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PROCESS EFFICIENCY AND DESIGN REWORK AT EARLY STAGES OF THE VEHICLE PRODUCT LIFE CYCLE

April 2003

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I. EXECUTIVE SUMMARY

The industry knows all too well that from concept to launch, the total product development process must take less time, consume fewer resources, and be more responsive to changes in the economy, the market, regulation, and technology. This is the core challenge that automotive executives, designers, and engineers live with every day of their working lives. Key to meeting this challenge are many trade-off decisions that must be made early in the concept development phase of the life cycle, and which are critical to the unfolding, and ultimate success, of a vehicle program. The industry must make these decisions based on more, and more certain, knowledge and must employ that knowledge in shorter decision cycles. Better information and shorter cycle times will decrease the need for costly and time consuming revisions at later stages. Also, because unpredictable changes will always exist, shorter decision times are needed to assure powerful responses to unforeseeable events.

Despite the importance of these early stage processes, there is little systematic knowledge about how early-stage vehicle design actually takes place in the automotive industry, what the problems are, and how companies are dealing with those problems. This project was an effort to provide that systematic knowledge. We detailed nine cases where manufacturers had significant trade-off decisions to make in the concept development phase of the vehicle product development. Five common themes emerged from these cases: 1) foreknowledge of consequences, 2) reasonableness of decisions, 3) business outcomes, 4) the quality and quantity of available information, and 5) the source of rework.

Based on these cases and their commonalities, we sketched respondents' diagnoses of early-stage problems and the solutions they are attempting. It is certainly the case that respondents were more concerned with organizational and human resource approaches to improving high-level design, than with a software-tool oriented technological approach. We base this conclusion not only on the content of responses, but on the amount of time and attention given to organizational, as opposed to technological, issues. At several instances during each interview we made a point of pushing the discussion in the direction of tools. However, the respondents continually came back to two organizational themes: first, establishing rich, cross-functional interaction with shorter feedback loops among the layers of management; and, second, populating these new systems with a relatively small number of very experienced people. There was a clear sense that personal expertise was vital and that the key to success was bringing that expertise to bear in an effective manner.

With respect to software tools, we found our interviewees focused on: 1) function-specific tools, 2) integration tools, and 3) history of success and failure. With respect to function-specific tools, some new functionality is needed in the form of better parts databases, but the main use of tools is within specific functional areas. As for integration tools, two types of functionality can be discerned: the ability to organize and cross reference diverse information and the ability to analyze dependencies. With respect to organization and cross-referencing, there is a desire for better tools, and effort is being put into acquiring that functionality. In terms of analysis of dependencies, however, there is more ambivalence. On the one hand, the industry is putting effort into development. On the other hand, similar effort has failed in the past and people are skeptical. The explanation for past unsatisfactory performance is that too many unknowables had to be factored into algorithms, thus, leading to a reliance on uncertain assumptions.

II. DESIGN'S ROLE IN BUSINESS SUCCESS IN THE AUTOMOTIVE INDUSTRY

The product development challenge to the automotive industry can be seen as a design problem layered over a business problem. From a business point of view:

- Ever shorter product development times are needed to gain and maintain a competitive advantage,
- Pressure is relentless to remove cost from product, and
- Customers must be continually satisfied, intrigued, and delighted with new product offerings.

The product design process that is invoked to meet these business requirements:

- Has a large number of complex interactions,
- Necessitates many difficult trade-offs,
- Requires decisions that must be made under conditions of uncertainty,
- Must be agile in the face of that uncertainty, and
- Fixes product cost, functionality, and market timing early in the years-long product development cycle.

This last point is critical. While there is a lot of research on the product development process, much of it focuses on the product-engineering phase of the process. There is little systematic knowledge about how early-stage design and concept development activities actually take place. There is also minimal information about the nature of the decisions confronted during these phases of decision-making. This report focuses in on the earliest phase of the product development process that defines[1]:

- What the product does: performance and technical functions,
- What the product is: packaging, configuration, component technology choices,
- Whom the product serves: target customer description, and
- What the product means to customers: character, personality, feel, and image themes.

It is the answers to these questions that establish all of the product development and engineering requirements throughout the completion of a vehicle product development program. It is the execution and how well the answers to these questions match to the realities of consumer demands, regulatory requirements, and competitive positioning that determine whether or not a vehicle succeeds in the marketplace.

A vehicle program is a market success if it meets the business case assumptions that justified the allocation of capital spending to its development. Generally, a program manager is evaluated on meeting sales volumes and return on investment targets, capital spending budgets, and program timing deadlines, all within the context of managing assembly plant availability and adaptability, competitive dynamics, senior management interest, regulatory requirements, purchasing requirements, and labor constraints. These

[1] Product Development Performance: Strategy, Organization, and Management in the World Auto Industry, Clark and Fujimoto, Harvard Business School Press, Boston, Massachusetts, p. 106.

are the major considerations that are forcing the need to improve the efficiency of the concept development process.

