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Hybrid Electric Vehicle: Mature Companies Launching Innovative Technologies

As he sank back in his seat and listened to the jet engines start winding-up, John Boyle was relieved to finally be headed home. He looked forward to the next 90 minutes of solitude he'd have as he traveled back to Detroit on the red-eye flight. "At least for a little while, I don't have to think about this product launch," he thought. He shook his head and wondered how a program that started with such promise could be in such turmoil. In a couple days, he'd have to make one of the biggest decisions of his career—whether to delay the launch of the new hybrid vehicle, or go forward with the launch and risk potential performance issues. Either way, he'd need to inform senior management of the decision, and convince them it was the right thing to do. He stared out the window and began reflecting back on the past 2 years, to try and understand how things could have been done differently.

Market Pressure

John Boyle was a Chief Engineer at Michigan Motors Corporation (MMC), an organization with over 75 years of history, and considered one of the original "Big 4" US automakers. MMC employs over 65,000 people worldwide, but unfortunately these staffing levels are only 50% of what they were only a decade ago. Slowing sales in the US auto market coupled with an increase in foreign competition have accounted for the decline. To exacerbate the problem, MMC is struggling financially due to deteriorating quality and brand image. Staffing reductions and budget cuts have been pursued for several years in an attempt to correct the situation. As a result, engineering staff levels the past couple years had reached their lowest point in over a decade.

In June of 2007, under continued pressure from environmentalists, several US state governments began mandating more stringent emissions standards for automakers. In an effort to reduce harmful greenhouse gases, they adopted a piece of legislation called ATPZEV (Advanced Partial Zero Emissions Vehicles) which required that every automaker make available for sale (in their state) a minimum number of clean-burning hybrid-electric vehicles by the end of 2010—only three and a half years away (reference **Exhibit 1** – Hybrid Program Timeline). Over the next 9 months the MMC Management Board analyzed the situation and agreed that the best approach was to pursue a joint venture (JV) arrangement to share the development risk with a partner (since MMC had no existing products employing hybrid technology and no prior experience developing one).

The joint venture was set-up with a company called Hy-pro which was already working with three other automakers on a hybrid transmission. Each of the Hy-pro partners is also a direct competitor of MMC. As part of the JV arrangement, all the partners agreed to develop one 'common' hybrid transmission that could be utilized in each of their respective vehicle lines. The primary technical challenges facing the partners were the packaging of the new powertrain into their vehicles, and integration / testing of the system. Both the mechanical and electrical systems required integration.

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The Hy-pro team planned to develop a hybrid transmission for use with a V8 gasoline engine, rather than a smaller 4 or 6 cylinder application. MMC management was excited about the strategy because it would allow them to package the hybrid transmission into their large trucks and SUVs (that only use V8 or bigger engines), which was considered the "bread and butter" of their product portfolio1 (reference **Exhibit 2** – Product Line-up). The hybrid application would be the first ever developed for a large truck by any automotive company. So with the opportunity also came risks in terms of both product design and consumer acceptance.

Operations Strategy

Designing the hybrid through the joint venture arrangement was projected to cost nearly $400M (reference **Exhibit 3** – Development Cost Comparisons). However, the MMC board of directors felt it was the best option in terms of managing design risk and learning about hybrid technology for the future. Once the joint venture was approved, Jack Wells (CEO of MMC) was anxious to get his team started. It would be a 24-month project and there was much to do2. The hybrid was an innovative product and generally outside the scope of what MMC typically deals with. In Wells mind, they needed to figure out how to launch this technology without disrupting the other key initiatives that were going on in the company. MMC was going through a lot of changes internally as part of a financial turn-around plan, and it was important to keep their cost reduction initiatives moving forward.

Over its 75 year history MMC had developed into a largely formal organization with many standardized processes. Despite occasional complaints about being a bureaucracy by some of it's engineers, it was understood by most that the industry demanded some level of consistency in how they executed their operations—particularly due to the complexity of the automotive industry and its inherent product liability risk3.

Over the next couple weeks Wells schedule several meetings with his key staff to develop an organizational strategy4 to support the hybrid launch. In the meetings, Wells included executives from engineering, program management, business strategy, finance, and human resources (reference **Exhibit 4** – Organization Chart). In his mind, the primary goal of the Joint Venture was to learn about the hybrid technology in order to integrate it into their product line.

In the executive strategy meeting there was much debate about how the product team should be structured to launch the hybrid vehicle. A common concern among the managers was the lack of engineering resources currently available at MMC—both for the hybrid transmission development and for packaging the powertrain into the vehicle. With the current budget constraints, the MMC management knew they had to be judicious about hiring additional staff and spending money. Finances were being strictly monitored across the entire organization. During the meeting, an outspoken engineering executive (Bob Felton, EVP Product Development) reminded the team several times about the "numerous six sigma projects underway to reduce headcount and streamline operations." It seemed the company was swarming with process standardization and complexity reduction initiatives, yet at the same time they

[1] The market-leading hybrid transmission from Toyota was designed for use with smaller engines which required less torque, and differing gearing ratios which made it incompatible with Hy-pro's application. No other automaker had developed a hybrid for large trucks, which forced Hy-pro to design their own transmission.

[2] 24-months spans from requirements completion to volume production. A program of similar complexity would generally require 30-40 months of development for an organization of MMC's capability and experience level.

[3] New technology affecting performance, safety, service and repair must be thoroughly validated before sale to consumers to reduce risk of customer injury or liability. Standardized processes help ensure consistent development and validation testing is employed.

[4] Organizational strategy includes the reporting relationships, tactical approach, and general operations.

were calling on his engineering team to be creative and launch a unique product for their customers. He feared this would make things more difficult for his team.

After hearing the concerns of his staff, Jack Wells was convinced that MMC should be careful not to disrupt the current initiatives with the hybrid launch. The cost reduction activities were proceeding well, and the operational environment was becoming very sensitive to change. “Rather than trying to integrate the hybrid activities into our existing organization, would it make sense to establish an autonomous hybrid engineering team so they’re free to operate more independently?” he said. As the team discussed this approach they agreed it had merit, and may help to minimize the disruption to other areas. Ultimately, the decision may could potentially speed-up the development time by avoiding some bureaucracy[5].

Ron Frank (VP Sales & Product Strategy) confirmed that two of the Hy-pro partners were already sharing a building locally, and suggested that MMC also co-locate their team into the same facility. This would physically remove the hybrid engineering team from the extended enterprise, allowing them more autonomy. The executive team agreed to the proposal and began making plans to move the engineers off-campus to be co-located with Hy-pro. The new facility would be only 30 minutes (travel time) from MMC’s headquarters.

John Boyle and his program managers were concerned that the off-site arrangement may cause communication and logistics problems with the launch. To try and mitigate this risk they established a recurring joint team meetings and management reviews to ensure the program remained on schedule. For simplicity, it was agreed that the hybrid program would use the same standardized launch process as the traditional programs--this meant using the same generic timeline, metrics, tracking reports, processes, etc. MMC had a lot of confidence in their launch process (termed ‘stage-gate process’) which had been refined and standardized over many years (reference **Exhibit 5** – Stage Gate Process)

Product Development Cycle

The product development cycle at MMC is based on a traditional stage-gate process. The Stage gate methodology provides an operational roadmap for product teams to use in launching their vehicle(s). The stage gate concept divides the product development process into five separate phases including: concept, detailed design, development, test & validation, and launch.

Each of the five development phases has specific goals that must be accomplished in order to transition to the next stage (in a sequential fashion). As the PD team accomplishes the objectives established for each stage, they must formally request management’s approval to proceed to the next phase. The closer the design gets to production, the more financially committed the organization becomes and the more difficult it is (for cost and timing) to make design changes. The stage-gate process ensures the executive team is informed of the program status before approving it for the next stage.

At each gate review[6] the product team presents the status of all deliverables (metrics) and the management team has the option to either: (1) approve the project to proceed to the next development phase, (2) deny the project from continuing until additional work is performed, or (3) cancel the program

[5] Bureaucracy refers to the degree of formalized processes and oversight administered to the team by management and internal control. Although bureaucracy may improve consistency, it may also slow development time and increase operating cost.
[6] Gate Review: A formal meeting set-up for the product team to present its status to senior management and request approval to transition the program to the next design phase (reference Exhibit 5).

entirely. Because MMC's hybrid program is operating under strict timelines, any delay or rejection in a stage-gate will likely affect overall launch timing for the product.

In order to simplify program planning, MMC classified every new vehicle launch into one of three categories based on complexity.[7] The categories include: (1) minor-refresh programs, (2) upgrade programs, or (3) new vehicle launches. Each of the three categories utilize a different lead time, and a unique set of reporting requirements. Minor-refresh programs are considered the simplest launches and have the shortest lead time (24-30 months). Reporting requirements are a minimum for these programs. A new vehicle launch at the other extreme represents the highest complexity and requires the most documentation and longest lead time available (typically 36-40 months). Reference **Exhibit 6 -** Program Lead Time Comparisons

After considering the various launch classes, MMC management agreed to categorize the hybrid program as a 'minor refresh' since by definition it only required a transmission upgrade. Historically, programs introducing an powertrain[8] upgrade alone (without sheet metal and content changes), could be fairly predictable. Consequently, the launch guidelines for this type of program required: (1) less stage-gate reporting to management, (2) the elimination of an entire prototype build phase, and (3) a compressed product development cycle.

