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INNOVATION AND VEHICLE ARCHITECTURE DEVELOPMENT IN A NEW AGE OF ARCHITECTURAL COMPETITION

Carlos Gorbea[1, 2], Udo Lindemann[1] and Ernst Fricke[2]
[1]Technische Universität München, Institute for Product Development
[2] BMW Group

ABSTRACT
The automotive industry is going through fundamental change as new car architectures begin to compete in the market. If the new hybrid and electric vehicle offerings prove to gain traction, established firms that are slow to join in the market can be facing potential failure. However, if conventional cars outperform the new entrant vehicle architectures, these can disappear as rapidly as they gained popularity as explained in informational cascades theory. Automotive manufacturers can mitigate this uncertainty by focusing on standard vehicle architecture packages alongside the traditional development process in order to filter new technology offerings that become relevant.

Keywords: Architectural Competition, Product Architecture Platform, Informational Cascades

1 INTRODUCTION

Automotive firms that are leaders in their markets, listen to their customers, are labeled as innovators in their product offerings can be close to disappearing from the market altogether. Why? The rules of the game are drastically changing. Petroleum prices have peaked and dropped dramatically showing an uncertain volatility, the depressed financial situation is causing consumers to hold on to their cars longer and become more selective on fuel efficiency when buying a car, start-up companies with alternative fuel car concepts are on the rise and governments in key automotive markets have set challenging short term goals in reducing CO_2 emissions. These are just a few indicators that beg incumbent firms to carefully choose their strategy going forward.

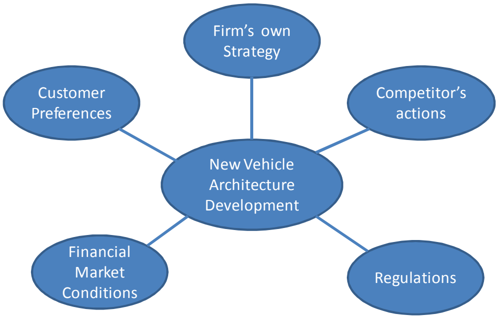

Figure 1. Key influencing factors to new vehicle architecture development

2 ARCHITECTURAL COMPETITION

Architecture in its traditional reference to building structures alludes to the interplay between form and function. Similarly, in the automotive world, vehicle architecture refers to the linking of function and components to meet a set of consumer requirements [1]. Modern cars are considered to be complex product architectures, as most systems are now mechatronical systems incorporating interplay of many mechanical and electric control sub-systems and components [2].

In this paper we classify vehicle architecture by how its powertrain is structured to propel the car. Examples of differing architectures include the internal combustion engine car, battery electric cars, hybrid cars, fuel cell electric cars, and steam cars to name a few. Within these categories finer architecture differences such as front wheel drive, rear wheel drive and four wheel drive can be also addressed, however here we consider only the highest or most abstract classification category.

Architectural competition is observed when multiple car architectures compete in the market and create consumer awareness [3]. During the early years of the automotive industry, cars used to compete primarily on architecture. Car buyers in the early 1900s had to make a conscious decision as to whether they were to purchase a battery electric car, a steam car or an internal combustion engine car. This early period is therefore one exhibiting architectural competition, starkly different to the mid-20th century where all cars in the market were dominated by a single architecture, the internal combustion engine car.

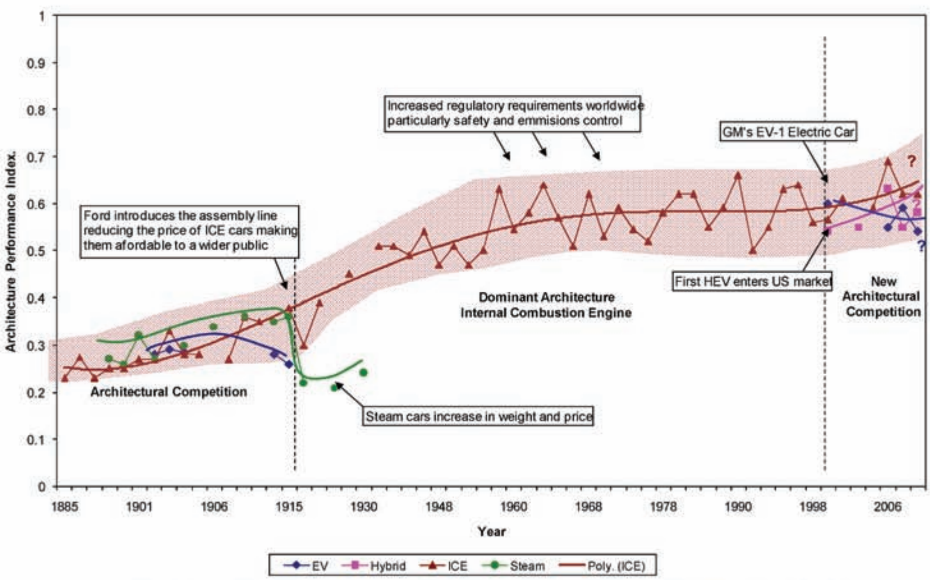

Figure 2. Performance of various automotive architectures from 1885-2008 [3]

