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PROGRAM on VEHICLE
and MOBILITY INNOVATION

Simplification Efforts in a Persistently Integrated Auto Industry: A Disruptive Force?

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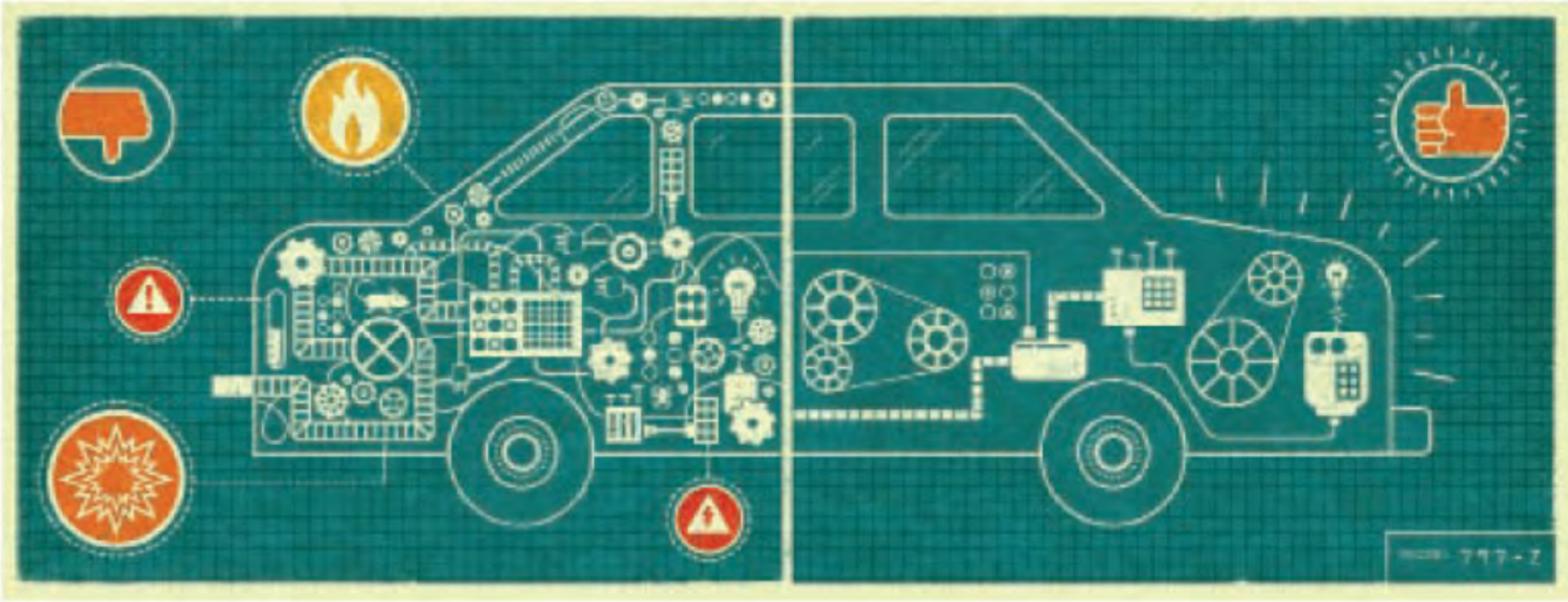
Simplification in a Persistently Integrated Industry

- My past research: Auto industry is **"persistently integral",** e.g. resistant to modularization of design *(most modularization we see is in production, not design)*
- Hence **vertical integration (and quasi-VI) at industry-leading firms (e.g. Tesla, BYD) during the transition to BEVs** makes sense
- Simplification efforts, through this lens, can be understood:
  - ***Optimistically*** with respect to the potential for weight and parts reduction for BEV, HEV, ICE
  - ***Skeptically*** wrt simplification as the basis for startups (e.g. Tesla) and new entrants (e.g. from China) disrupting the industry's structure and displace legacy OEMs *(cost advantages dissipate due to learning; pendulum swings…)*
- Simplification is not new; the pendulum that swings between simplification and complexification is always swinging back and forth (over time; w/in & across firms) due to:
  - Pushes and pulls from different OEM functions; within supply chains; customer preferences; regulatory changes
  - Cost vs. differentiation; life cycles of platforms, products, models; reaching extremes with negative outcomes
  - ***Prevailing trend: variety always increasing. New trend (untested): differentiation thru software, fewer product/model changes***

The Existential Essence of the Automobile

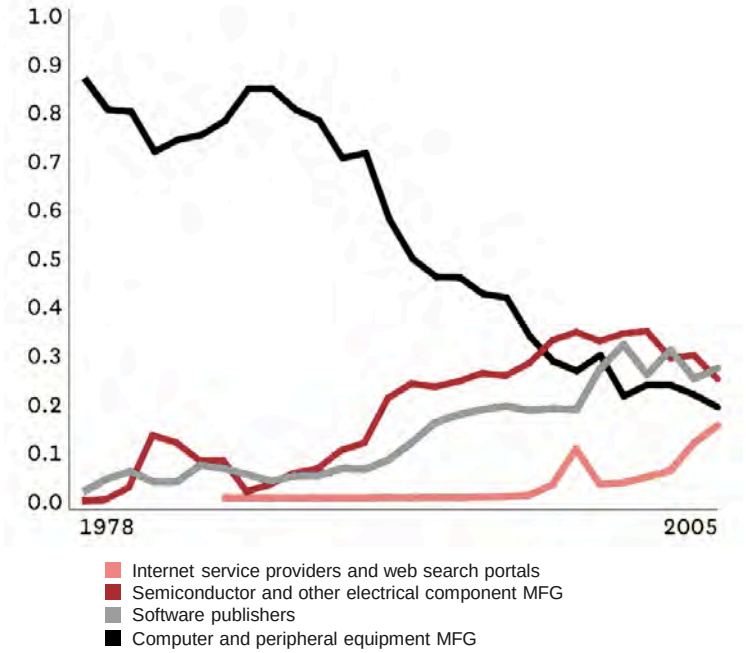


- Heavy, fast-moving physical object that operates entirely in public space and is dangerous to humans and property
- Integral product architecture requiring a capable system integrator, i.e. difficult to modularize design due to subsystem interdependencies
- Society holds the system integrator responsible (regulations, legal liability)