For several years, automakers have been compressing their development lead time by employing these strategies across over lapping development stages (such as vehicle build and test phases), and running them in parallel (reference **Exhibit 7** – Compressing PD Leadtime). A common example is when they begin building 2nd generation prototype vehicles before all of the testing is complete on the 1st generation prototypes. Naturally, this creates some level of risk for problems that are found late in the testing phase.

When developing vehicles that are less complex (such as 'refresh' programs) there are fewer unexpected technical issues encountered, and therefore less risk in over lapping development phases. Conversely, more complex programs (such as new vehicle launches) create increased risk when compressing program timing in this manner—primarily due to the unanticipated issues that may be found.

Knowing the complexity of the hybrid program and its aggressive timing, John Boyle was greatly concerned about applying a 'refresh' strategy to the launch. He felt the lead time should be extended to account for the added complexity and unexpected learning the organization would encounter[9]. He also anticipated a greater need for management involvement than the 'refresh' strategy typically provided. Unfortunately, MMC management was compelled to use the more simplified approach because it would save nearly $100M in costs by eliminating one of the early proto build phases (reference **Exhibit 8** – Hybrid 30 Month –vs- Proposed 42 Month Timeline). In addition, the compressed lead time required for the hybrid lined-up perfectly with the 'minor refresh' scheduling, and with management's goal to have the product available for the 2010 calendar year. The Chief Engineer and his team were told to simply "make it work."

Staffing

[7] Complexity is an assessment of how difficult the product will be develop and launch
[8] The powertrain (or powerplant) refers to the group of components that transmit power from the engine to the wheels. Generally the primary components include the transmission, drive shaft, clutch, and differential. Engine systems can also be grouped as part of powertrain components in some organizations.
[9] MMC had no previous experience with hybrid technology, and therefore was expected to learn a lot during the development cycle.

Immediately following the executive strategy meeting, Human Resources (HR) began working on a plan to staff their newly-formed hybrid development center. The plan was to recruit outside the organization in order to fill key supervisor / management positions with experienced hybrid engineers. Once in place, the new management team could help recruit the expertise needed for their specific departments. In the interview process, HR placed heavy emphasis on hybrid-technology experience, regardless of the application. Within 2-3 months, the hybrid team was fully assembled with a talented group of engineers representing several industries. Nearly 50% of the 100 person staff was new to MMC providing a broad and fresh perspective. Unfortunately, they were also unfamiliar with many of the business processes used within MMC. There was concern that this may eventually create challenges in terms of managing engineering changes, establishing documentation, and addressing manufacturing / build issues. Although many of the executives supported the idea of the 'autonomous hybrid center,' they also expected there would be regular interaction with corporate groups including: finance, manufacturing, change management, vehicle engineering, vehicle testing, etc. The executive team expected that a strong program management team, and collaborative efforts from the Hybrid Development Center (HDC), could overcome this challenge (reference **Exhibit 9** – HDC & HQ Organization Chart).

Product Development Team

The hybrid powertrain was slated to be launched on MMC's largest SUV (the Intella). John Boyle was the chief engineer (CE) for the large SUV product line which was comprised of three unique vehicles including the Intella. In his current role, John had full program management and product development responsibility for the vehicles (including timing, cost, quality, and performance). As the current chief engineer for the large SUV product line, Boyle was by default given the responsibility of managing the new hybrid project.

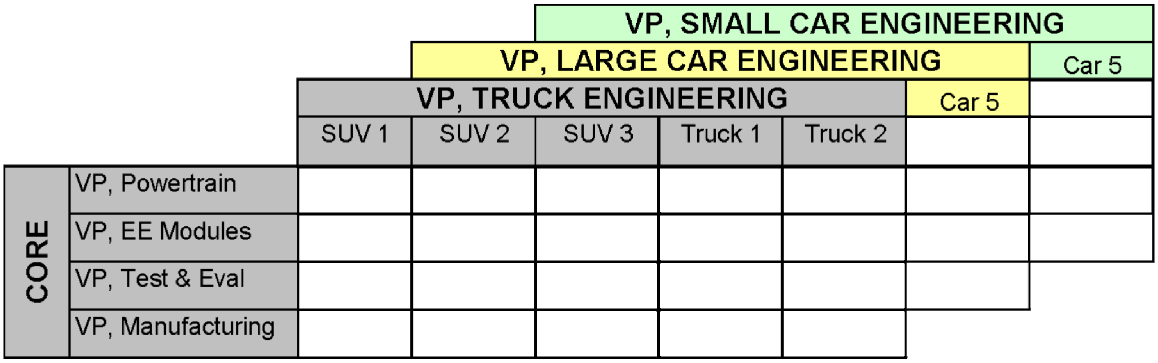
John was an experienced engineer with over thirty-five years at MMC. Although he did not have direct experience in powertrain or electrical integration, he did have experience launching innovative product features including dent-resistant body panels and fold-in floor seats—both drawing on his expertise in the body structures area. John was very excited about the opportunity to launch MMC's first ever hybrid vehicle, although he was a little concerned about the additional workload. He understood that the project had a strict 30-month timeline, and he already had two other major vehicle launches scheduled over the same two year period. Additionally, he knew his program management (PM) team was a little inexperienced, having recently rotated 3 new members into the area over the last 3 months. Looking back, he would have preferred to retain one of his recently departed PM's to launch the hybrid, but he was not informed by management in time to do this. At MMC, the PM organization was beginning to be used as a "developmental assignment" to train 'high-potential' engineers about product launches. As a result, engineers would rotate through the assignments every 2-3 years and gain their launch experience on the job. Boyle's entire organization worked in the main engineering center which was about a 30 minute commute from the hybrid design facility.

Matrix Structure

MMC's product development organization is divided into three divisions (or platforms10) including truck, large car, and small car. Each of the platforms is led by a vice president. Additionally, there are several core engineering teams which provide support across all products. The core engineering groups

[10] Automotive platforms consist of vehicle models that are built off of the same chassis, and often share the same engine line-up and design features. Organizing in products into platforms allow manufacturers to sell similar vehicles to different target groups (at different price points) by changing the brand name and styling.

include: powertrain, EE modules, test & evaluation, and manufacturing engineering. Each core team is led by a vice president, responsible to support their specific initiatives. The platform teams and core teams comprise a highly matrixed organization as shown in the figure below.



The primary mission of the core engineering teams (each led by a VP) is to implement common designs and processes across all vehicle lines in order to minimize complexity[11]. The result is a reduction of cost and variability. In a recent newsletter to MMC employees, the Chief Operating Officer, Jack Wells, captured it simply when he stated "the top three objectives of our core engineering group is: standardization of processes, communization of parts, and reduction of costs." To support these initiatives, a number of six sigma projects were well underway to reduce part cost & complexity, reduce staffing, and compress launch timing (reference **Exhibit 10** – Six Sigma Initiatives).

Program Management Team

As the chief engineer of the large SUV product, John Boyle reports directly to the VP of truck engineering (Steve Andersen). Mr. Andersen is a long-time veteran of the automotive industry and practices a hands-off style of management. Recently, several people have been speculating that Steve Andersen was due to retire, and some had even predicted the hybrid launch may be the final milestone to cap off his long and successful career.

Although his people generally appreciate the free-reign they are given, at times they have become frustrated at what seems like a lack of support when top management intervention is required. In the highly matrixed structure of MMC, it is sometimes difficult to get the level of attention one demands on a specific vehicle line. Often the CE's find themselves negotiating directly with the VP's in core engineering to get the support they need (if Mr. Andersen is unavailable).

Upon hearing the news of the hybrid program approval, John Boyle's counterpart and CE for truck products (Scott Kohls) congratulated him. John replied, "I'm excited about the project, but also a little concerned with the workload. I understand they talked about giving this project to your team Scott, but then thought it made more sense to keep it with the SUV products so the assembly plant could deal with just one Chief Engineer—since we'll be building the hybrid in the same facility as the current gas SUV.

[11] Complexity is reduced by using common components across multiple vehicle lines. This strategy will eliminate unnecessary design activity, and simplify part ordering and stocking in the plant. Reducing complexity can result in a significant decrease in component and operating costs.

Actually Scott, your electrical background would have been very useful for this project." Scott Kohls had spent several years working in the electrical area before moving into management.

Scott thanked Mr. Boyle for his kind words and offered to help if he could be of service. As Scott left, he wondered how much thought actually went into the decision to assign the hybrid to the SUV team, and how involved Steve Andersen was in the decision process. "Didn't management realize that his truck products just launched new models last year and would only require minimal changes over the next couple years?" he thought. He was sure he would have had more time to dedicate to the hybrid launch than Boyle.

Hy-pro's Next Generation Hybrid (NGH)

By the time the MMC team joined Hy-pro they were already moving forward with their new state-of-the-art hybrid technology called NGH (Next Generation Hybrid) which employs two motor-generators working in combination with the internal combustion engine (ICE) to propel the vehicle. Two major design challenges that the hybrid truck application had to contend with were: (1) requirements for off-road capability and (2) a high towing capacity which is considered essential for most truck buyers. The MMC engineers felt the NGH concept was an ideal solution for their large SUV, the Intella. For the last three years, the Intella boasted the number one towing capacity of any full-sized SUV (at 7,200 lbs). John Boyle and his team knew they needed to keep maintain this attribute as a differentiator12.

The NGH hybrid system was designed to have three unique operating modes including: electric power only, gas power only, or a combination of gas and electric power. The speed of the vehicle and required torque would determine its mode of operation. The NGH is a smart system and will automatically select the appropriate mode without the need for driver intervention, although the driver will always have the option to disengage the electric motor-generators so the vehicle could function solely as a gasoline powered vehicle at all speeds and loads.