III. OVERALL APPROACH

Our objective was to identify and understand inefficiencies in the early stages of the vehicle design process, with particular emphasis on procedures that generated redesign and rework later in the product development life cycle. To this end, we interviewed many people who were able to talk at length and in some detail about high-level design – when it was working well (or poorly), what the important unknowns were, where improvement was needed, and what they were doing to solve the problems. While this information was interesting and useful, it also tended to be general and abstract, thus, making it hard to discern what had a real impact on real problems. To avoid this ambiguity, we opted for an analysis approach that began with real cases of redesign and rework. We assessed what these examples had in common, either in terms of the nature of the problem, its etiology, or the way it was treated. This assessment provided a framework for understanding the more general narratives about high-level design. With this knowledge in hand, we proceeded to analyze global assessments of the process, solutions undertaken, and the role of information technology-based tools in improving early-stage vehicle design activities.

Data collection took place through interviews with six people. (In some cases, more than one interview took place with a respondent.) Two interviews can be classified as "high-level executives in the product design centers of U.S. OEMs, three were at or near the level of "chief engineer," while one can be classified as a mid-level engineer working on early-stage design tools for a U.S. OEM. Appendix 1 is the handout we provided respondents prior to the interviews.

IV. CASES AND COMMON THEMES

We were able to identify nine cases of early-stage design decisions that had to be revisited later in the design cycle. All but one case (the case relating to developing a vehicle for multiple marketing divisions) related to the most significant cost and time drivers in the product development system: engines, transmissions, body structure, and international homologation.

Specific Cases

1. Engine – Design for a V6 and a V8 or for a V6 only?

   Powertrain configuration decisions drive a significant amount of ultimate product differentiation and the resulting product development cycle time and cost. For example, major product differentiators such as acceleration, noise and vibration characterization, and towing capacities are dependent on displacement and cylinder configuration (inline-4, V6, V8, etc.). In one concept development program we were informed about, a decision was made to offer only a smaller V6 engine at vehicle launch and not to offer the option of a larger displacement V8 engine. This decision, in turn, drove decisions about the packaging of the engine bay, the design of the front chassis rails, the engine cradle, front suspension design, driveline, brakes, and the fuel system.

Later, due to competitive offerings, as well as the desire to add additional nameplates from the same platform, work to incorporate the V8 was initiated. In this process, many early decisions had to be revisited. For instance, due to its longer length, quite a bit of effort was needed to modify the front-of-dash area to accommodate the larger engine, underhood plumbing, and the heating and ventilating control module. In addition to design costs, production schedules of the original vehicle (the V6) needed to be adjusted as the mix between V8 and V6 shifted to the V8 as the new premium model. The bill-of-material and total costs needed to be adapted to capture not just the engine, but all of the vehicle production parts that needed to be changed to fit the V8 requirements and to ensure as much part commonality for both vehicles as possible.

These redesign consequences arose because as the concept phase progressed, the V8 was considered and then dropped in order to minimize time to market and maximize common parts as a tactic for simplifying vehicle assembly and logistics. Had vehicle design for both engines been designed in parallel, market introduction would have been postponed by 6 to 12 months. While the time delay and additional costs may not have been explicitly calculated, their general magnitude was understood and taken into account when deciding to launch the vehicle without the V8. While we do not know if the later decision to add the V8 option proved to be correct from a business point of view, we do know that as a result, additional design work and tooling requirements added another two, or perhaps three, years (depending on how the calculation is done) to the time when the V8 was introduced.

2. <u>Drivetrain – Design for two-wheel only or offer all-wheel drive option?</u>

An all new passenger car concept entered a manufacturer's product development process. Early on, the possibility of an all-wheel drive (AWD) version was considered as a tactic for meeting both current and future competitive positioning challenges. However, an AWD option would require significant architectural revisions to a basic two-wheel drive-only version. Such revisions would include alterations to the: 1) floor pan to allow room for the drive shaft, exhaust, and fuel line routings; 2) suspension height to accommodate ground clearance; and 3) instrument panel (with associated wiring harness changes) to accommodate AWD system controls, brake system, and engine packaging.

There was considerable uncertainty about the AWD's penetration rate in the targeted, current customer base. A penetration rate of approximately 10 percent would have been needed to justify the required engineering, production tooling, and parts and service requirements. It was not at all clear if that rate could be achieved. Without that business case, it was too risky to incur the extra cost, thus, jeopardizing base model sales while simultaneously increasing long-term service requirements for a low-volume AWD product. Designing simultaneously for a two-wheel and AWD vehicle would have added six to eight months to product introduction. All told, the extra cost and time could not be justified even though this timing contrasts with a projected two to three years' time needed to bring an AWD to market once job one was launched with only the two-wheel drive version. Depending upon the entrance of competitive vehicles and the manufacturer's own vehicle portfolio, the manufacturer will likely revisit this decision during a major platform revision or postpone this option altogether for the vehicle during this platform life cycle.