Figure 2 shows a that vehicle architectures lifecycles can be depicted by s-curves similar to that of technology s-curves. The basic theory of technology s-curves is that technologies follow a basic four phase model that includes an early adoption phase, a fast adoption phase, a saturation phase and in some cases a decline phase or a jump to a new technology. When the technology performance is plotted against time, an s-curve results where the early phases display very little change in technology performance during early adoption. A fast adoption phase brings in more market players that achieve marked improvements to the technology's performance. As the technology matures into the saturation phase technology performance slows down, making way for new disruptive technologies.

Because vehicle architectures consist of many sub-systems technologies, the product lifecycle of the aggregate of these technologies is of a much longer time scale. Figure 2 shows that we are now entering a new age of architectural competition marked by the entrance of hybrid and battery electric cars to the market. The last time period of such architectural competition lasted roughly 30 years to produce a dominant architecture. This new age of competition can last much longer as the complexity of the systems have increased dramatically. New architectures must be able to compete not only in taking the customer from point A to B, but also providing the same level or better of comfort, safety, navigation and added entertainment.

The variety of offerings during this new age of architectural competition can be extensive. A panel of experts formed by the California Air Resources Board (CARB) expects that by 2050 ten different vehicle types will be mass produced and offered for sale [4]. For each type of architecture a variety of sub-categories can be expected. For example, today the ICE car includes gasoline, diesel, CNG, LPG and others. Likewise, hybrid architectures will also bring extensive variety including micro, mild, full, and plug-in hybrids with varying functionality, component structures and electric range capabilities.

This varied offering will make it difficult for firms and consumers to decide on which architecture will prevail, or be most popular in the future. This is why a new age of architectural competition brings an added dimension of risk to automakers – firms must compete in multiple architecture segments without knowing which will be ultimately more popular or profitable.

Established manufacturers that want to bring new architectures to market rapidly might not be able to do so without out-sourcing more to suppliers. Firms that have grown with the conventional car have fine tuned their core competencies in creating engines and car designs around this particular power train for the last 50 years. Items that fall outside this core competence are usually outsourced. One example is tires. No major OEM produces their own tires as they are not part of their core competence. Now as OEMs shift to new architectures that entail competence in electric drive systems, they have the choice to either make it a core competence or buy products from suppliers.

In summary a new age of architectural competition entails the following implications:

- Potential to last several decades until dominance or co-dominant architectures are established.
- Introduces more risk – architectural risk entails investing in an architecture that will not prevail, thus losing out in the market.
- Increased regulatory activity might favor some architectures over others.
- Allows for more small players to enter the market with niche-products that might not seem to compete with incumbents at first hand. If these firms succeed and grow they might circumvent major barriers to entry the large firms have enjoyed for years.
- Customers will have more choices to make. Not only choose car segment, body type, and price category, but now also powertrain architecture.
- As established firms race to fill the voids of new architecture offerings in the market, they will need to seek additional capital and re-think the way they produce and sell cars.

3. INNOVATION IN THE AUTOMOTIVE INDUSTRY

The implications of fundamental changes in the automotive market require firms to re-think how they approach innovation management. Firms that are successful today have mastered the traditional product development process. This process is established on incremental innovation, where most new cars consist of slight variations and improvements to earlier models in the same product lines. However, continuing down the path of evolutionary innovation increments can allow disruptive new architectures to enter, create and capture new markets and redefine the broader market altogether.

Once the ICE car emerged as the dominant architecture platform, auto firms continued to improve the process of integrating new technology into diverse automotive sub-systems in a type of risk minimizing technology portfolio model. At the more detailed level of sub-system components, modular and even radical (or disruptive) innovations are more commonly witnessed (ie. modular: changing from mechanical window operation to power windows; radical: airbags, catalytic converters, fuel injection systems).

As pressure to decrease vehicle fuel dependency and emissions generation now grows beyond the limits of local sub-system improvements, firms that will be successful in the future must update their product development process to allow for *architectural innovation* [5]**.** This type of innovation refers to the reconfiguration of sub-systems and redefining linkages between functions and components in order to achieve desired improvements that go above and beyond that of today's cars. In short, new product offerings must be flexible in reconfiguring themselves in new ways that allow for alternative fuel car platforms [6].