At low speeds (<25 mph), the Hy-pro transmission defaults to powering the vehicle with the electric motor-generator(s). At higher speeds (>25 mph) and heavier loads the vehicle will switch off the motor-generators and switch on the internal combustion engine to operate in gas-only mode. The motor-generators will also remain available at speeds above 25 mph if more power is needed under such conditions as high-speed passing, pulling a trailer, or climbing a steep hill.

The NGH design employs two motor-generators, allowing one to supply e- charging power while the other provides power to the transmission. At higher speeds, both motor-generators can be used in tandem to supply maximum power, boosting the total engine output by an estimated 50 hp (depending on the engine and vehicle configuration). The sales and marketing team led by Ron Frank, was planning to advertise the additional 50 hp as a selling point for truck buyers interested in bigger, more powerful engines.

In terms of innovation, the NGH transmission ranks high due to its dual-mode operation (powering the vehicle at low and high speeds) and unique planetary gearset. Mechanically, the gearset is packaged on

[12] A product differentiator is an attribute that no other competitor has, and therefore, can be used extensively in advertising and pricing. To maintain strong sales, engineering teams work to create and maintain multiple product differentiators.

the input side of the transmission, and paired with additional gearsets on the output side in order to multiply the number of fixed gear ratios. Because the gearset is highly complex, it will require the expertise of a key supplier working with Hy-pro (Pinion Corporation). Like many of the key suppliers for the hybrid program, MMC will not be able to manage them directly, but instead must work through the Hy-pro lead organization (US Motors).

From the onset, the inability to manage all of his suppliers directly was a concern for Boyle. However, he understood that in order to minimize hybrid components costs it was best for the partners to consolidate their volumes[13] of common parts and award them to a single-source that could be managed by one organization. Although Boyle understood the financial reasons for this decision, he recalled a number of problems it created for his team when coordinating issues through US Motors. Two of the most significant issues were the long lead time for problem resolution, and difficulty ordering and tracking parts[14].

The NGH technology is considered revolutionary and is expected to put the development team out in front of the competition in terms of innovation. As pioneers in the dual-mode[15] technology, Boyle anticipated there may be some challenges with the software integration. Computer modules in the engine, transmission, and charging system must be coordinated at all times to determine how power should be applied to the drivetrain. Managing this transition from electric power to gas power was a primary concern, and could only be executed by collecting information from sensors located throughout the vehicle system (including torque, speed, and battery charging levels). MMC soon realized that a significant level of expertise was needed in automotive systems architecture to design the system properly, and troubleshoot it throughout development.

Packaging Challenges

Unlike the other Hy-pro partners, MMC opted to integrate the hybrid transmission into their existing vehicle model, rather than develop a "next generation" model with a unique chassis & engine compartment. Although this strategy increased the design complexity for the MMC engineers, it was done to minimize total program cost and timing. Under the current budget constraints and accelerated timeline, the executive team was not prepared to launch an entirely new vehicle model to accommodate the hybrid transmission.

Based on engineering's estimate, the hybrid application was expected to add over 240 new parts including finished assemblies, components, and brackets for integration (reference **Exhibit 11** – Hybrid Components). End-item[16] part descriptions ranged from major components such as the 300V battery and high voltage cables, to minor components like clips, support brackets, and hoses. From the start of the program the design team was under pressure to find available space for these new components and 'kick-off' suppliers to begin developing prototype parts. Since the gas version of the Intella was already in

[13] Consolidating common parts to one supplier will allow Hy-pro to purchase only one set of tooling, and and allow higher volumes of each component to be ordered, which creates lower part costs through economies of scale.
[14] MMC issues and part order questions needed to flow-through US Motors in order to be addressed based on the business relationships. The added coordination often prolonged time for answers and/or corrective actions.
[15] The dual-mode hybrid system operates at both low- and high-speeds. The transmission also incorporates multiple gear ratios to provide more efficiency and power for the truck application.
[16] End item parts are defined as those components or sub-assemblies that are shipped directly to the automotive assembly plant for final installation into the vehicle. End item parts can be made up of several components that have been put together to comprise the final "end item" which was shipped to the plant to for installation.

production, any modifications made to these existing components had to be negotiated for cost and timing, as well as coordinated with the assembly plant to ensure they could still be installed properly. With the low sales volume of hybrids anticipated (10,000 units over two years[17]), MMC needed to use as many common components as possible (between the gas and hybrid vehicles) in order to take advantage of economies of scale. Despite John Boyle's best attempt to explain this to the sales and marketing team, Ron Frank continued to push for unique components between the vehicles in order to make the hybrid more "distinct" and therefore more "saleable." Ron Frank would argue, "With an anticipated price step of $5,000 for the hybrid[18], we have to distinguish it from the gas version. Our customers need to know they are driving a hybrid.".

As the product development cycle evolved, multiple interior option packages and unique configurations were suggested by sales and marketing, and often fought-off by engineering. As the vehicle headed closer to production, the discussions on vehicle content became more heated between the engineering and sales groups. Ron Frank, concerned that overall hybrid sales may start leveling-off in the market (in general), wanted to give MMC their best chance for success (reference **Exhibit 12** – US Hybrid Sales). John Boyle, concerned that his engineers, suppliers, and assembly plants couldn't accommodate the late changes, and unique parts continued to push back.

From experience, John knew that even relocating an existing part (to make room for additional components), could introduce reliability and warranty issues that were not present before -- this could happen as a result of changes to temperature, vibration, or moister in the area the part was being relocated to. To validate each change, additional durability testing needed to be run on the hybrid — meaning additional scheduling and man-hours were needed in the vehicle test chambers and at the proving grounds. This issue alone created challenges for the hybrid development team, as they were competing with other higher volume vehicles for limited testing resources[19].

Manufacturing Challenges

The hybrid posed major concerns for the manufacturing team as well. Boyle recalled a discussion he had with his assembly plant manager (Martin Boone) following the first program 'kick-off' meeting. "So John, you have a big job ahead of yourself to try and package[20] those 240 new parts. I trust your team will make sure we have enough access to install them into the vehicle? And remember, we still need room to install the current parts as well? I've been under that hood, and I don't see room for 240 new parts," he said pointedly. Boone knew from experience that it would be a major task to integrate the new components into the existing vehicle packaging. "I don't have to remind you that the UAW (United Autoworkers Union) gets very upset when those parts aren't accessible and visible during installation.

I also have a fixed amount of floor space out here, so I need those engineers to keep the number of fasteners and support brackets to a minimum—it's just one more component I'll need to install, and one more part I'll need to maintain stock for on the line. I'm sure those engineers of yours understand that,

[17] Volumes for a typical truck model average 100k – 500k+ units annually.
[18] Price step refers to the additional amount a customer must pay for the hybrid vehicle. The delta price step was based off of the standard v8 engine.
[19] Testing resources were generally prioritized based on program complexity, and volume / profitability. The hybrid vehicle was technically classified as a refresh program (lowest priority) with minimal volume—creating challenges for the engineering development team.
[20] Packaging a component includes identifying the location that the component will placed in the vehicle to maximize ease of installation, functionality, reliability, and serviceability. The activity includes designing proper geometry, support brackets, and integration hardware such as wiring, hoses, clamps, etc.

right?" he asked. Boyle sarcastically nodded his head with a big grin. He knew it would be a challenge if they didn't hire some engineers with solid manufacturing and packaging experience.

In order to control cost, senior management approved the hybrid vehicle to be produced on the same assembly line as the gas-powered version. Both Boone and Boyle knew this would add complexity to the plant. Each of the new parts needed to be assigned to an operator for installation and the assembly line re-balanced[21]. By contract, no single station was allowed to have more than 60 seconds of work, equaling about 85% efficiency. When installation times at a worker station exceeded this maximum time (due to component changes), the jobs and part installation sequences needed to be reorganized in order to balance the workload properly. Each time the assembly plant built pre-production vehicles they would use the opportunity to assign the new processes and assembly sequences for the new components.

Material handling areas would also need to be re-organized to make space available for each of the new components at the work stations. Currently, there was just enough room on the assembly line to stock parts for the gas-powered vehicles. Also, additional error-proofing techniques would be needed to ensure the operators didn't accidentally install hybrid components on the gas-powered vehicles and vice-versa. Since both versions of the vehicle used over 95% common parts it would be difficult to distinguish them apart at various stages of production.

A key operation in the assembly plant was electrical testing and validation (ETV). Historically it was this area that struggled during a new vehicle launch. ETV required electrical test stations throughout the facility which were used to input vehicle software, calibrate vehicle features, initialize subsystems, and check for compatibility of components as the vehicle rolled down the production line. If an electrical part was not properly connected, or was malfunctioning, the system could often detect it at one of the several electrical testing stations. With the growing complexity of vehicle electronics each year, the ETV requirements were constantly expanding, and now included one or more test stations in each sub-system assembly area[22]. The system culminated at the final line where the vehicle was completely assembled. Boyle remembered the first time he had seen this test station where nearly 3,500 separate electrical tests were performed in a period of about 4 minutes. This was necessary to ensure every vehicle was functioning properly before it left the assembly line.

The final inspection station for the gas powered vehicles stretched across the last 12 operator stations in the plant. Boone could only imagine what unique and complicated validation and calibrations would be required for the hybrid vehicles—and how much additional space it would require. "One thing is certain," he thought, "if it required any additional processing time at all, they'd be in trouble." There was simply no room available on the assembly line to accommodate the testing. Martin Boone knew manufacturing engineering would need to shorten the test sequence, or develop a method to perform it quicker. He hoped someone on the hybrid team understood ETV well, or it was going to be a difficult launch. "Hopefully," he thought, "they're going to hire people from within the truck engineering team that understand our assembly process."