3. <u>Transmission – Design for automatic only or for automatic and manual?</u>

   In this case, the manufacturer's original plans for a passenger car called only for an automatic transmission to be mated with offered engines. In contrast to the AWD case, here, the designers knew from the start of the program that a manual transmission would eventually be required. The question was when to do the design work. Designers could incur the extra development cost while the platform was initially redesigned for the new vehicle, or they could wait and do redesign work for the manual transmission after the initial product launch. It was known that by waiting, later work would have to deal with many vehicle body and bill-of-material changes, including the console instrument panel, packaging inside the vehicle and engine compartment for pedals, and packaging for a different shape and size of transmission housing. In addition to these vehicle design issues, many additional changes would be necessary to accommodate post-production parts and service requirements. An educated guess at the time of this decision was that the consequences of a sequential design process (launch the vehicle and adapt a manual afterwards) would be a year in lost time to market and a 50 percent increase in cost over and above the inherent cost of designing for the manual during the primary product development process. Despite this knowledge, time, resources, and budget for a parallel development effort were not available. The manual transmission was not an afterthought or response to a surprise competitive event. It was a good idea that had to wait, and by waiting, incurred extra time and extra cost. The manufacturer is believed to be looking at adding a manual option to this vehicle in 2004, some 24 months after job one.

4. <u>Seating – Design to offer a SUV third row seat.</u>

   A vehicle manufacturer began work on a sport utility concept vehicle. One of the ideas that bubbled up – before competitive vehicle information was known – was to package a third row bench seat into a smaller and more competitively priced SUV. The manufacturer actually ran prototype vehicles with the third-row design through styling clinics to judge potential consumer reaction. While the proposed concept vehicle packaging was larger in overall dimensions than the current model being replaced, because of the concept vehicle's proposed wheelbase and rear-wheel overhang (along with other packaging constraints in the rear), the third row seat – as it had to be packaged – was judged insufficient. Consumers then rated other features and vehicle performance requirements as more desirable than a third row seat option. As this feedback was analyzed and the manufacturer looked at the competitive positioning of existing vehicles in its vehicle portfolio that could seat six or more persons (if a customer really needed that utility function), a decision was made to pull the third row seat from the concept development process.

   Midway through the vehicle design process, a competitor's SUV with a third row seat debuted at a North American automotive show. An immediate effort was undertaken to have the manufacturer's designers run through several iterations to determine if its original concept vehicle could accommodate a third row seat at the benchmark comfort levels it determined must be met to be "best-in-class." Again, because of the package constraint, a decision was made not to proceed with a third row seat in the original concept package. Rather, because the competitor's potential market advantage was so large, a decision was made to fund the development of a longer wheelbase model that would be introduced after the new model's introduction and slotted in-between existing and planned vehicles in the manufacturer's product portfolio.

This sequential process required considerable redesign of the vehicle, including major stamped components such as the frame, floor pan, and roof, as well as the windows, fuel tank, fuel lines, interior trim, and electrical systems. This additional design and engineering work was pushed through in approximately 12 to 18 months. This sequential design process could have been replaced with a shorter, incremental, six to eight month parallel process that would have designed the short- and the long-wheelbase simultaneously. Doing so would have resulted in the greatest possible common architecture and packaging elements, along with a greater overlap of shared components between the two models.

While the third row seat option was identified and tested in the concept development phase, this case may have benefited from the ability to perform additional design iterations in the concept development phase. Had the solution of an extended wheelbase been identified to better package the third row seat, it might have tested better, changing the manufacturer's decision to pull the option from the concept development process. The extended wheelbase version is now in production, approximately 12 months after the launch of the standard wheelbase version.

5. <u>Cargo space – Design for internal or under-the-floor spare tire storage?</u>

In this case, a vehicle manufacturer had already significantly moved through the concept development phase for a SUV model that would have been considered a "major facelift" model. That is, major components, such as the chassis and floor pan design, were carried over from the previous platform. This is usually a prudent strategy – using existing components – to minimize the product development process time and costs, as well as carrying over supplier and assembler experience to help ensure smooth product launch curves and initial quality. For this program, the early decision to carry over the chassis and floor pan was a reasonable decision based on time, capital cost budgets, and known business case assumptions regarding competitive positioning, market acceptance, and resulting sales and production volume forecasts.

However, the manufacturer was caught off guard when a revision of an existing, competing vehicle was shown to have moved the spare tire storage location from inside the passenger cabin (upright in the rear cargo area) to underneath the rear of the floor pan. (SUVs typically carry a full-size spare as their off-road capability requires that any spare maintain the vehicle's ground clearance in case the owner experiences a flat tire in off-road conditions.) To keep a full-size spare in the cargo area would significantly minimize the new model's competitive position in cargo carrying capacity. In addition, compared to existing models that carried the spare on the tailgate's swing-away carriers, the new location under the floor pan improved vehicle styling.

The manufacturer's marketing department insisted that to be competitive the "major facelift" model must include spare tire storage below the floor pan. This forced a redesign of the carryover floor pan, pushing the total product development process and job one back six months. This case shows the ever present pressure to shorten the product development cycle in the auto industry as, here, the competitor had a unique feature on the market for only six months (one half a model year).

6. <u>Passenger Car – Design for a coupe and a convertible or for a coupe only?</u>

   Here the question was whether accommodation in design should be made for a convertible version of a basic coupe. Oftentimes, mass volume manufacturers extend a nameplate's life cycle by developing a convertible model based on an existing coupe design. In many cases it is not cost effective to do so as significant additional cost and mass are required for the base vehicle to accommodate the special body characteristics of a convertible. The handling and crash characteristics of the coupe are dependent on a roof panel and other structural components that cannot be maintained in a convertible. Typically, significant reinforcements must be added to the floor pan, rocker panels, and other areas to increase the body's stiffness back to original parameters. In addition, one of the most significant challenges with a convertible is to find space for the convertible top and its operating mechanism while maintaining a competitive amount of trunk storage space.