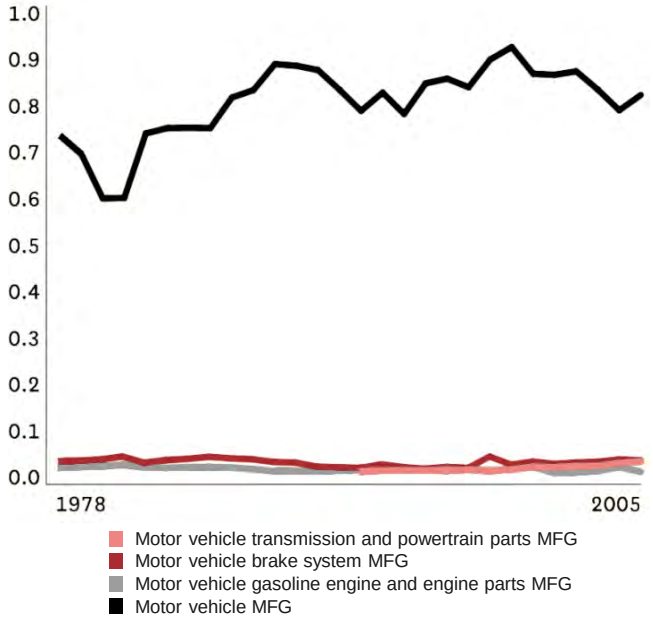
MacDuffie and Fujimoto,2010

Comparing the computer and automotive Industries (data from 1978-2005) reveals a marked difference in whether value was retained by OEMs or migrated to new players in a new industry structure.

Computer OEMs have seen their share of the sector's total market cap fall from more than 80% to less than 20%



Automotive OEMs retained its share of the sector's total market cap



Jacobides & MacDuffie, Make value migrate your way, *Harvard Business Review*, 2013

Structural Features of Auto Industry (why value didn't migrate in ICEV era)

- Primarily integral (vs. modular) architecture *(more to follow)*
- Strong and persistent **system integrator (SI)** role for OEMs
- SI role bolstered by OEM's regulatory responsibility, legal liability
- OEMs invest to "know more than they make" via massive R&D budgets (Brusoni, Principe, Pavitt, 2001)
- OEMs outsource much of a vehicle's value to suppliers, yet retain control over product architecture & differentiation + supply chain

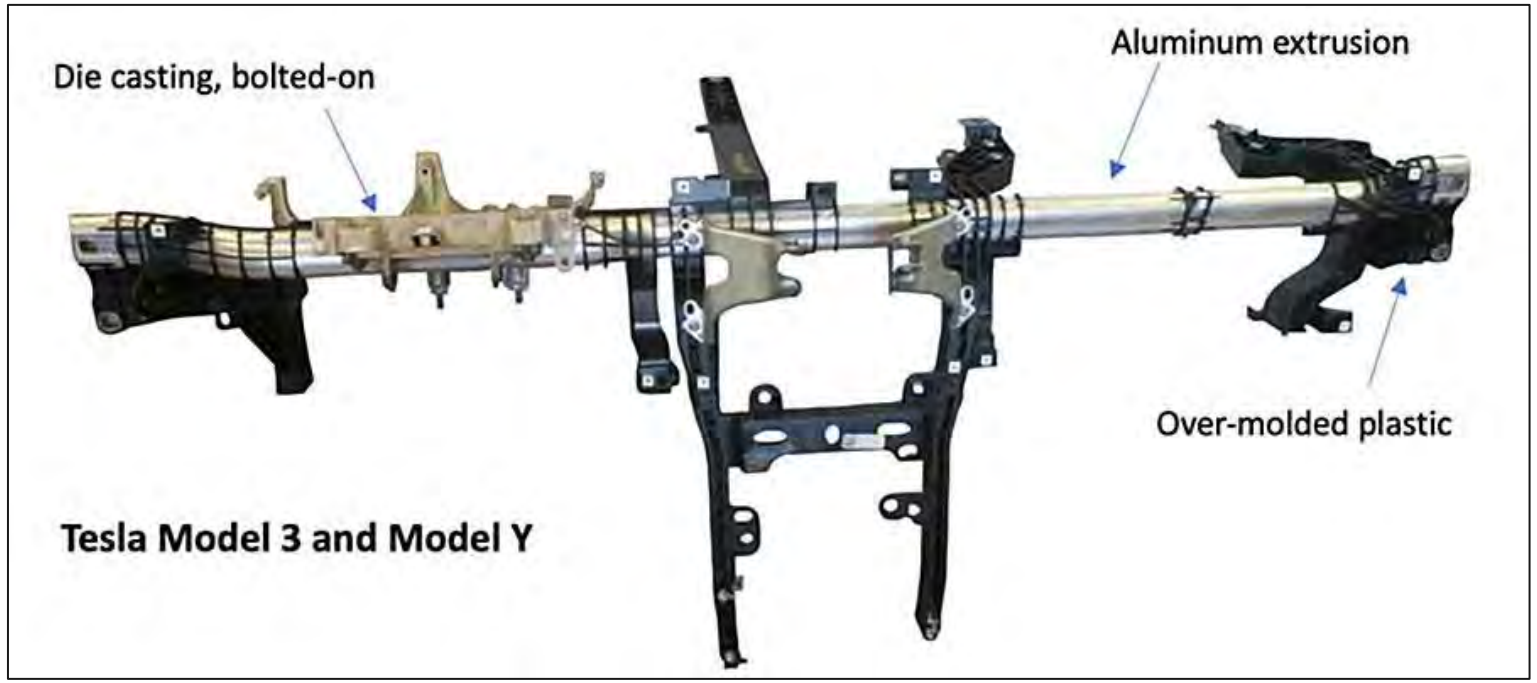
My current research focuses on:

Q: Will CASE Migrate Value from Auto OEMs to Tech New Entrants?

(whether *de novo* startups or Big Tech)

Will CASE Bundle? Why It Matters

- **Bundling creates more design interdependencies because together CASE technologies require redesign of virtually all legacy subsystems**
- Hence bundling favors OEMs' system integration capabilities
- Tech companies do better with modular initiatives, i.e. just C, just A, just S, just E – but that isn't where market trends and product strategies are going
- More bundling slows diffusion in the short run but could provide societal and economic momentum towards a "tipping point" with better overall outcomes



Today I will focus on:

Q: Will a new dominant design allow radical simplification that could disrupt the industry?