Beyond the assembly and test issues, Boone was also concerned about coordinating issues between the engineers in Detroit, and his plant in Tennessee. He remembered too many difficult launches when the engineers weren't available for support. If the hybrid was going to be more complicated to assemble and test, he imagined it would require a lot of good support.

[21] Line balancing ensures the assembly time for each operator / station is equivalent to avoid bottle necks and over-utilization in the process.
[22] The primary subsystem assembly areas employing ETV testing included: door subsystems, instrument panel build-up, interior trim, chassis systems, and the final assembly area.

Performance Targets

At the inception of the hybrid program, MMC's management felt they had to establish strong performance targets in order to meet customer expectations. This was necessary to keep-up with their competition and to justify the anticipated price increase of the hybrid powertrain. In general, hybrids were expected to achieve about 30 - 35% improvement in fuel economy. For the Intella, this represented an improvement of about 5 mpg based on the current 15 mpg combined city and highway fuel ecomony the base vehicle provided. For marketing purposes, MMC management insisted the full 5 mpg improvement be achieved so they could advertise the vehicle at 20 mpg or better. Boyle recalled many discussions with the sales & marketing team insisting "20 mpg" was a marketing milestone, and "19.2 or 19.4 just wasn't the same" in terms of marketing power. 20 mpg had become the minimum acceptable performance. Unfortunately for Boyle and his team, it represented the extreme of what was achievable from an engineering standpoint. Adding to the challenge were the new hybrid components which added over 200 lbs of weight, creating a direct and negative impact to fuel economy and other key performance measures[23] such as top speed and towing capacity.

Throughout development, the fuel economy had become so important that engineers began designing unique hybrid components such as side-mirrors and fog lamp fascias that could provide incrementally better wind resistance than the standard components. Many of the changes resulted in thousands of dollars in tooling cost, and an increase in component costs—while only returning improvements of 0.03 mpg. The team began pursuing numerous engineering changes under compressed timelines in order to achieve collective improvements of only .1 to .2 mpg. With each change came additional part complexity for the plant in terms of part ordering, part storage, and error proofing. But Ron Frank and the marketing team made it clear that the new hybrid had certain "customer expectations" were unyielding, and needed to be achieved to make the vehicle "competitive".

Component Sourcing

The engineering and manufacturing teams were not the only groups that were impacted by new parts. For months the purchasing department had struggled to find sources for some of the original new components. The problems began when they had no choice but to source some of the low volume hybrid components to their high-volume suppliers that were simply not suited for the business[24]. Having recently gone through supplier reduction campaigns (to consolidate their parts to fewer sources), the pool of candidates became considerably smaller for some commodities. In addition, with the compressed timing of the program and reduced staffing levels it was taking too long to identify and approve new supplier sources[25].

Suppliers that were accustomed to delivering parts in excess of 100,000 per year were being asked to quote volumes of 5,000 pieces annually. Boyle remembered vividly a conversation he'd had with his purchasing agent, Robert Tanner. When asked why there was still a number of components that hadn't been sourced yet, Tanner responded by saying, "nobody wants them, John. We're literally having to force our suppliers to take on this business in some cases. This program is simply not profitable for a supply base that operates in mass volume. Some of these suppliers can literally run our annual production

[23] As vehicle weight increases for a given level of power, performance metrics such as top speed, acceleration, fuel economy, etc. will deteriorate.
[24] Production methods for high-volume components were sufficiently different from low-volume small lot production methods.
[25] Approving a new production source often included visits to their facilities and formal assessments of their: production capability, production capacity, maturity of their quality systems, and financial health.

in a single week, so they want to ship us a year's supply in one batch. They don't want to store these parts, and they don't want to stop and change-over their machines every week to make the 100 pieces we need for our production schedule…and then pay to ship that small quantity here over 40 times per year.

These suppliers ship us parts from all over the world, using processes that were built on models of efficiency. We can't even amortize[26] our tooling costs into these small volumes to make the numbers work! Nobody wants to pay our suppliers tooling dollars directly, yet there's no volume to spread the cost to. We have little negotiation power, except to try and entice them with future business that would be profitable. We're doing the best we can."

Boyle understood clearly because the program was already operating at a loss. The cost of each hybrid unit produced was projected to exceed the revenue by about $4,500[27] (reference **Exhibit 3** – Cost Comparison). MMC was planning to lose money on every hybrid they sold. Although the organization knew from the start that the hybrid program would not be profitable (it was a government mandate), they pressed the team to try and minimize losses as much as possible.

As MMC struggled to source the components it began to impact delivery dates for prototype and development parts. Boyle recalled the many long meetings with his program manager (Lucas Tyler) trying to expedite late parts before each build phase. Special production runs and expensive air shipments were needed for several components in order to meet the program timeline. For suppliers shipping internationally, components could be held-up in customs as well[28].

Coordination

Shortly after the program kick-off, John Boyle began seeing problems with the coordination between MMC and the hybrid center (HDC). The management staff at the HDC began complaining that they didn't want the vehicle engineers contacting their hybrid engineers directly, as it was "distracting them from their development work." Instead, they insisted the hybrid center manager be the interface for all technical communication between the program team and the hybrid staff. This would allow HDC to "manage their resources more effectively" they argued. At work were some strong personalities including the new HDC technical manager Armondo Bizzeli. Armondo was a veteran of the powertrain group with 25 years experience at MMC. He was known for his strong autocratic management style and did not hesitate to remind the team of his responsibility for the 100+ engineers at HDC which were matrixed through him (reference **Exhibit 9**).

Mr. Bizzeli generally favored delegation over collaboration and was determined to make the hybrid program a success if he had to manage every aspect of the project personally. He confessed to Boyle that he was a little concerned with the lack of experience of the PM team and was willing to assume part of that role if needed. Boyle confirmed that his team was very capable and the current PM was one of the most experienced engineers from MMC—having worked in several areas of the organization including electrical engineering, manufacturing, business strategy, and product planning.

[26] Amortizing costs is a method that allows organizations to pay fixed costs, on a variable cost schedule. For example, rather than paying a supplier $50k for tooling, + $1 per part (for 50k parts), an organization may prefer to pay their supplier $0 tooling costs and $2 per part—thereby "amortizing" the $50k in tooling across the volume of parts being purchased. Although each option results in total payments of $100k, the amortizing strategy eliminates the initial outlay of $50k.

[27] The initial development costs of the hybrid program were too high to earn back in the small volume projected to be sold.

[28] Parts arriving from international destinations were subject to random inspections and audits. If proper documentation did not accompany the parts, customs officials would not approve shipments into the country.

Based on Bizzeli's request, the PM office reluctantly agreed to let him be the POC for engineering communication. Steve Andersen (VP Truck Engineering) thought it was best to maintain positive relations between the two groups. To help facilitate dialogue, Bizzeli began running weekly meetings at HDC. The agenda for the meetings primarily covered engineering issues, although the PM team was free to include program issues as needed. The team would discuss these issues "as time permitted." The program manager (Lucas Tyler) found himself having to use these opportunities to educate HDC staff on their program metrics and quality gate deliverables29. Tyler described the meetings as "an uphill battle the entire way" because the program launch requirements had become secondary to hybrid design issues. The HDC team was busy trying to understand their test results, while the PM team was trying to document design changes and implement / close-out vehicle integration issues.

As Tyler began preparing for gate reviews, he consistently found many of the HDC engineers would delay reporting program status despite repeated requests. Frustrated, Tyler requested Bizzeli to get his team more focused on the program deliverables. "We are on a strict timeline for this project. We have to freeze the design, document our progress, and prepare for our gate review. Your team needs to update their metrics so we can report it to management." Bizzeli assured him "it's under control. The HDC engineers are working through me…we're just resolving a couple minor issues before we do our report-out." The two continued their struggle throughout the program launch in a similar manner. Bizzeli preferred to manage the program details within HDC so as not to alarm senior management, while the PM team always strived to report the project status with transparency.

Per the guidelines of the 'refresh' strategy, the gate reviews for the hybrid program only required a presentation of the metric scorecards (reference **Exhibit 13** – Metric Scorecard). The decision to proceed to the next gate could also be made at the program level (i.e. VP level and below). Consequently, the documentation and reporting tended to be minimal for the gate reviews. Often, the individuals being briefed were the same individuals working closely on the program. Furthermore, since the hybrid project was being driven by a government mandate, MMC management appeared to have no intention of denying or delaying the hybrid program. This was a high-profile project and one that the CEO was personally anxious to get launched so he could begin touting his company as being "green." The situation created a challenge for the PM team. Boyle's team often felt they couldn't fully leverage the quality-gate requirements on the team because of the almost 'pre-determined' outcome and simplified reporting arrangement.

Engineering Changes

A key metric for each gate review was the number of unapproved design changes (CN's). Any time a design change was requested it needed to be captured on a Change Notice (CN) report, and routed to several departments for approval. Boyle had become increasingly alarmed as he saw the number of open CN's continue to grow from one build phase to another (reference **Exhibit 13** – CN Trend Chart). He feared this might be the result of trying to meet marketing's drive for product differentiation, or even worse, the result of unanticipated problems found during testing & validation. As it turned out, it was a combination of both.