   As a result, once a decision is made to add a convertible model, it can take up to two years for job one to occur. However, relatively small changes made early in the concept development phase can greatly reduce subsequent development time for a convertible. For example, the addition of two inches to wheel well space in the base coupe could reduce the need to design a complex and costly roof retracting mechanism to fit into a constrained space. Designing for this kind of accommodation would add approximately four to six months to the initial design time. Of course, a program manager who is not incentivised to consider potential future platform options would not likely take on this additional design complexity because she/he would not benefit from the additional units and revenue that a convertible model would deliver after launch. In this case, the convertible model was added with the additional capital costs being allocated to a new product development program.

7. <u>Global markets – Design for North America only or for global opportunities?</u>

   A global vehicle manufacturer's North American operations had entered into the concept development phase for a new vehicle. An early critical decision was whether or not to design the vehicle for the North American market only, or to consider incremental requirements for export as well. Designing for export would have required consideration of differences in safety and emission regulations, vehicle styling, operating characteristics, and competitive positioning.

   A global perspective requires attention to regional tastes and requirements. For instance, some markets require a shorter turning radius than others, and turning radius has consequences for exterior body panel design and styling. As another example, regional considerations may affect the touch and feel of switches and knobs in a vehicle's interior.

   If these elements are not considered early in the design stage, later rework can be extensive. Overlooking the steering system's turning radius requirements, for instance, can force major rework of the front fender wells, where a simple rework of dies is not likely to be sufficient. New tooling may have to be designed and procured. Similarly for the interior, an after-thought to redesigning the instrument panel to meet export requirements would involve retooling the instrument panel molds, a process that easily runs into the millions of dollars in capital expenditures. Time for major die changes after launch can range from 8 to 10 months. Total delay, including tooling and other design work, can be at least 12 months. Export opportunities are important because a vehicle's business case can significantly improve if exporting gives an assembly plant an additional marketing channel, thus, helping to assure that the plant runs near capacity. At the corporate level, a manufacturer's international group could benefit by the profit of incremental vehicle sales brought forth by a "niche" import vehicle from a sister division versus supporting a business case for a full assembly module (typically 250,000 units) on its own. In this case, an international variant of the model was developed.

8. Global Markets Case – Design for left-hand only or left- and right-hand flexibility?

   In this case, the platform team needed to decide whether to design an all new passenger car platform for left-hand drive only, or for both left- and right-hand drive. If the decision is made at early design stages, mirror image and ambidextrous components can be designed to work with both versions of the vehicle. For instance, an HVAC module can be designed so the outlet can be reversed from one side to the other. If these reversal issues are not considered in the early stages, redesigning the engine compartment packaging, steering and suspension components, and instrument panel to accommodate both left- and right-hand drive could significantly increase costs. For example, it is estimated that costs for retooling the instrument panel to accommodate export is approximately twice the amount of an optimized system incorporating mirror images of HVAC and other systems.

   Again, similar to the other cases, reasonable cost and time estimates exist to guide the platform teams with respect to the consequences of delayed action. For example, simultaneous design for left- and right-hand drive would be approximately 1.3 times the cost of tooling for left-hand drive alone. Redesign later increases that multiple from 1.3 to 2. However, the decision to design for both left- and right-hand drive is fraught with marketplace uncertainties because it is very difficult to predict market demand for exported, right-hand drive models. Therefore, the decision is typically postponed or the opportunity is forever overlooked. In this case, a right-hand drive model was never added.

9. Base Vehicle – Design for single or multiple division brand names?

   Several vehicle manufacturers have multiple divisions that sell either identical or "tuned" vehicles through different dealer channels targeted to different customer demographic and psychographic profiles. The number of different nameplates the vehicle will be marketed under is a critical concept development decision. Often, a decision to add a nameplate comes from the internally-driven need to add volume to justify the business case. The challenge, particularly with a base vehicle, is to provide styling and performance variation to deliver vehicles that the customer can differentiate in terms of price and value. If a decision is made to add a brand later in the design process, brand differentiation will likely require more extensive rework than would have been necessary had provisions for differentiation been considered early. Over and above rework, a greater risk is that brand differentiation might be compromised to save development program time and capital.

   In tandem with the differentiation process, adding a nameplate variation late in the product development process also poses costs related to lost parts commonality. Component sharing across vehicles is desirable. However, doing so as nameplates are added imposes reconsideration of parts requirements already determined for the original vehicle. The typical compromise made is to simply tool for an additional part that will provide the required brand differentiation. If it is known early that multiple brand vehicles will be produced, tools can be designed creatively with inserts that allow the same tool (with or without the insert) to produce differentiated parts for different nameplate brands. It is typical that these additional marketing divisions are added to extend the life cycle and production volumes of a platform.

Common Themes

While these cases cover a wide range of design topics, they all have five characteristics in common.

1. Foreknowledge: In all but one of the cases ("cargo space" excepted), designers and business planners were well aware of the choices they faced and made informed decisions. It can be forever debated whether at the time of decision the right choice was made, but in no case can it be said that the decision was made blindly.