A: Let's look at cross-car beams…

… and this question:

Bloomberg

Live TV Markets Economics Industries Tech Politics Businessweek Opinion More

Electric Vehicles: Sales Stumble | Europe EV Tariffs | Growth Under Trump | German Carmakers Scramble | The Cost to Switch | World's First All-EV Ma

Businessweek | The Big Take

How Long Can Toyota Put Off Figuring Out EVs?

The world's No. 1 automaker has kept its focus on hybrids and gas-guzzlers, for better and worse.

[Bloomberg, February 1, 2025]

NB: Talks about simplification and cross car beams!

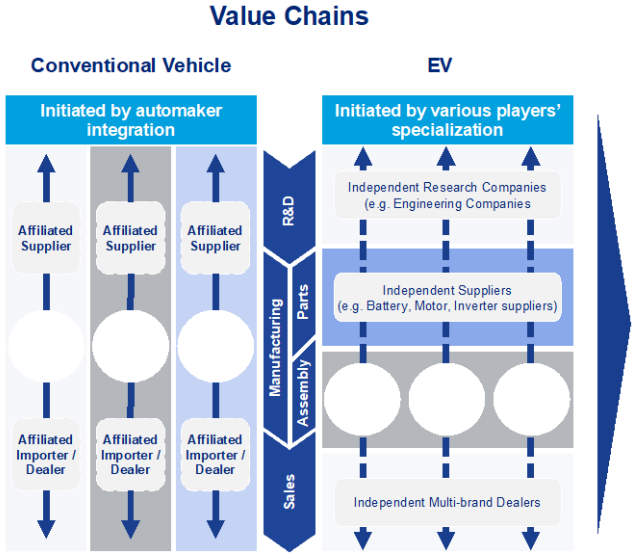
Electrification

What Impact of Simplification?

- Most easily incorporated within OEMs' existing SI role and supply chain mgmt
- Drive train is more modular but must still be integrated with all other systems → **architecture stays primarily integral**
- Hardware/software integration is key, but OEMs can learn this *(hmm…)*
- Still many barriers to customer acceptance of EVs – but EVs don't threaten OEM's role or opportunity to maintain share of value

Many have predicted that BEVs will be more modular than ICEVs

With the transformation to e-mobility there will be a significant change in the value chain of the auto industry



Key Points

- **Shift in profit allocation from assembly to information technology and components**
- **New "players" from different industries such as energy, IT and electronics**
- **Change from one-to-one towards multi-multi structure**
- **Lower entry barriers**

With "modularization-" and "plug-and-play-" concepts the role and power of suppliers in the industry will significantly shift

- Definition of global standards enable "***Modularization***"
- Connectivity without calibration - ***"Plug-and-Play"***

1. Supply to two or more automakers
2. Achieve economies of scale (similar to semiconductor industry)
3. Mega-suppliers would become profitable, while automakers producing relatively small volumes of EVs would be less so

Based on evidence to date, they are **wrong.**





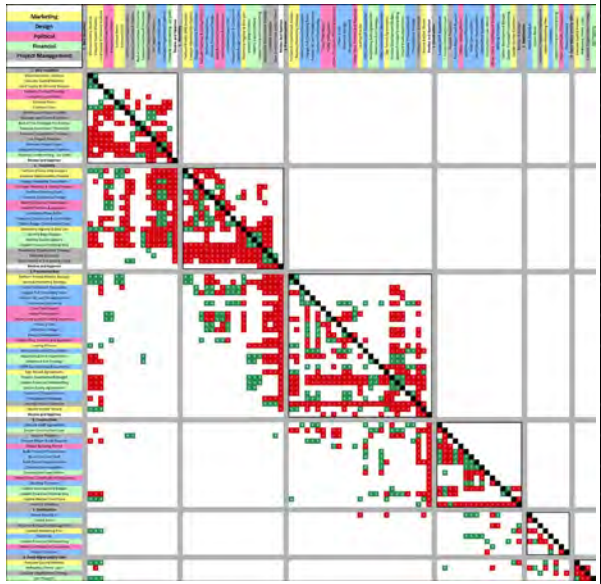
Murmann & Schuler (2023) Investigated the Modularity of BEVs and ICEVs

- Design:
  - Created detailed structural descriptions of the two powertrains
  - **Collected design structure matrices (DSMs) of BEVs and ICEVs at the system level**
  - Computation of propagation cost of BEVs and ICEVs as a measure of modularity

- Data:
  - From 2 global automakers manufacturing both ICEVs and BEVs and 1 start-up manufacturing exclusively BEVs

"Exploring the Structure and Modularity of ICEVs and BEVs"
Johann Peter Murmann & Benedikt Alexander Schuler
Industrial and Corporate Change, 2022

Experts at incumbent and startups filled out DSMs (Design Structure Matrix)



