller.

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