2. Reasonableness: Every case portrays a reasonable decision. Of course, partisans on the losing side would dispute the judgment call but we believe that a neutral observer could consider the decision understandable given the information available at the time and the forces working upon the stakeholders.

3. Time, cost and business model: In every case, a decision for more inclusive design (or more radical redesign), would have increased both the time to market of the initial vehicle and the initial design cost. Assuming that decisions not to incur those costs were reasonable, why were they made? It is safe to assume that these seemingly counterproductive decisions arose because some combination of pressures for market entry and available resources mitigated against the extra expenditure. Internal accounting mechanisms may also play a role by setting up a perverse incentive for program managers. If managers are rewarded *only* for the performance of their programs, there is little motivation to incur short-term cost for longer-term payoff.

4. Quality and quantity of information: In every case, people could rightly have said, "If we knew then what we know now, we would have made a different decision." On the other hand, decision-makers cannot be faulted for not knowing more. In fact, it might not have been possible to posses better information. In some cases "knowing more" required knowledge of competitors' tightly held plans. In other cases, "knowing more" meant divining the uncertainties of markets in ways that no market research could reasonably be expected to accomplish. In still other cases, "knowing more" meant being able, in the context of market uncertainties, to build a very strong business case that ran against prevailing wisdom that early market entry is the critical priority.

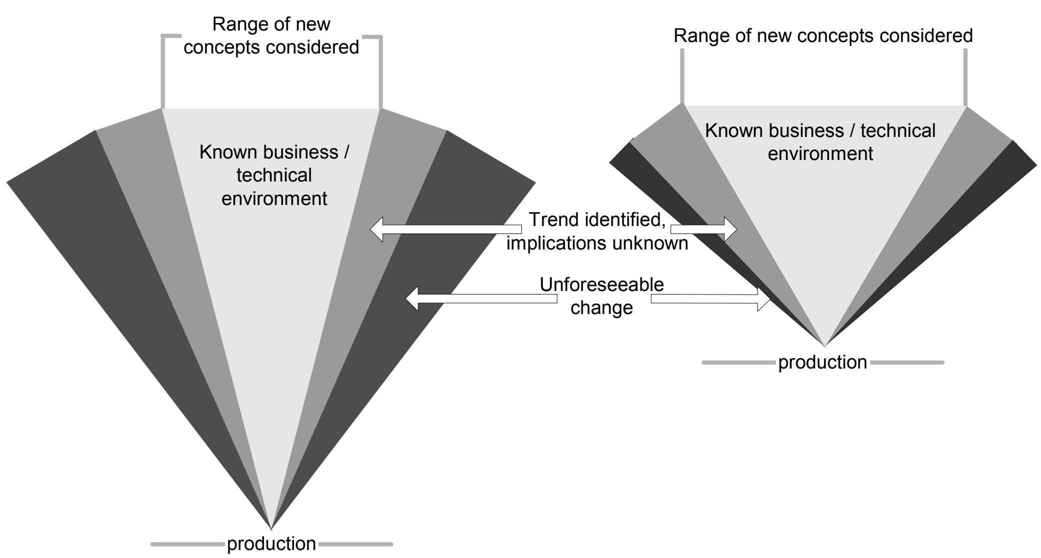
5. Markets versus design: In all cases, the reason for rework emanated from the business environment. In no case were changes needed because of unanticipated vehicle characteristics that were in the control of the vehicle manufacturer (e.g., bill-of-material cost, handling, or weight).

V. GLOBAL ASSESSMENTS OF EARLY-STAGE DESIGN / DIAGNOSIS AND PRESCRIPTIONS

It is certainly not surprising that all respondents agreed that their design processes took too long and were inefficient. The industry knows all too well that from concept to launch, the product development process must take less time, consume fewer resources, and be more responsive to changes in the economy, the market, regulation, and technology. This is the core challenge that all our respondents live with every day of their working lives. While unpredictable change will always exist, the industry must make decisions based on more, and more certain, knowledge and must employ that knowledge in shorter decision cycles.

Figure 1 shows this challenge in schematic form. We illustrate that the industry is attempting to improve the concept development process by expanding the "known business/technical environment," and by shortening the time between concept development and production job one. The "funnel" depicts a process where business cases are considered for different vehicles. These business cases are developed with knowledge about the environment that ranges from "certain" (light gray), through "unforeseeable" (dark gray). With better competitive intelligence, regulatory knowledge, and market information, the funnel of possibilities that can be assessed with confidence expands while, simultaneously, design time is compressed. Of course, the process must be iterative because unforeseen events will always occur, but when they do, shorter cycle times allow faster responses to new contingencies.

Figure 1: Move to Shorter, More Informed Concept Development Funnel



During the interviews we pushed our respondents to explain why they thought concept development inefficiencies existed and what they were doing about it. Consistently, the responses were:

- Establish rich, cross-functional interaction with shorter feedback loops among the layers of management. Primarily, this involved restructuring the vehicle engineering groups and the product development processes used by those groups.
- Populate the new system with a relatively small number of very experienced people. There was a clear sense that personal expertise was vital and that the key to success was bringing that expertise to bear in an effective manner. Respondents had a general sense that their challenge was to make more of what they had, *not* that their difficulties resulted from a lack of information, a dearth of creative ideas, limited design alternatives, or weak analysis capabilities. (To anticipate a later discussion, better design tools were appreciated but not seen as a critical part of the solution.)