BEV Startup

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
A		0.4	0.1	0.3	1				1				0.5	0.5				0.2			0.1		0.1				0.4	1
B	0.4		0.1	0.5	0.5				0.5	1		1	1					0.2	0.1		0.1		0.1		0.3		1	1
C	0.7	0.7		0.8			0.2			0.3		1	1	0.5				0.5	0.5		0.7	0.5	0.3		0.3		1	0.5
D	0.5	0.5	0.7		0.5	0.5		0.5	0.5	0.5	0.7	0.7	0.5					0.1	0.1		0.1	0.2	0.3			0.3	0.3	1
E	1	0.5		0.7		1			1				1					0.1	0.5		0.1		0.1					
F	0.1				0.2																							
G	0.5	0.5		0.8					0.5		0.8		0.5		1	0.8		0.3			0.3		0.1	1	0.7	1	0.8	
H	0.5	0.5		0.5			1		0.3	0.5	0.3		0.5	0.3	0.5		0.3	0.5	0.3				0.1		0.3	1	0.8	
I	1	0.8	0.2	0.3	1		0.5	0.3					0.4											0.3		0.2	0.7	
J	0.3	0.5	0.5	0.3					0.2				0.2			0.2		0.1	0.1		0.2		0.1	0.1			0.3	
K	0.2	0.2		0.3						0.3		0.3	0.3	0.3		0.3							0.3	0.1	0.5		0.3	
L	0.3	0.5	1	0.5				0.3		0.3	0.5		0.3				0.5		0.2		0.1		0.3				0.5	
M	0.5	0.5		0.5	0.3				0.7																			
N							0.5														0.8	0.5	0.5	0.5				
O	0.3	0.2	0.1	0.5			1	1	0.5				0.2	0.3		0.3		0.1	0.1		0.2			1	0.5	1	0.5	
P	0.3			0.3		0.7	1	0.5	0.7		0.5		0.3	0.7	0.7			0.3			0.1		0.1	0.7	0.5	0.5	0.5	
Q	0.5	0.5	0.2	0.3					0.5		0.3	0.3	0.2			0.3		0.3	0.3		0.2			0.3	0.2		0.5	
R				0.1												0.3			0.5					0.3		0.3		
S	0.2	0.1		0.2														0.8										
T	0.1			0.2									0.1	0.3							0.1							
U	0.3		0.3	0.3			0.5				0.3		0.3	0.5								0.5	0.5	0.3			0.3	
V	0.3			0.3																			0.5					
W	0.2			0.3																								
X	0.2	0.2		0.2									0.3	0.5	0.7	0.7		0.3	0.2		0.5				0.5	1		
Y	0.3			0.3			0.5				0.3	0.3	0.2	0.1	0.3						0.3		0.1	0.3			0.5	
Z	0.5	0.1	0.1	0.5			0.7	0.3	0.5		0.5		0.5	0.8		0.9		0.8	0.3		0.5		0.3	1	0.3		0.3	
AA	0.7	1	1	1			0.8	0.5	0.7	0.5	0.5	0.5	0.7	0.3	0.3	0.5		0.5	0.5		0.7	0.3	0.5	0.3	0.5	0.1		0.3
AB	1	1	0.7	0.5	1		0.5	0.7	1		0.3		0.8	0.8	0.3	0.7		0.5			0.3		0.3	0.3		0.5	0.8	

- ***A modular product architecture clusters interdependencies along the diagonal.***
- ***This BEV startup should have the most ability to modularize – <u>and yet hasn't</u>.***

On all measures of product architecture, ICEVs and BEVs were the same – or BEVs were more integral

	Global Automakers (n=2)			BEV Start-up (n=1)	
	ICEV	BEV		BEV	
Design Parameters	28	28		28	
Direct Dependencies	229	241		328	
% of all DSM cells	29%	31%		42%	
Symmetric dependencies	164	132		170	
Propagation cost	0.931	0.966		0.966	

Conclusion: The claim that BEVs are more modular than ICEVs is CORRECT at the level of the drive train and INCORRECT at the level of the entire vehicle

Based on evidence to date, they are **wrong.**





BEVs Are More, Not Less Integrated in Production
(c. 2021)

- BEVs slotted readily into existing ICEV production, *though w/ volume, BEV-only plants will be built*; legacy manufacturing capabilities still valuable.

- Rather than a boost in full outsourcing to suppliers, the trend is ”make” or “ally to make” for battery packs & e-motors. Little contract manufacturing.

- Innovations in BEV production (e.g. gigacasting) will affect body shops yet limit product variety, disincentivize model changes, and increase repair costs.

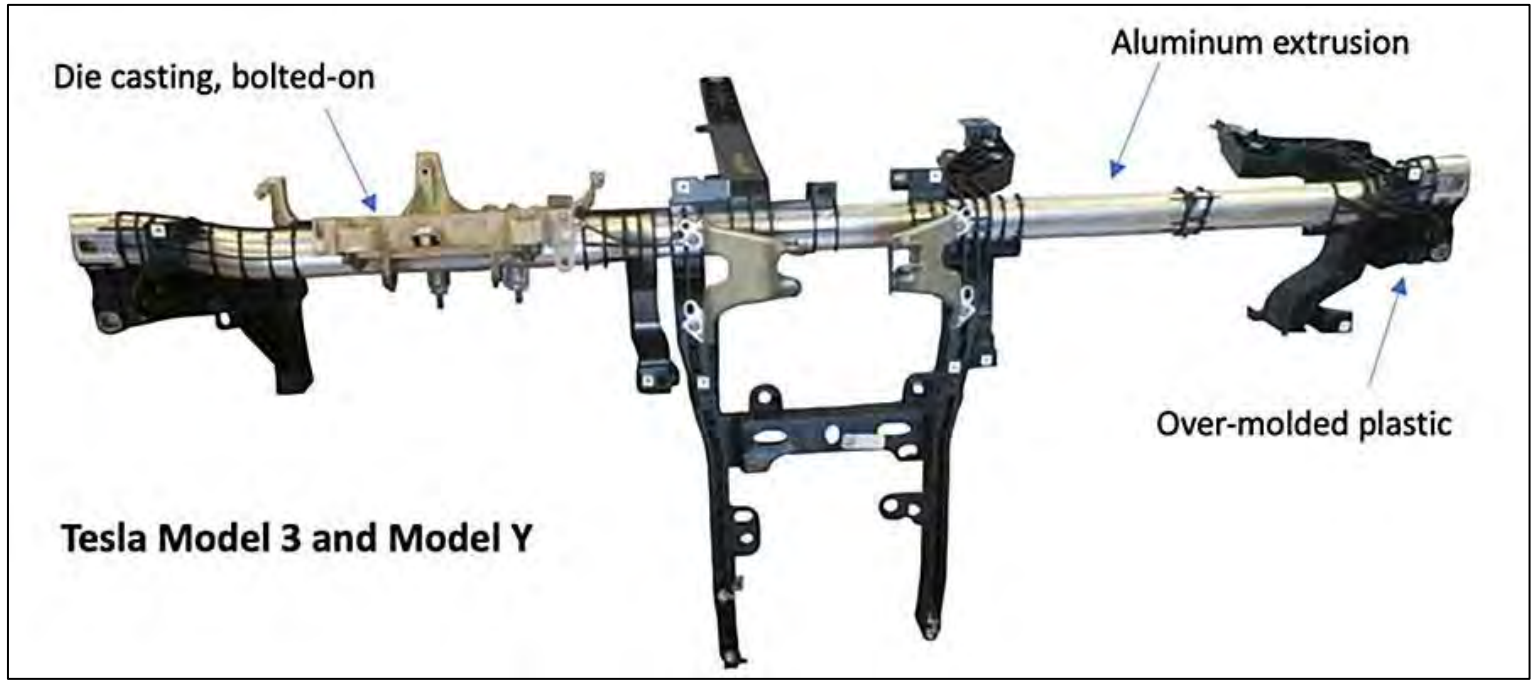
- Overall, BEVs are produced with ***more*** integration *(more integral design, more vertically integrated supply chains)*. ***This trend continues to the present.****