Boyle knew under ideal circumstances a program should see a majority of design changes in the early build phases, and they would begin to decrease as the design stabilized. On the hybrid program, he was seeing exactly the opposite trend. The CN numbers were climbing as they reached closer to production. As he investigated the phenomenon he found three key issues contributing the problem. First, the CN's

[29] Quality gate deliverables included a status of key issues, and progress (High / Medium / Low) assessment of design activities – reference **Exhibit 13** – Metric Scorecard.

that were in the system were not being approved promptly (reference **Exhibit 14** – CN Trend Chart). They tended to be sitting in the queue of several new managers at HDC, or were sent to the wrong approval personnel by the engineers that initiated them. He recalled there had been some discussion among the PM team that several new HDC people did not understand the CN system at MMC, and may need more training.

Boyle also found that large batches of CN's were coming through just before key program reviews which made them difficult to process in a timely manner. He was curious to understand why the engineers were waiting until the last possible moment to initiate these CN's, and wondered if it was related to the way Bizzeli attempted to manage his issues internally, so as not to generate management attention.

Finally, he noted a constant stream of CN's being initiated from the vehicle test and vehicle build areas. Often he would find requests for changes coming through during a build phase because a vehicle being tested (from a previous phase) was experiencing a problem. This was happening frequently. The number of change notices was far exceeding anything he had seen in his 25 year career for a 'refresh' program. The CN count seemed to be an order of magnitude greater than what he would consider typical.

Vehicle Build Plan

The hybrid launch included only 2 pre-production build phases in the assembly plant before volume production (reference **Exhibit 1** – Hybrid Program Timeline). This build strategy was common for a 'refresh' program. For more complex programs there could be up to four build iterations scheduled before volume production. Generally, for these highly complex programs the first two builds will be at the prototype (or pilot) plant[30]. MMC's pilot plant is located at the headquarters so it is accessible to all of engineering. Building prototype vehicles in the pilot plant enables the engineers to work out many assembly and integration issues without having to impact the production plant. In addition, issues identified on these early vehicles tend to get resolved more quickly because of the significant engineering support available on site.

For the hybrid program both of the pre-production builds were completed at the assembly plant. This was the result of strong politicing from the manufacturing team (led by Martin Boone) because they needed to be familiar with the vehicle as soon as possible due to the shortened development cycle. In addition, it was not unusual for 'refresh' builds to be completed at the assembly plant.

For each of the hybrid build phases, a team of engineers from HDC and the headquarters (in Detroit) would visit the plant (in Tennessee) to coordinate assembly issues. Generally there were between 30 – 40 engineers on site coordinating issues across all areas of the vehicle.

During each build phase Martin Boone struggled to make the HDC engineers understand the level of urgency and support his plant needed. Boyle recalled many frustrated phone calls from Boone saying "these engineers just don't understand this isn't a science project. We're building these vehicles on the same line as production. When we have a problem, it stops the entire flow of vehicles…and they want to start conducting research out there on the shop floor." Under normal operations a completed vehicle should roll-off the production line every 80 seconds, representing $30k - $40k in revenue. If the line is down for any length of time it can be devastating to the plant. For the manufacturing team, profitability is counted in minutes, and is earned or lost in that timeframe.

[30] Early proto-type vehicles are often built off of previous model year vehicles that have been upgraded with new electrical systems and components. This strategy enables system integration activities to begin well in advance of new sheet metal availability.

Although the hybrid engineers had impressive technical backgrounds, many lacked experience in an automotive manufacturing environment. As time went on, Boyle got the sense that some issues were taking far too long to be resolved, and there was a continual stream of CN's in the system. As the program moved closer to production, the frustration between HDC and the manufacturing team was growing. Boyle couldn't help but wonder how things would've been different if a prototype build would have scheduled in Detroit to help work out the integration[31] issues early on?

From management's viewpoint, "refresh" programs typically do not require significant changes which makes them ideal to build in the production facility in the early stages. In the case of the hybrid launch, this didn't seem to be the case.

Recommendation to Board

After Boyle recounted the major challenges over the last 2 years, he thought about the upcoming program status meeting he had with the board of management on Monday. He needed to confirm that the team was still on-track for the launch, or take the opportunity to recommend a launch delay as they worked through the details of their open issues. Boyle understood that any recommendation for delay would be met with an extremely negative reaction by senior management—particularly because the public expectations were so high, and the ATPZEV mandate timing was fast approaching.

There were three major areas of concern that Boyle noted including: (1) open engineering changes, (2) manufacturing & assembly issues, and (3) late parts timing.

There were currently over 20 engineering changes that were not completely implemented on the hybrid, and the vehicle was less than 6 weeks from production (reference **Exhibit 14 -** CN Trend Chart Chart). The software team was responsible for a majority of the issues and assured Boyle that they would be ready with the corrections in plenty of time for launch. The question was, would it allow enough time for proper vehicle-level testing and validation. There was no guarantee that a software revision which fixed one issue wouldn't trigger another problem, particularly with the complexity of the hybrid electrical system. In fact, Boyle had seen this happen on several occasions during development. Since the vehicle modules communicate on the same data bus, a malfunction in one module will often cause failures on others.

In terms of unresolved assembly issues, engineering still needed to address several manufacturing improvements requested by the plant (such as hose and wire routings, revised brackets, fasteners, and clips). These items involved accessibility of parts and wire routings during installation. The engineers were attempting to make the requested changes, but, it was clear that there would still be some challenges for manufacturing.

The final issue involved projected late parts. A few key components needed to be expedited from suppliers to meet the launch ramp-up schedule. According to production control, the parts were being closely monitored and were planning to be air-shipped to meet the build dates. Although the team was forecasting the parts to arrive on time, Boyle was concerned because some of the parts were being shipped internationally (and needed to go through customs).

After a good night sleep Boyle sat down to assess his options. The program was clearly at risk in several areas, however, he wasn't sure any single issue was significant enough to delay the launch. The problem

[31] Integration requires the coordination of vehicle subsystems to ensure overall system functionality. Electrical components, software, and mechanical systems interfaces must be designed, connected, and validated to ensure vehicle performance goals are achieved.

he thought, was that management would likely push-back if he recommended a delay, and mandate they meet the original timing. He recalled the time his team was told to "make it work" when contesting the original launch strategy.

He began to think his best option for success would be to move forward with the scheduled launch but identify to management the key risks that would need to be mitigated in the next six weeks. As part of this assessment, it would be important that he explain what should have been done differently on this launch (in hindsight) as lessons learned. Specifically, as MMC hoped to reinvent themselves as a more successful company launching more innovative products in the future.

Questions

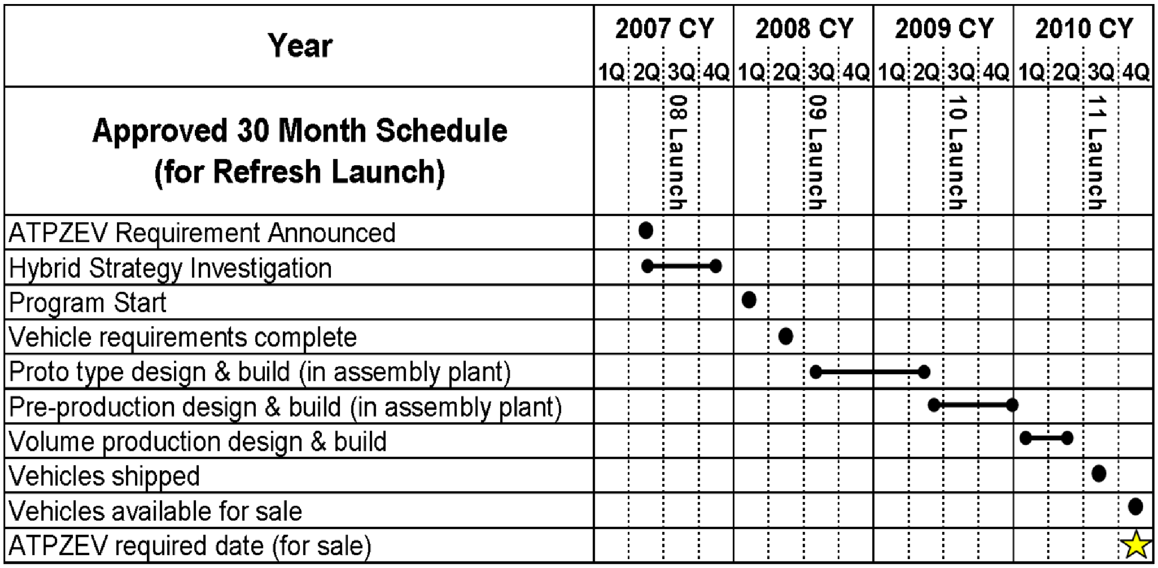
1) Do you agree with Boyle's assessment of the path forward, and why?

2) Considering the requirements of the hybrid technology and capabilities of MMC, how could the management team have better planned / organized for the vehicle launch?

3) Identify three key areas (or elements) that were a detriment (i.e. a negative) to MMC launching an innovative product like the hybrid vehicle.

a) What, if anything, could MMC have done to minimize the impact of these elements on the launch?