The notion invoked above about a "small number of very experienced people" is important. The complete product development process for a new vehicle is an extremely expensive and time-consuming process. Some traditional, mass-volume programs have involved as many as 2,000 experts spread across many sub-fields of engineering and design. For concept and design development, however, a relatively small number of people will do. To develop a sense of the number of people required, consider some paraphrases of responses during our interviews. (Throughout this report, responses are edited to convey a sense of the response while preserving respondent confidentiality.)

- A core group of approximately 40 to 50 engineers, 20 designers, and 5 to 10 business and finance experts is sufficient to vet new concepts and ideas to continually fill the product development pipeline.
- A core group of approximately 300 engineers is sufficient to fully develop new vehicle architectures and upfront engineering before passing it through an established product development process.
- A core group of 40 to 50 senior vehicle integration engineers can satisfy vehicle integration requirements for systems and overall vehicle packaging.

Clearly, the industry's problem is not the number of people. Rather, it is the challenge of finding, organizing, and managing a small number of experts to work productively and effectively. Interviews revealed three themes that, in varying measures, constitute the levels of change that manufacturers are using in order to improve early-stage design processes:

- <u>Organizational structure and behavior</u>: The number of management levels is being decreased while the richness of formal and informal reporting among levels is being increased.
- <u>Cross-functional teaming</u>: More cross-functional teaming is taking place and more attention is being given to ensuring that deep expertise is represented on these teams.
- <u>Nurturing talent</u>: Companies are recognizing that they have lost talent and need to replace it.

VI. ORGANIZATIONAL STRUCTURE AND BEHAVIOR

The trend is toward having fewer people in fewer management layers consider new product concepts and combining that organizational structure with frequent formal and informal communication. Fewer management layers and more communication results in better understanding of work in process throughout the organization, thus, minimizing the tendency for top management to perturb the development process in later stages, or for good ideas to go unheard. It is one thing to implement a structure and to declare policies about communication; it is something else to make the structure and the policy a living, daily reality. Efficient companies have the discipline to use this process. The combination of process and discipline "levels the political playing field," thus, allowing a fair hearing for the best ideas regardless of executives' personal interests or individual personalities. Paraphrases of interview responses illustrate respondents' beliefs about reporting relationships and management:

- If we reduce the number of engineers committed to a project and the number of committees, execution improves.
- The process is moving to crisp decision-making. The issue is really who is involved and how decisions are made.
- It is up to our coordination team to maintain timing, cost, budgets, and product definition.
- The risks are assumed by the program. However, if the team has been there from day one, they know the risks, challenges and trade-offs that were made. The cross-functional team needs to be as far upstream as possible in order to shorten the execution phase.

VII. CROSS-FUNCTIONAL TEAMING

Developing powerful cross-functional teams is critical to shortening communication feedback loops and assuring that appropriate resources are available to address problems quickly and accurately. Respondents' emphasis on cross-functional teams is not surprising. The important question is what expertise needs to be represented on such teams, and what aspects of vehicle design require particular degrees of input from particular functions. Interviews revealed that the critical functions that need to be involved include Marketing, Planning, Advanced Engineering, Styling, and Manufacturing. The extent of their involvement depends upon the type of vehicle concept that is being developed (e.g., Is it an "all new" platform, a major program that might include a convertible model based on an existing platform, or a minor exterior facelift?) and the specific aspect of the vehicle being considered (e.g., powertrain or body-in-white). These relationships are depicted schematically in Table 1. Appendix 2 contains the full details of these relationships as revealed through our interviews.

Table 1: Schematic Overview of Cross Functional Teaming in Early Phases of the Vehicle Design Life Cycle

	All New	Major	Minor	Mkt	Eng	Others…
Powertrain	See Appendix 2 for complete list and relationships					
Front/rear drive						
All wheel						
Others						
Body in white						
Body style						
Frame type						
Others…						

Because cross-functional teams during early design stages become so familiar with critical business and technical decisions and know the reasons for various trade-offs, successful programs extend these teams into the larger product development team. To illustrate respondents' beliefs about teams, consider the following paraphrases of their statements:

- Engineers need training to be cost estimators; we need cross-functional skill sets.
- To do early-stage design right, you need to start with a very experienced cross-functional team, give them lots of information, and let them scope the vehicle.
- Teams should be small and less complex to increase networking, however, that may limit technical expertise. You need to build a critical skill set.
- The decision group is cross-functional with the leadership group. There is mutual respect.

VIII. NURTURING TALENT

Respondents recognized the importance of developing strong domain expertise. They know that downsizing has eliminated important expertise and that reorganizations have scattered the remaining knowledge and broken powerful informal linkages. While showing deep respect for narrow and deep knowledge, respondents also realized that cross-functional understanding and the ability to integrate across domains is important. Here too, we illustrate with paraphrased remarks:

- We need seasoned engineers who can swim in their lanes for their careers. We need performance measures to reward this.
- Skill sets are important, particularly as you infuse more technology into the organization and the product. You can't move a parts guy laterally with good results. You can't take a headlight guy and make him a fascia person, particularly if you have already outsourced a lot to your suppliers.
- Information resides in people's heads. Having a library does not mean you are all knowing. We need to be able to tap into a deep experience base.