3.1 The innovator's Dilemma

Firms that are leaders in their market and suddenly fail due to a disruptive innovation are said to have been trapped in an innovator's dilemma. The inability to act in time to counter the new product entrants is mainly due to the processes that made the firm succeed in the first place.

Competition on vehicle architecture may lead to failure of established automotive firms that are not flexible in adapting. The accumulated institutional knowledge can become a liability when market conditions change as documented in various case studies where incumbents that face an architectural innovation challenge decide to stay the course even after better solutions emerge [5][7].

Christensen notes "that the problem established firms seem unable to confront successfully is that of *downward* vision and mobility, in terms of the trajectory map. Finding new applications and markets for these new products seems to be a capability that each of these firms exhibited once, upon entry, and then apparently lost. It was as if the leading firms were held captive by their customers, enabling attacking entrant firms to topple the incumbent industry leaders each time a disruptive technology emerged." [7]

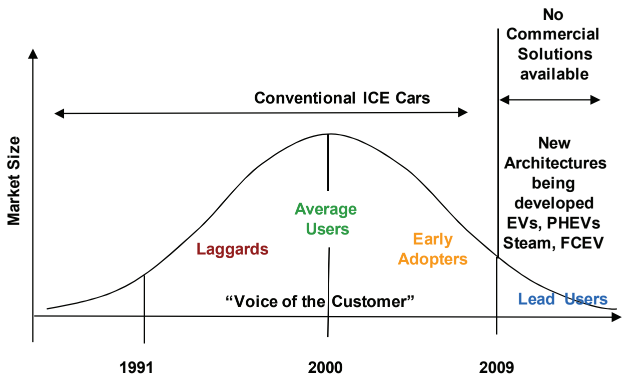

Figure 3. Schematic showing the age distribution of cars in operation and customer typology (based on registered vehicle data from the US Department of Transportation 2001 report)

The figure above helps explain why the innovator's dilemma occurs. The average driver according to the US DOT in their 2008 annual report is registered to drive a 2000 model car [8]. If we consider that to be the average customer, then early adopters would be those driving newer than average cars and laggards being those customers that drive older than average cars. Only lead users are those customers that have modified existing cars to meet their needs, and have created their own vehicle architecture [9]. If firms listen to what their customer's needs are, the voice of the customer comes from a population that is far away from the newest automotive innovations; hence their requirements will mostly reinforce the dominant vehicle architecture.

Lead users are individual innovators that create new architectures and technologies such as plug-in hybrids [10] and battery electric cars on their own. They have the ability to create awareness of a new niche-technology. Start up firms can offer a very limited market segment of these products without attacking the market segments of incumbent large manufacturers.

According to Henderson and Clark [5], architectural innovation has both elements that are core competence enhancing and others that may destroy competence as the design requires re-linking functions, components and their configuration. If the firm cannot build knowledge quickly enough to adapt to architectural change by means of restructuring its organization, it might seek for ways to buy knowledge from suppliers or competitors. When this occurs across several firms in a particular market segment, the market supply chain can experience shifts in terms of supplier power and buyer power. Economic power will go to where "right" core competencies are being generated.

We have seen evidence of such realignment of power in the automotive industry as hybrid electric vehicle (HEV) architectures enter the market. HEVs require both knowledge in producing battery electric and internal combustion engine (ICE) powertrains. Most of today's major automotive manufacturers lack the first and hold the latter. So when Japanese auto makers Toyota and Honda entered the hybrid vehicle market in 1999, competing firms looked to create joint ventures with suppliers and other competitors or simply seek to license the new architecture as was the case of Ford in 2003. Because the heart of the electric power train lies in high voltage battery technology, firms that can supply this core competency require a hefty premium for their products placing pressure on the automaker's profit margin.

3.2 Informational Cascades

When is it the right time to bring about a new architecture to market? Moving first might earn a firm the reputation of a pioneer, however costs and the high uncertainty that the new product will succeed are large deterrents. Taking on a fast follower strategy might entail buying still unproven technologies at a high premium. Not taking action can lead to the innovator's dilemma. The heightened level of uncertainty in the market can lead to irrational decisions similar to what occurs in the creation of fashion fads or technology hypes.

Most competing firms take on development strategies based mostly on the actions others take until they gather enough information to re-evaluate their strategy. The so called "me too" strategy derives from situations where only limited information is found within the firm and all competitors are facing a *real option* of whether or not they should invest in the new architecture now, in order to have the ability to enter the market at a later time. Because information is so scarce early on, if one competitor commits and enters the market with a new vehicle architecture, it is in fact exercising its *real option*.