Exhibit 1 – Hybrid Program Timeline



[Source: MMC Program Planning Package]

Exhibit 2 – MMC Product Portfolio

	Economy Brand	Premium Brand	Niche Brand
Trucks / Van	Mid size Pickup	Passenger Van	-
	Full sized Pickup	-	-
	Cargo Van	-	-
	Passenger Van	-	-
SUV's	Cross-over Wagon	Cross-over Wagon	Compact SUV
	Mid-size SUV	Large SUV	Small SUV (a)
	Large SUV		Small SUV (b)
		-	Mid-sized SUV (a)
		-	Large SUV
Cars	Small (2 Seat) High Performance Car	Compact Car	-
	Mid-sized Hatchback	Small (2 seat) Sports Car	-
	Mid-sized Car	Mid-sized Sports Car	-
	Large Car	Large Car	-

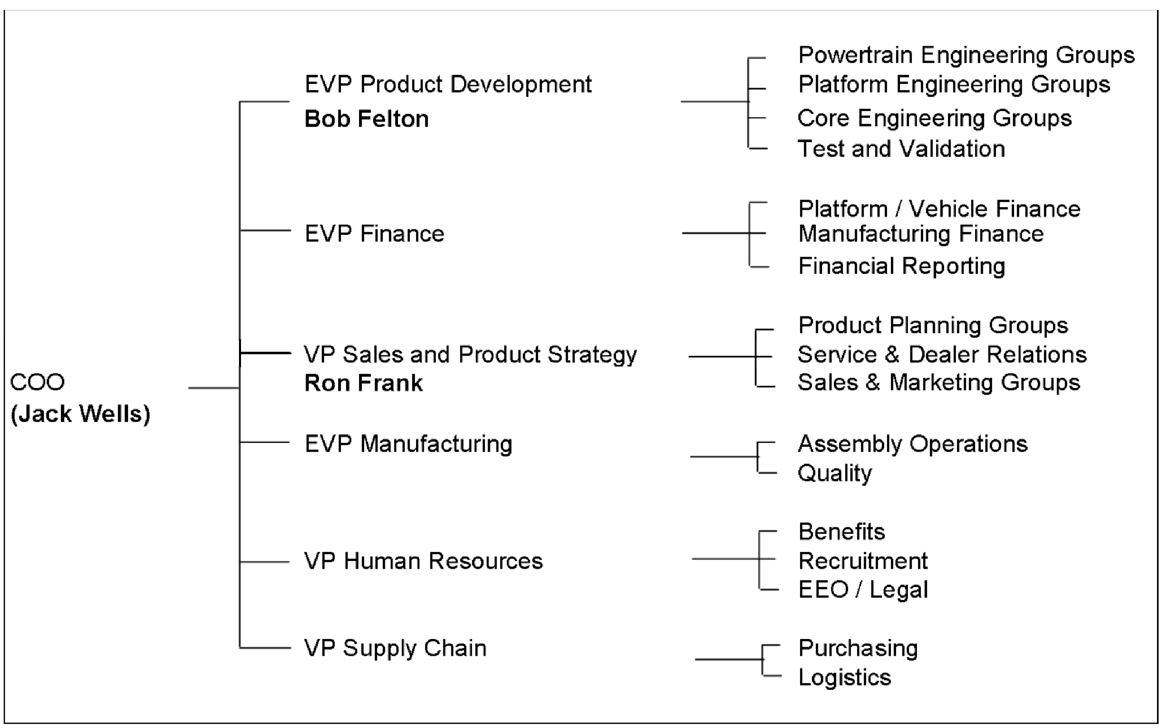
[Source: MMC Annual Report – Product Line (2008-2009)].

Exhibit 3 – Development Cost Comparison

	Rebadge	Partnership	In-house
Prototype Builds	5,000,000	25,000,000	50,000,000
Staffing	-	60,000,000	120,000,000
Testing & Development	10,000,000	50,000,000	150,000,000
Facilities & Special Equip	-	40,000,000	80,000,000
Production & Assy	220,000,000	160,000,000	320,000,000
G&A and Misc	10,000,000	60,000,000	90,000,000
TOTAL PROGRAM COST	245,000,000	395,000,000	810,000,000
Total Volume	10,000	10,000	10,000
Cost per unit	$24,500	$39,500	$81,000
Projected Revenue (per Unit)	$35,000	$35,000	$35,000
Net Income (Loss) per Unit	$10,500	**($4,500)**	($46,000)
Total Revenue / Loss	$105,000,000	**($440,000,000)**	($1,270,000,000)

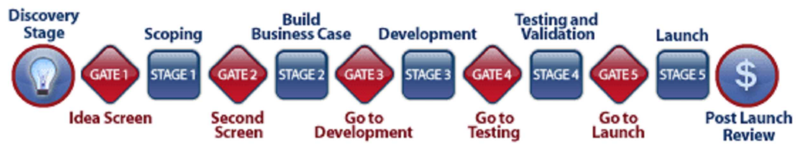
[Source: MMC Program Planning Package]

Exhibit 4 – MMC Organization Structure



[Source: Adapted from MMC Annual Report Data (2008-2009)]

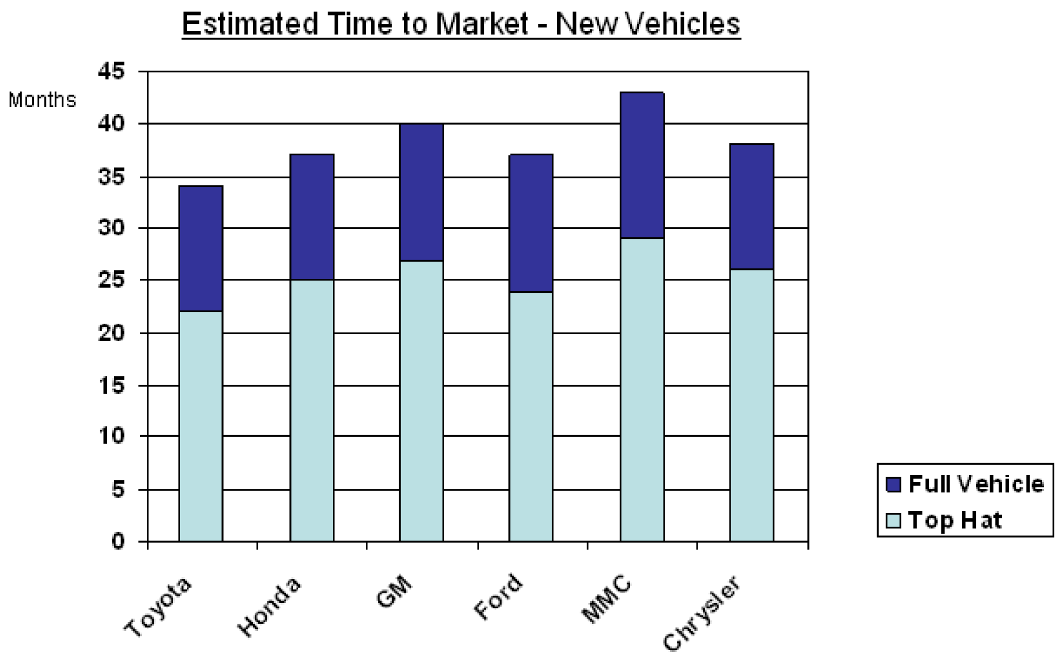
Exhibit 5 – MMC Gate Review Schedule



		Gate Review Meeting
GATE 1	Idea Screening / Business Case (select alternatives)	complete
GATE 2	Scoping (establish program goals & objectives)	complete
GATE 3	Product Development	
3J	Program Approval / Start	Date TBD
3I	Preminary Specifications Confirmed	Date TBD
3H	Vehicle Concept / Theme Approved	Date TBD
3F	Final Program Specifications Confirmed	Date TBD
3E	Product / Process Design Complete	Date TBD
3D	Phase 1 Proto-types (proto tools, proto process, initial integration)	Date TBD
3C	Phase 2 Proto-types (initial integration complete, tooling designs confirme	Date TBD
3B	Phase 3 Preproduction vehicles (partial hard-tooling)	Date TBD
3A	Phase 4 Production intent (final integration and hard-tooling complete)	Date TBD
GATE 4	Test and Validate	
	Feature validation / testing Phase 1	Date TBD
	Feature validation / testing Phase 2	Date TBD
	Feature validation / testing Phase 3	Date TBD
	Feature validation / testing Phase 4	Date TBD
	Lifecycle testing	Date TBD
GATE 5	Launch	Date TBD

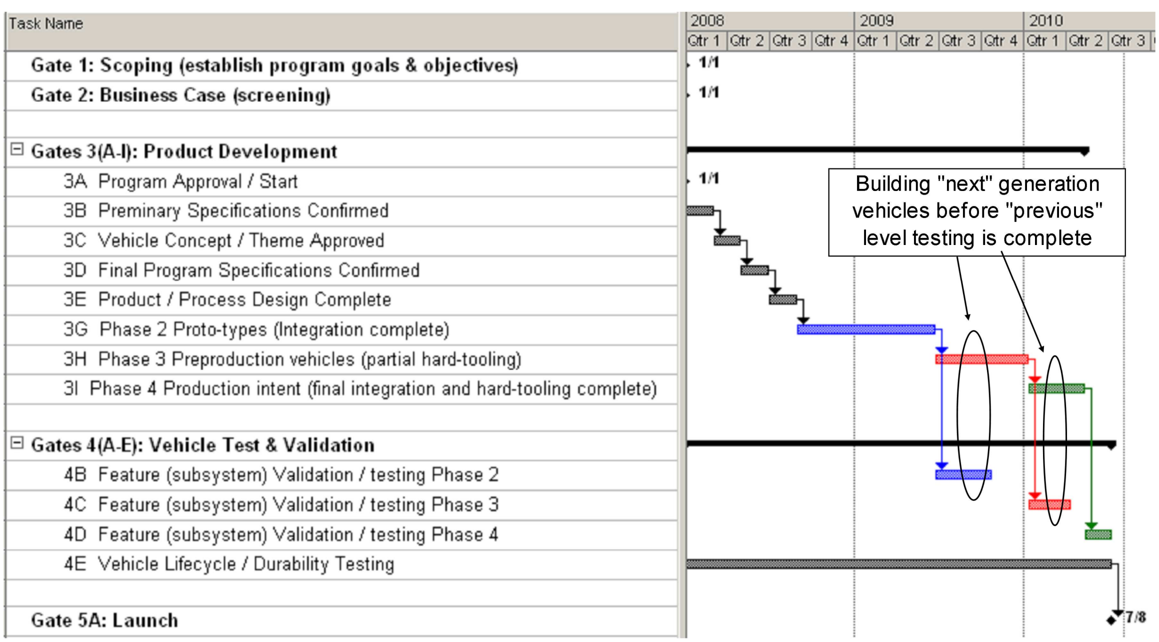
[Source: MMC Program Planning Package]