IX. TOOLS

It is certainly the case that respondents were more concerned with organizational and human resource approaches to improving high-level design than with a software-tool oriented technological approach. We base this conclusion not only on the content of responses, but on the amount of time and attention given to organizational, as opposed to technological, issues. At several times during each interview, we made a point of pushing the discussion in the direction of tools. Uniformly, responses were sparse and terse, after which respondents enthusiastically turned back to talking about how they were implementing organizational and human-resource based improvements to their high-level design activities. It is also true, however, that tools are appreciated and seen as having value in improving early-stage design. To understand the role of tools, we begin with a presentation of data – what people told us about tools – and move on to identifying themes that emerged from that data:

1. At one point, we worked on a system to do trade-off analysis of vehicle attributes, but it did not work because it required too many assumptions.

2. Scoping needs tools. For instance, it would be useful to have a 3-D space tool that tied vehicle concept to bills-of-material and bills-of-process. It would be good if math data and physical attribute data could be included.

3. We once worked on a tool to forecast consumer behavior, but it never gave satisfactory results.

4. We need a good parts database to help assess cost, investment, and scalability.

5. There are tools to help with scoping but we use them only with difficulty. The problem is that the tools are not integrated.

6. We have the tools that are needed.

7. Execution is tied 80 percent to the tools in each functional area and 20 percent to strategic vision.

8. The critical issue for any IT solution is the ability to access resources with the right skill set.

9. Ford Motor Company has gone to the effort of developing a tool designed to integrate diverse vehicle attribute information and analyze interactions among those attributes. (In contrast to the bullets above, this information comes from a publicly available source that emerged from the literature review we conducted for this project.[2])

Information about three topics can be gleaned from the above information: 1) function-specific tools, 2) integration tools, and 3) history of success and failure. With respect to function-specific tools, some new functionality is needed in the form of better parts databases, however, the main use of tools is within specific functional areas (4, 7 in list above).

As for integration tools, two types of functionality can be discerned: the ability to organize and cross reference diverse information and the ability to analyze dependencies. With respect to organization and cross-referencing, there is a desire for better tools, and effort is being put into acquiring that functionality (2, 5, 8, 9 in list above). In terms of analysis of dependencies, however, there is more ambivalence. On one hand, the industry is putting effort into development. On the other hand, similar effort has failed in the past and people are skeptical (1, 9 in list above). The explanation for past unsatisfactory performance is that too many unknowns had to be factored into algorithms, thus, leading to a reliance on uncertain assumptions (1, 9 in list above). The theme of limited analysis power as a function of imprecise assumptions is echoed in the assessment of tools to predict consumer behavior (3 in list above). This is a topic which must surely require dependency on assumptions about complex dynamics taking place in an unspecifiable environment. It is not surprising, but worth noting, that both cases of out-and-out tool failure were efforts to interject analysis into domains with very high degrees of uncertainty – vehicle attribute dependencies and consumer behavior (1, 3 in list above).

[2] Hsu, Albert (2003) *Method of a web-based attribute target setting tool* SAE World Congress, Detroit MI. March 3-6. paper #2003-01-0109

X. CONCLUSIONS

The industry knows all too well that from concept to launch, the total product development process must take less time, consume fewer resources, and be more responsive to changes in the economy, the market, regulation, and technology. For maximum enterprise level benefit, many of the most important decisions must be made, or at least formulated, in the concept and design phase of the product development process. While the importance of concept design as a determinant of overall cost, quality, and time is well known, there is little systematic knowledge about how early-stage design and concept development actually takes place or the nature of decisions confronted during these phases of the product life cycle. This project was an effort to fill that gap.

Our approach was to conduct in-depth interviews with people involved in early-stage design and to collect detailed information about specific product development efforts and specific decisions that were made. Our analysis began with a search for commonalities among the individual cases and proceeded to draw a general sketch of how early-stage design works and what automotive companies are doing to improve their processes.

All of the nine cases analyzed involved situations where early-stage decisions had to be reconsidered in light of unfolding events. Contrary to our expectations, none of the cases involved what might be termed an "engineering surprise," (i.e., situations where early decisions resulted in unanticipated problems in vehicle performance, cost, or manufacturability). Rather, the reason for design rework always had to do with changes in the competitive environment, which, in turn, caused a company to reconsider attributes and features in its vehicle offerings. In all of these cases, the original decision was reasonable and defensible. Often, however, it also turned out to be wrong. The general lesson is that while unpredictable change is inevitable, the industry must make decisions based on more, and more certain, knowledge and must employ that knowledge in shorter decision cycles.

The auto industry is well aware of this challenge. Their solutions turn to organizational change to support cross-functional teaming, fewer management layers, and shorter feedback loops among layers, finding and deploying deep expertise, and nurturing talent that has been lost. Information technology is important but only as an adjunct to organizational and human resource fixes. Tools for finding and integrating far-flung elements of a company's knowledge are seen as important and practical. There is ambivalence about tools that substitute human expertise with computer-powered analytic capability. Such tools are being pursued and would be welcome, but past experience with such functionality has not been encouraging.