**Tesla’s promise of “unboxed” assembly is an extreme extension of modularity-in-production, not modularity-in-design.*

Prediction: Future for Autos Won't Be Like Computers & Smartphones

Obstacles ahead for: Designed by Mobility in Harmony (MIH), Built by Foxconn

- Expect that auto OEMs will continue to play a central system integrator role
- Design and manufacturing will evolve, not transform
- Simplification will happen via VI and quasi-VI organizational arrangements
- Redesigns for BEVs will spill over to HEVs and ICEVs
- Services will emerge from "coopetition" between auto and tech firms
- Integration in product and industry architecture will increase, for now; over time, potential for more modularity



Today I will focus on:

Q: Will a new dominant design allow radical simplification that could disrupt the industry?

A: Let's look at cross-car beams (CCB)

Cross-Car Beam (CCB) Mini-Cases

Cross-Car Beam (CCB)	Ford and Visteon (2000-3)	Hyundai & Mobis (2008-18)	Tesla & ErlingKlinger (2020-)
Governance	Visteon spun away from Ford – proposes cockpit module	Mobis spun *into* H/K; is holding co. for H. Motor	Tesla is only OEM to show interest in EK new CCB design
Organization	Visteon prepares design independently, protects IP	New R&D facility - Mobis and H/K staff sit together – eng faculty too	Tesla and E/K work closely together on Tesla S Plaid design
Design Goals	Lighter, # parts & cost down, less NVH, fast innovation	Lighter, # parts & cost down, less NVH, long-term platform (2019->)	Lighter, # parts & cost down, better fastener durability
Design Outcomes	Reduction: 44% weight, 30% parts, 20% cost, 10% NVH	Reduction (2018): 3.3 lbs less; 20% cost; NVH & crash test improve	Munro teardown finds weight, #parts gains over past Tesla CCBs, competitors (e.g. Ford mach-E)
Usage	Ford Mustang Chief Engineer rejects as not durable/reliable enough, questions the cost	Ongoing CCB project → variable thickness, new shape, mixed mtls, more bracket stiffness, durability	In Tesla S Plaid since 2021; top-priced ($130K); reviews find steering unstable at top speeds
Questions	What if more Ford-Visteon collaboration?	Is H/K/Mobis CCB design used on current H/K BEVs?	Is EK CCB used on Model X, Y, 3?

Recent CCB Designs at H/K and Tesla

Hyundai/Kia CCB developed by Mobis (2018)

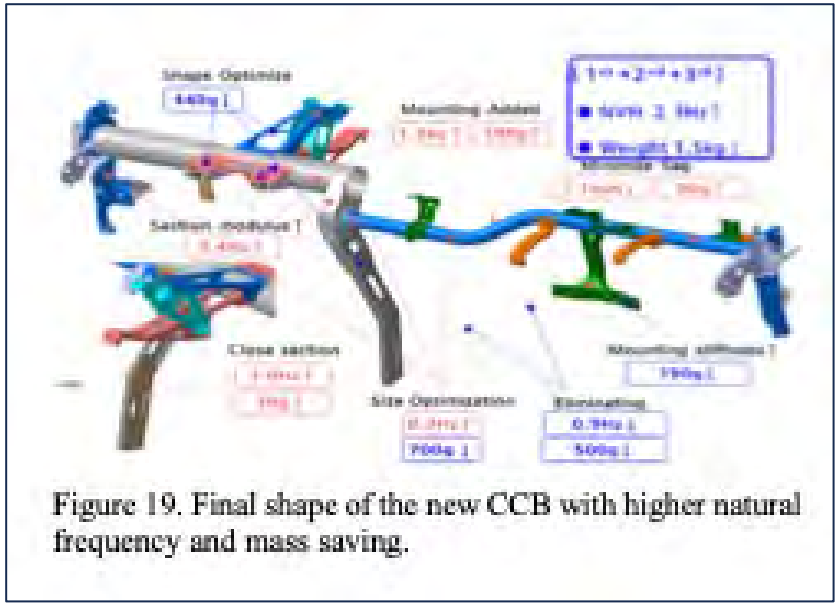


Figure 19. Final shape of the new CCB with higher natural frequency and mass saving.

Mobis design

• Variable thickness; new shape with mix of materials; more bracket stiffness

•Weight reduction of 3.3 pounds; NVH and crash test improves; cost savings of 20%

Tesla CCB developed by ElringKlinger (2021)

EK Metal forming hybrid cross-car beam

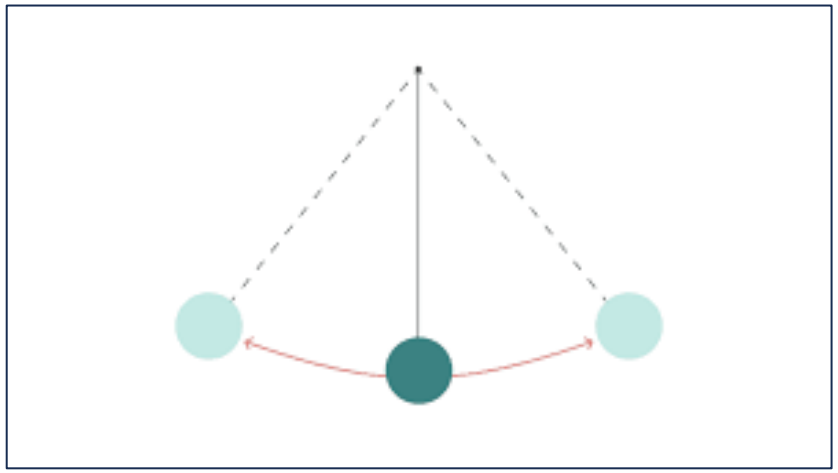
- Uses aluminum or steel tubes w/ hollow structures
- Combined w/ thermoplastic injection molding with local metal re-enforcement out of steel and aluminum
- Reduces weight, keeps functional rigidity, secure fastening; faces less vibration with electric drive train