Exhibit 6 – Program Lead Time Comparisons



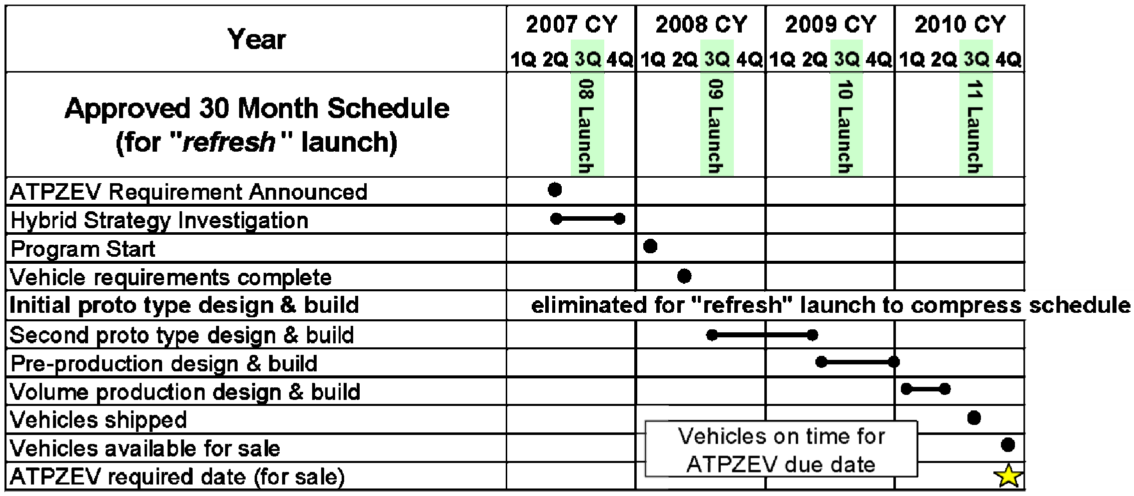
[Source: MMC Benchmark Study - Time to Market Vehicles]

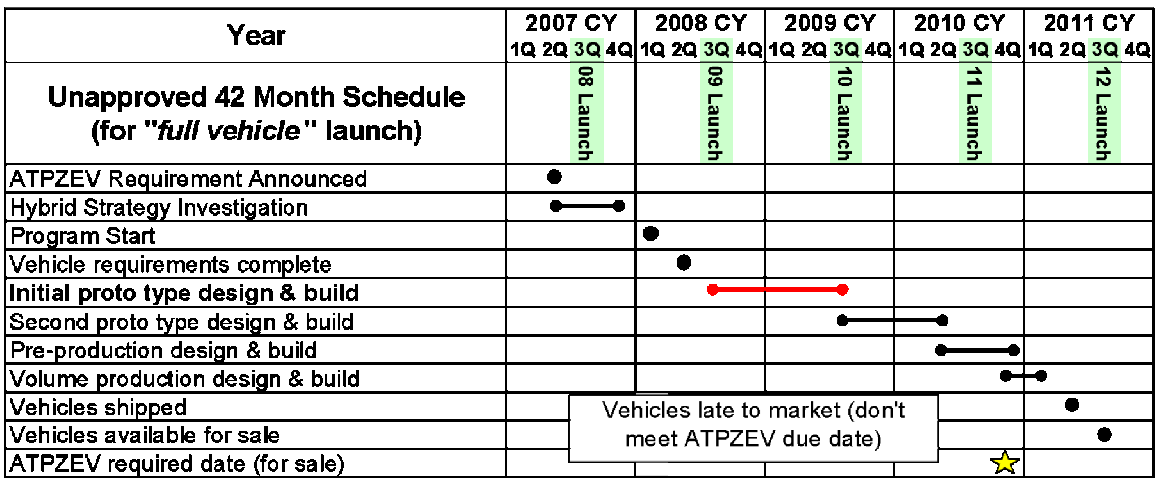
Exhibit 7 – Compressed Timing



[Source: MMC Program Planning Package]

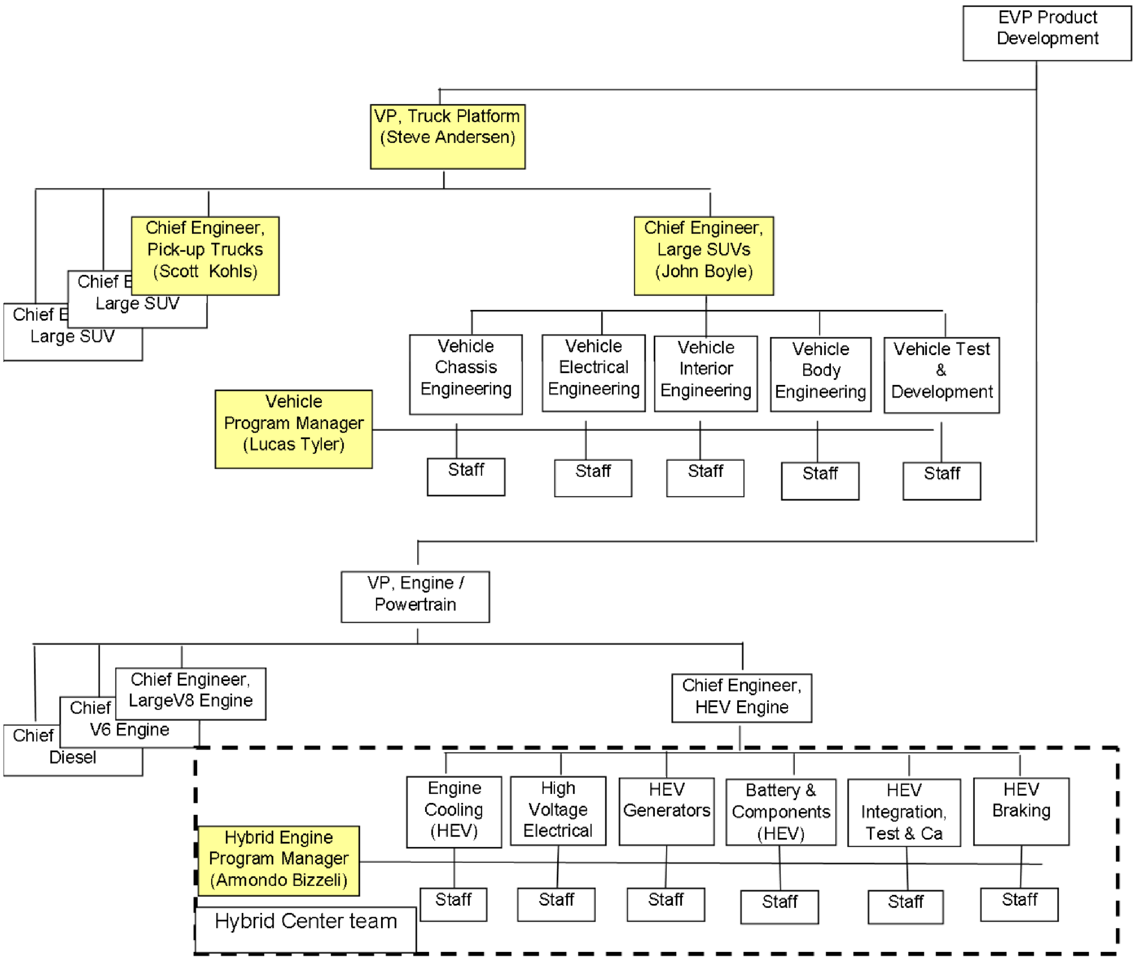
Exhibit 8 – 30 Month –vs- 42 Month Timeline





[Source: MMC Program Planning Package]

Exhibit 9 – Hybrid team Organization



[Source: MMC Hybrid Development Center Organization]

Exhibit 10 – Six Sigma Initiatives

Test & Evaluation

1. Reduce number of vehicle tests performed to shorten validation cycle
2. Implement more modeling in place of real-world testing to reduce cost and leadtime

Core EE

1. Commonize EE modules across multiple vehicles to reduce part complexity and part cost
2. Commonize vehicle EE features across multiple platforms to simplify programming and reduce software engineering support