While encouraging change is under way, the problem of sustainability remains. The complaints and responses we discovered are familiar themes to old hands in the industry who have seen and heard it all before. It is far too easy for history to repeat itself. For long-term viability, the industry must embed and integrate self-reinforcing changes in culture, organization, human resources, and technology. Only then will automakers be able to defend their market share in the face of increasing pressures from global competition.

APPENDIX 1: PRE-INTERVIEW HANDOUT

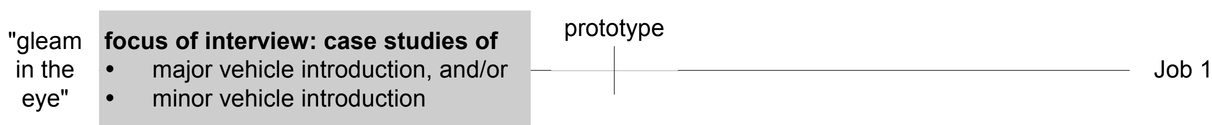
INTRODUCTION AND BACKGROUND

Thank you for agreeing to participate in our study of the early-stage vehicle design process in the automotive industry. Below is a summary of the issues we will cover during the interview. By assessing these processes in a variety of companies, we hope to develop knowledge that will lead to faster and more efficient development of better products. As a participant, you will receive an early view of the report we develop. Be assured that no company-specific findings will be divulged outside of the interview team. If you have any questions about the project or the interview prior to our meeting, please contact David Andrea at david.andrea@altarum.org, 734 302-4779.

FRAMING THE DISCUSSION

Our focus is early-stage decision making for major *or minor vehicle changes. (Figure 1 is a visual view of the scope of this project.)*

Figure 1: Visual Overview of Project Scope



THE CASE/S

We want to ground the discussion in real examples. Please describe the vehicle change example (or examples) that will be the subject of our discussion today.

- What was/were the vehicle/s?
- When were they introduced?

STRUCTURE AND PROCESS OF DECISION MAKING

Please provide an overview of the process of the vehicles' early-stage development.

- Who was involved?
- Reporting relationships
- Milestones / tmelines
- IT systems and data bases involved
- Resources for early-stage activities (.g., budgets, personnel)
- How decisions were really made

CRITICAL DECISIONS AND TRADE-OFFS FOR THE CASE/S

For your example/s, please tell us about the critical trade-offs and decisions that were made. Table 1 is a visual overview of the issues and relationships we are interested in.

	Departments / Functions Involved								
Decision factors	Sales/ marketing	Planning	Product engineering	Plant manufacturing	Finance	Purchasing	Legal	Corporate	Others
Product content									
Piece cost									
Investment									
Time to market									
Manufacturing – cost, timing, capacity									
Part tooling capacity									
Product pricing									
Projected sales									
Revenue									
Portfolio mgmt.									
Company image									
Environmental impact (MVSS/ EPA / political)									
Labor relations									
Corporate politics									
Other									

*What relationships depicted in this table were **most important**? For those, please tell us:*

- *What direction was given about the vehicle?*
  - *constraints*
  - *wants*
  - *needs*

What were the critical decisions and trade-offs that were made?
Issues considered?
Formal information used?
Tacit knowledge exploited?
Role played by formal and informal process?
Role of hard data, expert opinion, and informed guesses?

As new information came in over time, what changes had to be made?

What would have improved the process?
Information – timeliness, detail, decision support tools?
Groups and people involved?

IMPROVING DECISION MAKING

In light of market performance, how good did your early-stage decisions turn out to be?

- Sales
- Profitability
- Vehicle performance

What were the major reasons why original assumptions differed from actual performance?

- Competitive environment
- Product definition
- Cost projections
- Customer needs and wants

What are the key changes you would make to improve early-stage decision making about major or minor vehicle changes?

- Data
- Analysis tools
- Formal process
- Informal process

APPENDIX 2: TOP LEVEL CONCEPT DEVELOPMENT DECISIONS THAT DETERMINE PRODUCT DEVELOPMENT COSTS AND TIME

	All New	Major	Minor	Mkt/Planning	Engineering	Styling	Mfg.
Powertrain							
Front/rear drive	H			X	X		
AWD	H	X		X	X		
Engine orientation	H			X	X		
Engine displacements	H	X	X	X	X		
Engine options (gas/ diesel)	H	X	X	X	X		
Automatic/ manual	M	X	X	X	X		
BIW							
Body panel material	H	X	X	X			X
Body styles – convertible, coupe, sedan, wagon	H	X		X	X	X	
Frame/unibody	H				X		
Braking							
Front suspension configuration	H				X		
Rear suspension configuration	H	X			X		
Right/Left hand drive	H	X		X	X		
Tire size	H	X	X	X	X	X	
Braking/ traction control systems	H/M	X	X	X	X		
Interior							
HVAC	L	X	X	X	X		
Sophistication of electronics/ electrical options	H	X	X	X	X		
Navigation/ antennas	M	X	X	X	X		
Packaging							
Seating configuration	H	X		X	X	X	
Other							
Towing capacities	H	X	X	X	X		
Off road capabilities	H	X		X	X	X	
Number of vehicles off platform	H	X		X	X	X	
Marketing divisions	H	X	X	X	X	X	
Export Requirements		X	X	X	X		

H=high complexity/influence of downstream costs; M=medium complexity influence of downstream costs; L=low complexity/influence of downstream costs