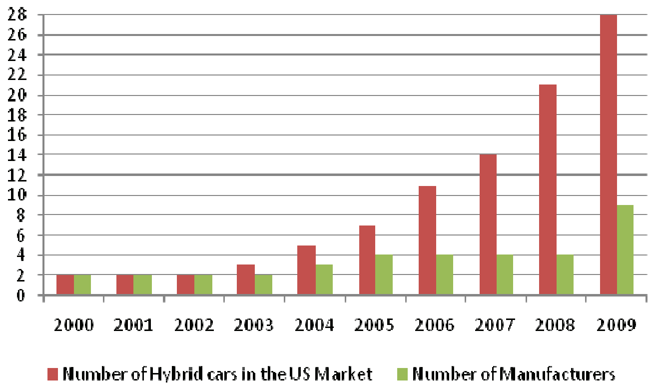

Figure 4. Growth of hybrid car offerings and HEV manufacturers in the US Market suggests the pattern of an informational cascade

The firm that commits to the new architecture releases positive information about the new innovation since options can be assumed to be only exercised if they will deliver value. Other competitors facing a similar decision attempt to improve their own information by observing what other in the market do. This can lead to an informational cascade where multiple firms commit to the new architecture, attracting others that are watching their actions to do so as well.

Hirschleifer [11] has studied these informational cascade problems from the customer perspective of buying new products and concludes that informational cascades on average lead to good decisions. However, if the early consumers take on a wrong decision the cascade can lead to irrational behavior and harm successors. Once the consumer can obtain more complete information on the product, fads that seemed to be right can be proven wrong and disappear just as quickly as they appeared.

At the moment most major auto manufacturers have invested in HEV real options. Meaning, they are building knowledge in order to be able to enter the market in the future if need be. However as several firms have exercised their options and entered the HEV market, others that have been watching are now entering the market with their own HEV models. Figure 4 suggests that an informational cascade favoring the introduction of hybrid vehicles is well on its way.

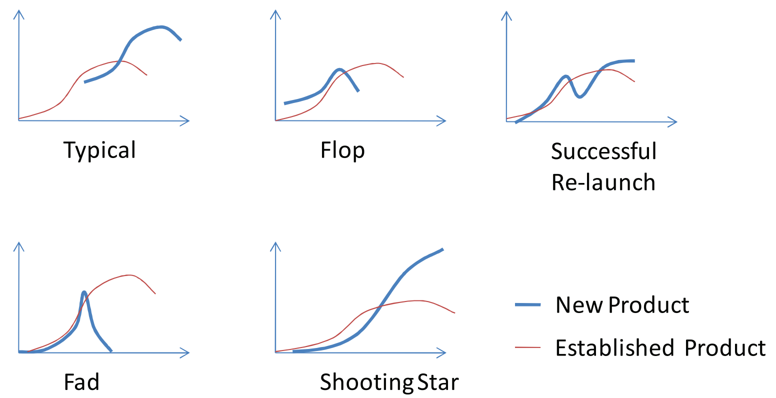

Figure 5. Performance vs. time qualitative graphs for Product Lifecycles Transitions

Firms need to continually evaluate and track architecture performance in order to ensure an informational cascade remains correct and that the trend will not disappear. Figure 5 shows performance vs. time graphs for various types of product lifecycles (adapted from [12]). So long the performance of new vehicle architectures are below that of the established architecture types, they still have a chance to disappear as is the case of a 'flop' or a 'fad'. Architectures that exhibit higher overall performance will continue to grow and may remain to dominate the market.

4. CREATING STANDARD ARCHITECTURES FOR MULTIPLE PRODUCT LINES

Product lines that have been optimized for combustion engine cars through the years will be strongly affected as the need grows to bring new architectures such as hybrid and electric cars to market. For example, performing a conversion design from a conventional sedan to a hybrid sedan requires considerable changes to the vehicle frame structure in order to include a list of new components such as the high voltage battery, electric motors, inverter, control system and other components including additional cabling and tubing. Most changes made to the base vehicle for making the hybrid car must be then taken for all other derivatives within the product line. This increases costs of materials and design that detracts from economies of scale in commonality.

Schulz and Clausing (et. al.) propose a model where the product development process works in parallel with the technology development process. The product development stream is said to "fish out new technologies" from the technology stream based on a given technology's maturity, robustness, flexibility and superiority [13].