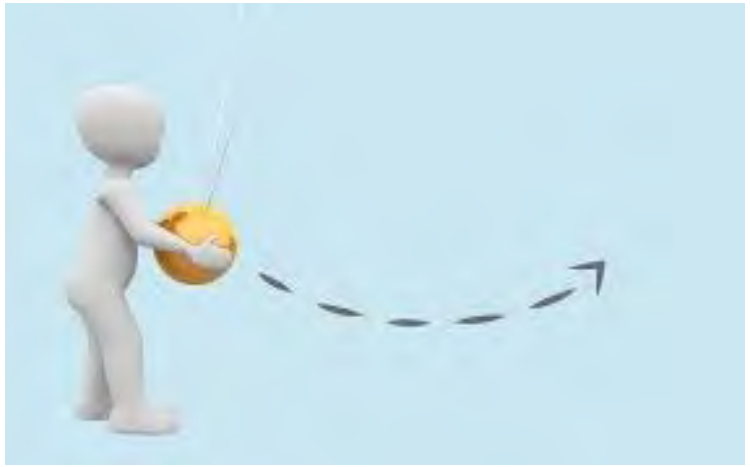
Lessons from Cross-Car Beams

- Best designs come from supplier working very closely with OEM
  - 2000: Visteon moving away from Ford towards “arms-length” relationship
  - 2008-18: Mobis becomes increasingly integrated into H/K R&D for proprietary designs
  - 2018-21: ElringKlinger establishes close working relationship with Tesla
- Best designs combine materials and topological innovations with new manufacturing techniques for reductions in weight, size, NVH, cost
- The resulting CCBs are highly integral, customized, and simplified; achieved through quasi-VI at Mobis; through a supplier at Tesla
- Questions:
  - What if Ford and Visteon had collaborated closely?
  - Is Mobis CCB used on H/K BEVs?
  - Is EK CCB used on Model 3?
  - I.e. Are these designs that can be applied across product segments and BEV+HEV+ICEVs?

The Simplification Pendulum Swing (1)

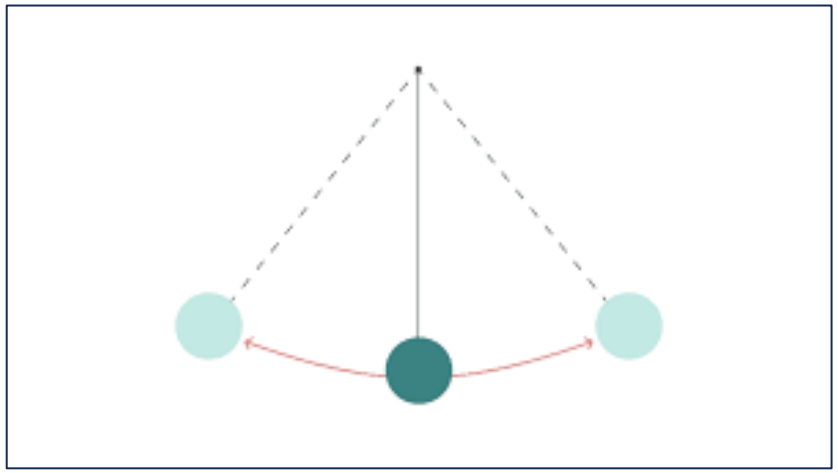
- Consumers like variety, production likes standardization
- Marketing likes differentiation, manufacturing likes low complexity
- Product development alternates big and small change cycles (new platforms; new models; major and minor model changes)
- Cost competition drives simplification, market share competition (tends to) drive brand differentiation and design variety
- Tension, within firms and across firms, on these dimensions

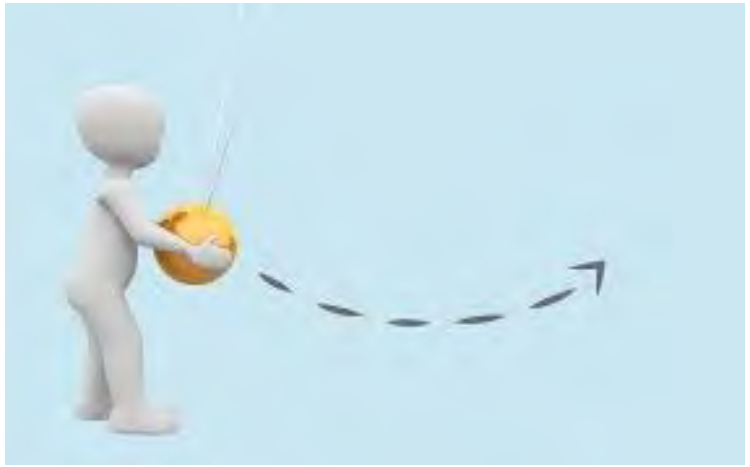




The Simplification Pendulum Swing (2)

- Pendulum swing over time – simplification and cost reduction after big changes (new platform, new model); differentiation and variety expansion based on growth in sales; new markets (incl. global); competitor actions
- Notable simplification fiascos: GM-10 platform (1987 forward) supporting multiple GM brands, yielding many models that look, drive similarly *(can't find my car in the parking lot…!)*
- Secular trend: variety always increasing, manufacturing can't stop it
- New trend: differentiation through software, infrequent model changes (Tesla's bet) – will it prevail over long-established consumer preferences for variety in hardware?





Can Toyota and its suppliers pull off an innovative CCB design?

Bloomberg

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Electric Vehicles: Sales Stumble | Europe EV Tariffs | Growth Under Trump | German Carmakers Scramble | The Cost to Switch | World's First All-EV Ma

Businessweek | The Big Take

How Long Can Toyota Put Off Figuring Out EVs?

The world's No. 1 automaker has kept its focus on hybrids and gas-guzzlers, for better and worse.

Of course!

When will volume of BEVs justify a different CCB design, separate from HEV/PHEV and ICEV designs?

Or could the same simplification effort lead to a CCB design better for all types of vehicles?

Toyota doesn't only do kaizen.