Powertrain

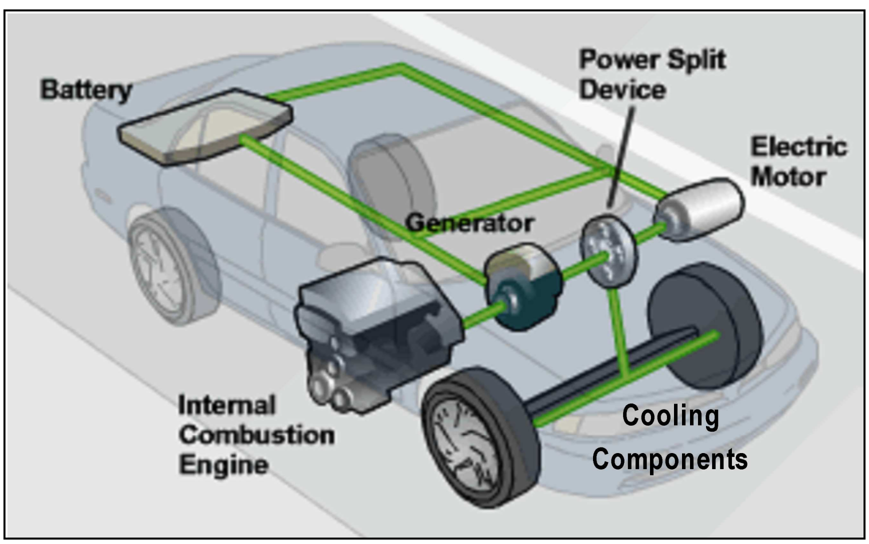
1. Reduce powertrain support staff by organizing by platform -vs- assembly plant. Re-align responsibilities to accommodate.
2. Reduce number of engine and transmission modules by commonizing calibrations across platforms & vehicles. Will reduce part count and software engineering support

Program Management

1. Compress launch timing through reduction of build iterations
2. Compress launch timing through concurrent engineering techniques (running phases in parallel)

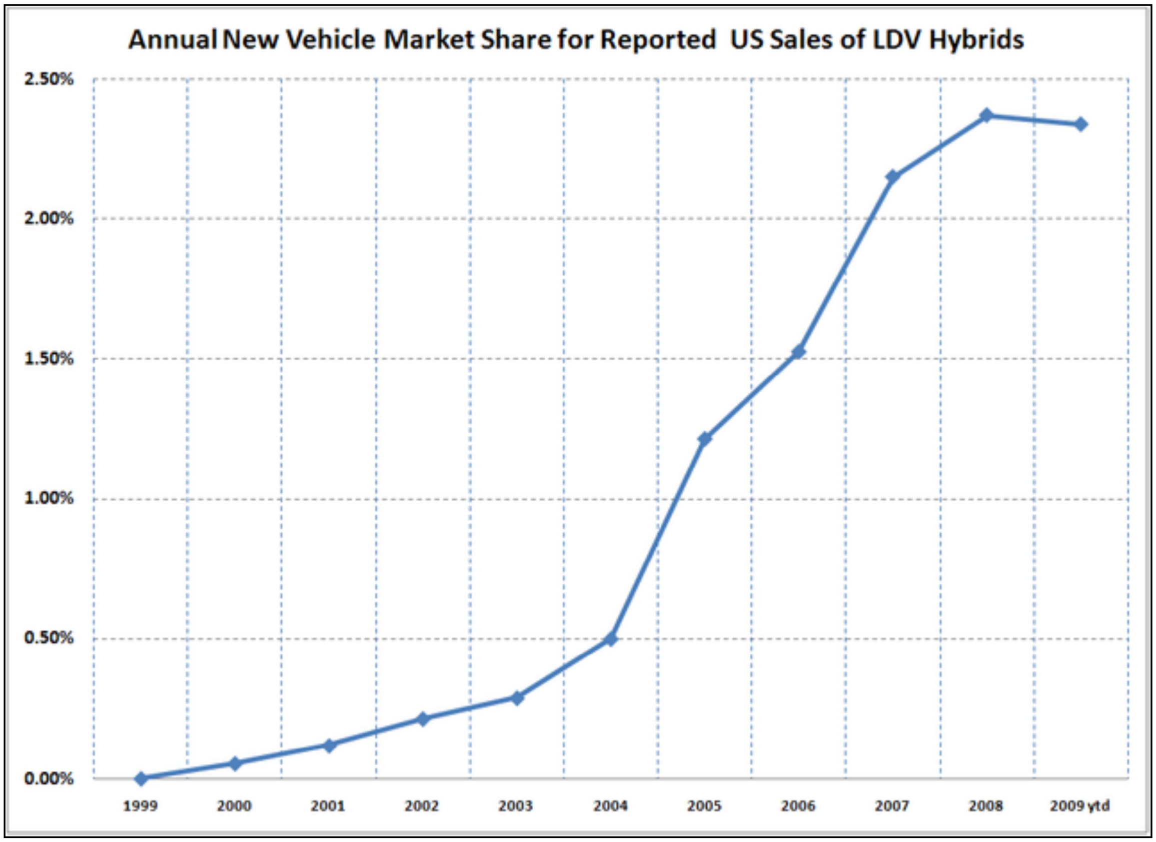
[Source: MMC Program Planning Package]

Exhibit 11 – Hybrid Components



[Source: http://www.howstuffworks.com/hybrid-car.htm.]

Exhibit 12 – US Hybrid Sales



[Source: Green Car Congress: http://www.greencarcongress.com/2009/03/us-hybrid-sales.html.]

Exhibit 13 – Metric Scorecard

Program Objectives:	Status
Investment status	H / M / L
Vehicle cost status	H / M / L
Resource usage	H / M / L
Technical & service manual status	H / M / L
Part commonization	H / M / L
Engineering Hours per Vehicle	H / M / L
Status of product changes	H / M / L
Design for six sigma projects status	H / M / L

Plant readiness	Status
Vehicle assembly sheets status	H / M / L
Paint operations	H / M / L
Assembly operations	H / M / L
Chassis operations	H / M / L
Body & stamping operations	H / M / L
Ordering system validation	H / M / L
Control plans status	H / M / L
Vehicle assembly sheets status	H / M / L
Tool delivery status	H / M / L
Fasteners and torque status	H / M / L

Engineering Performance Objectives:	Status
Powertrain performance	H / M / L
Vehicle Weight	H / M / L
Fuel Economy	H / M / L
Electrical integration	H / M / L
Vehicle exterior integrity	H / M / L

Test & Development	Status
Design validation (for subsystems)	H / M / L
Vehicle design validation	H / M / L
Engine certifications status	H / M / L
Vehicle emissions status	H / M / L
Safety systems certifications	H / M / L
Durability test completion	H / M / L

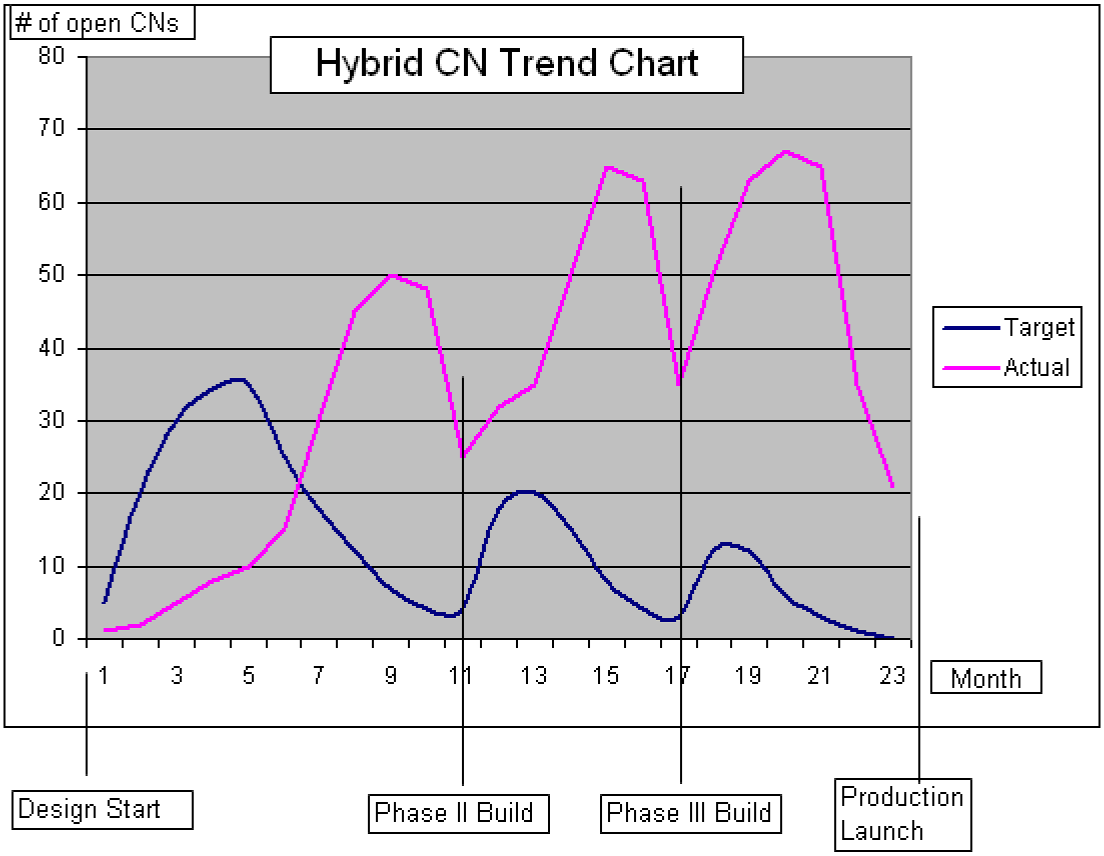
Supplier Quality	Status
Component sourcing status	H / M / L
Supplier certification status	H / M / L
Quality plans status	H / M / L
Supplier readiness	H / M / L
Process FMEAs	H / M / L
Tooling design plan status	H / M / L

Overall Program Status H / M / L

Approved to proceed to the next development stage? YES / NO

[Source: MMC Program Assessment Package]

Exhibit 14 – CN Trend Chart



[Source: MMC Program Assessment Package]