We build on this framework by adding an *architecture stream* where sub-component technologies are analyzed for their integration to a specific architecture concept. It is within this parallel 'architecture stream', that architecture options can be scrutinized for value prior to the initial phases of the product development process for a particular product line. Figure 6 depicts architectural filtering as a way to refocus existing knowledge from the firm's product lines while building on new knowledge coming from the latest technological advances.

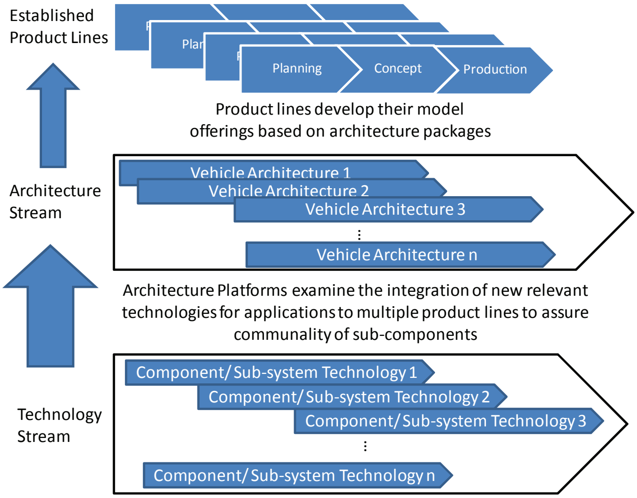

Figure 6. Flexible architecture platforms create commonality of technologies across two or more product lines. Technology infusion occurs through architecture filtering.

The architecture stream flows in parallel to both the product development process and the technology stream. This allows the vehicle architects to create architecture centric platforms that can be integrated across multiple product lines. It also allows for engineers to consider how second and third generation architecture platforms will change and how to create flexibility in the product line design to allow for future changes.

The development of future hybrid cars provides a good example of how architecture platforms could be applied. Consider two product lines that produce sedans in the compact and midsize vehicle segments and are looking to incorporate hybrid models to their product offerings. Product line managers look towards the architecture stream and select architecture packages that meet their needs. Within the architecture stream there can be multiple platforms for several levels of electrification. Engineers in the architecture stream identify various battery technologies existing in the technology stream and select technologies that show maturity, robustness, flexibility and superiority that meet the product line requirements. Because engineers in the architecture stream focus on how various battery technologies are evolving, they can suggest design commonalities across product lines that allow for future battery technology upgrades.

5. CONCLUSIONS AND FURTHER RESEARCH QUESTIONS

In this paper we discussed a new age of architectural competition that is likely to continue for several decades. In this changing market, we expect both established and new firms to enter the market with new architecture niche products that will compete in established car segments. These added products will increase the variety of architectures available, thus providing more choices to consumers.

We examined informational cascades as away to explain the behavior of OEMs entering the hybrid market. In the early stages of architectural competition, there is a high level of uncertainty as to how an architectural innovation will be accepted in the market. Once several firms decide to manufacture a new architecture, they exercise a real option that provides positive information to other competitors. These other competitors follow suit by observing what others in the market do and compare it with their own information about the new architecture.

In the near future, new car buyers will be asking themselves whether or not they should purchase a new hybrid as opposed to a conventional car. So long the new car architectures being offered do not exceed the performance of conventional cars; they may disappear from the market and be merely a temporal fad. If this occurs, the informational cascade that was mounting is proven wrong. However, researchers have found that on average informational cascades result in good decisions, suggesting that the current trend is bound to continue.

We also considered the innovator's dilemma. This phenomenon refers to established firms that fail for ignoring the changes occurring in the market. The disappearance of the steam car industry is an example of the innovator's dilemma that applies to the automotive industry during a time of architectural competition. Lessons from this dilemma will be especially important in the years ahead for car manufacturers.

Finally, the idea of creating standard architecture packages was presented. Architecture packages are a way of capturing knowledge and information on new architectural innovations coming to market and selecting key technologies that will be enablers for new architectures. The benefit of the architecture stream is in the offering of commonality to various product lines looking to implement an architectural innovation. Standard architecting can also be used to predict technology evolutionary changes ahead of time allowing product lines to implement flexibility for future changes.

Questions for further research include the following:

1. How can we accurately compare architectures in terms of performance? As we enter a new age of architectural innovations, it is important to judge whether it is a disruptive innovation.
2. What factors make up the performance metrics? Some ideas include technical measures such as power, maximum speed, etc. Other possibilities can be more abstract such as personal safety, image, profit and comfort.
3. How can strategy be devised to address architectural competition?
4. Is there an ideal architecture for certain customer uses that can build and sustain niche markets?

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