Conclusion

- Product and industry architecture for ICEV & BEV is “persistently integral”
- CASE technologies are advancing as a bundle, i.e. more interdependencies
- Managing those interdependencies during change in dominant design is best done by vertically-integrated (and quasi-VI) OEMs
  - *Legacy (not all) and a few new OEMs (yes to Tesla & BYD; others??)*
- Simplification pendulum is swinging to reduce weight and parts count through innovative design and production methods – across the industry
- Modular production gets attention but lighter, fewer parts via integrated designs are more impactful as they accumulate
- Some firms lead in simplification - but all are doing it. Can imitate the leaders plus learn internally and via supply chain. Pendulum will swing…
- High potential for spillover benefits across BEV, HEV, ICEV – but timing and cost calculations are tricky


thank
you

Backup Slides

Electrification

Connectivity

"A Once-in-a Century Transformation"

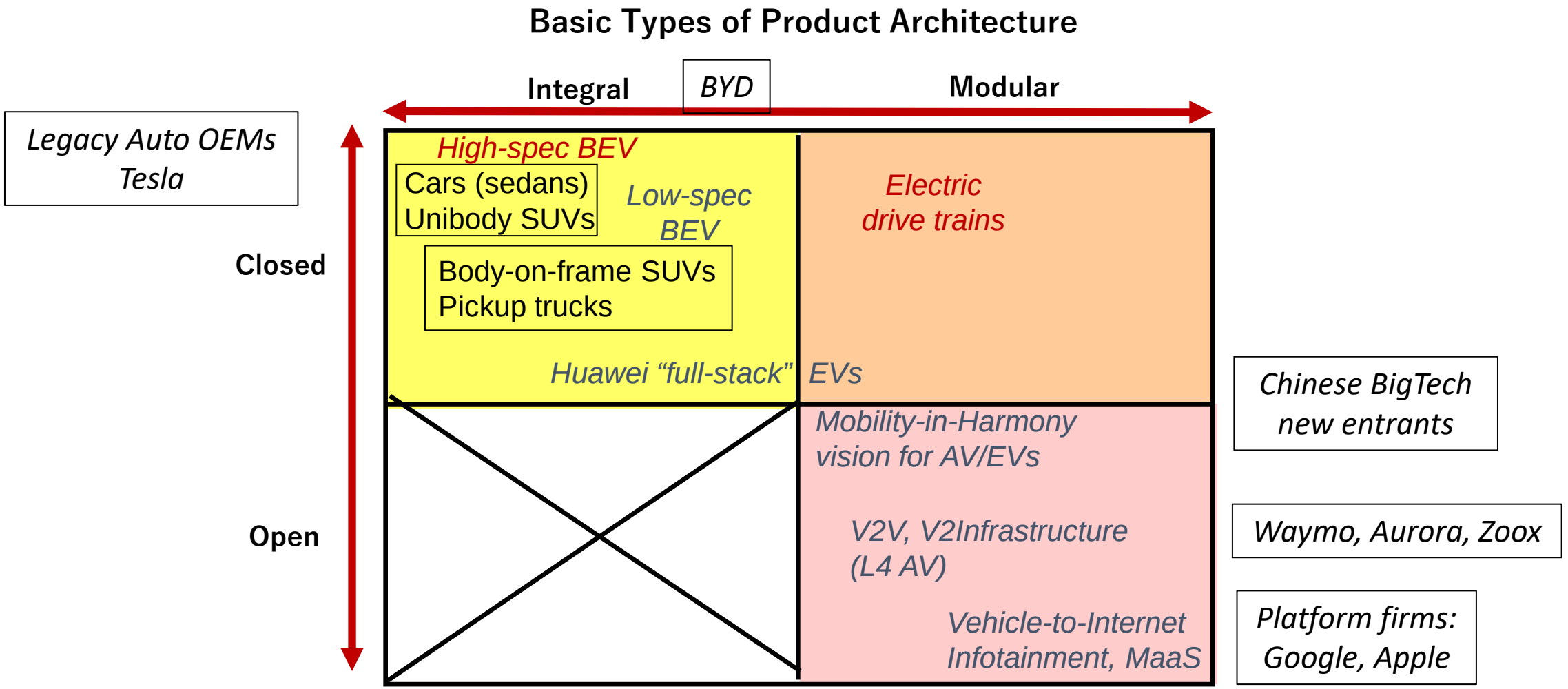
Autonomy

Shared Mobility Services

Figure 1b:
***CASE* VEHICLES IN MOBILITY SECTOR**
circa 2024

Three Basic Types of Product Architecture

(1) *Closed-integral* , (2) *Closed–modular*, (3) *Open-modular*



Fujimoto and MacDuffie, 2024

Note:

BYD Sales are
New Energy Vehicles =
BEV + PHEV.

Tesla Sales are BEV only.

If EVs of the Future Are Made by Multiple OEMs (incumbent and new), Will They Be:

- More modular?
  (Product Architecture)
- Produced and sourced differently?
  (Industry Architecture)
- How does simplification fit in?

Are BEVs Manufactured Differently? (c. 2021)

74/76 of the observed BEVs from 19 OEMs are manufactured in mixed-model production within their existing assembly plants.

Newcomers (e.g. pure BEV OEMs) follow a production process that is highly similar to that of legacy automakers.

This study didn't take into account different OEM strategies for simplification.

	Company name	Region of origin	Status
1	BMW	Europe (Germany)	Incumbent
2	BYD *	China	Incumbent
3	Daimler	Europe (Germany)	Incumbent
*	FCA	USA / Europe (Italy)	Incumbent
4	Ford	USA	Incumbent
5	Geely - Geometry pure EV brand	China	Incumbent
6	GM	USA	Incumbent
7	Honda	Asia (Japan)	Incumbent
8	Hozon	China	Newcomer
9	Hyundai/Kia	Asia (South Korea)	Incumbent
10	Lucid Motors	USA	Newcomer
11	Nissan	Asia (Japan)	Incumbent
12	NIO	China	Newcomer
*	Groupe PSA	Europe (France)	Incumbent
13	Renault Group	Europe (France)	Incumbent
14	SAIC - MG brand	China	Incumbent
15	Stellantis *from merger of FCA and PSA	Europe / USA	Incumbent
16	Tesla	USA	Newcomer
17	Toyota	Asia (Japan)	Incumbent
18	VW	Europe (Germany)	Incumbent
19	XPENG	China	Newcomer

** BYD purchased a legacy OEM when it began production and builds HEVs & BEVs (no longer ICEVs), but could also be categorized as newcomer*

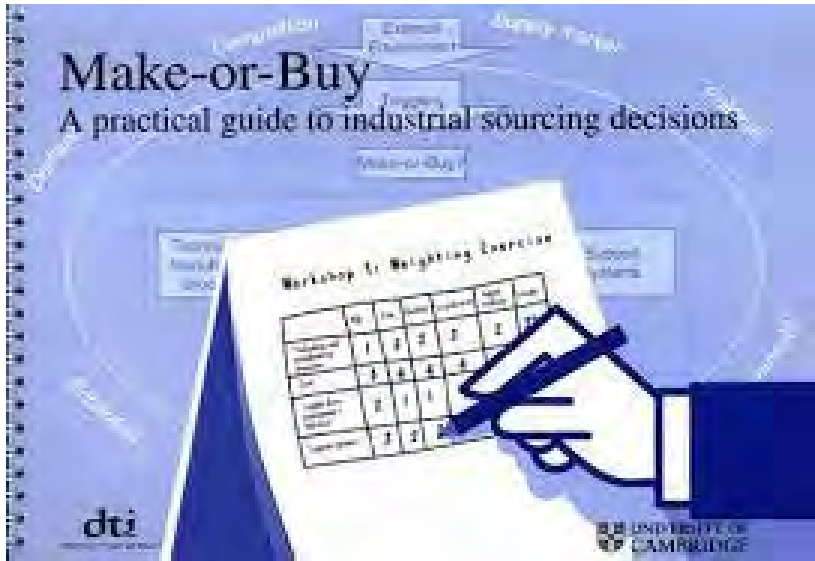
"Mirroring in Production? Early Evidence from the Scale-up of BEVs"
Marc Alochet, John Paul MacDuffie, & Christophe Midler, *Industrial and Corporate Change,* 2022

Are Components of BEVs Sourced Differently? (c. 2021)

None of the observed automakers make cells.

But 68% of them have a “make” capability for battery packs and over 50% have design capability for the Battery Management System (software)

68% of the observed automakers have a “make” capability for e-motors.



“Mirroring in Production? Early Evidence from the Scale-up of BEVs”
Marc Alochet, John Paul MacDuffie, & Christophe Midler
Industrial and Corporate Change, 2022

CCB Mini-case #1: Ford and Visteon (2000)

- 1999: Ford established Modularity Task Force – vehicle defined in 19 modules
  - Production goals: reduced parts count; defined interfaces; one-step install)
  - Design goals: draw on suppliers for faster, cheaper innovation; set up mft. changes
- 2000: Visteon (spun off) approaches Mustang chief engineer with "super-integrated instrument panel" (SI-IP) design (100 patents, 500 disclosures)
  - Claimed reductions: 44% in weight; 30% in # of components; 20% in cost; 10% in NVH; 30% in quality defects; much smaller cubic feet space requirement
  - Challenges: must meet 10-year+ durability; reliability in extreme temperatures; resistant to vibration, oxidation, corrosion, water – and would Ford pay for the design?
- 2001: Ford's evaluation was positive on weight, parts count, space reductions but found SI-IP could not pass extreme conditions test
- Chief engineer: No to SI-IP. Would worry and "throw double engineers on it" – adding to costs and time – supplier wants the value-added but "I can't justify doing it"

Field work with Sue Helper; see MacDuffie (2013)

CCB Mini-case #2: Hyundai/Kia and Mobis (2008-2018)

- Hyundai acquires Kia in 1998. In 2000, Mobis combines H/K parts companies, is holding company for Hyundai Motor, very close managerial/financial ties.
- New R&D facility for H/K and Mobis engineers, who often sit together. Launch of modular strategy focused on design (not production) innovations.
- Cockpit and chassis projects focus on collaboration to reduce weight, parts, NVH. Mobis brings in knowledge from other suppliers, e.g. Samsung, LG.
  - Within modules, ever-increasing interdependencies w/highly integrated organization
  - Focus on H/K vehicles; designs are closed, proprietary, non-standard; learning approach
- CCB project for new platform aims for lightweight design that still meets NVH, crash performance, durability, and supporting rigidity
- Design: CCB has variable thickness; new shape with mix of materials; more bracket stiffness; extensive durability testing. Adopted for new platform in 2019.
- Weight reduction of 3.3 pounds; NVH and crash test improves; cost savings of 20%

Field work in 2005-8; MacDuffie (2013); updates in Jo, Jeong, & Kim (2023); cross-car beam in Kong & Park (2018)

CCB Mini-case #3: Tesla and ErlingKlinger (2018-24)

- Tesla has few models but makes ongoing design and manufacturing changes to reduce weight, parts count, and cost
- ElringKlinger (German supplier) brings its metal forming hybrid cross-car beam to U.S., offers it to several OEM customers – Tesla shows the most interest
- EK CCB is adopted for Tesla Model S Plaid (2022)
  - Teardown contrast by Munro with Ford Mach-E CCB (magnesium with separate plastic molded cover for fasteners that adds weight and an extra manufacturing step)
  - Also EK contrasted with designs where plastic attachment points aren't securely embedded in metal structure of CCB
  - In terms of shape, materials, extrusion of plastic through openings in the CCB for rigidity, stable fastening, and durability – looks similar to H/K design
- EK CCB is a highly integrated design requiring a sophisticated production process and close coordination with the customer – supplier is driving the innovation
- Costs? Aluminum/steel cheaper than magnesium; production more expensive?
- Gains in weight reduction and reduced parts count, plus 1-step install, make it worthwhile for Tesla (BEV); other OEMs may find design won't work across BEV and ICEV

Caresoft teardown data in Dziczek and Helper (2024); Munro video (2022); ElringKlinger (2021); Bloomberg (2025)

Will CASE Bundle? Why It Matters

- Bundling creates more design interdependencies because together CASE technologies require redesign of virtually all legacy subsystems
- Hence bundling favors OEMs' system integration capabilities
- Tech companies do better with modular initiatives, i.e. just C, just E, just A – but that isn't where market trends and product strategies are going
- **More bundling (achieved best through VI) slows diffusion in the short run but could provide societal and economic momentum towards a "tipping point"**
- Slower pace delays SOME societal benefits but allows more time to prepare for:
  - Regulations to insure safety of autonomous vehicles
  - Displacement of people doing driving-related jobs by autonomous technology
  - Ensuring that individually-oriented mobility services don't create huge congestion problems
  - Rebound effects in how human beings choose to be mobile