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Chrysler and BMW: Tritec Engine Joint Venture

Product engineers are generally not upset with having to change a design. We recognize that is part of engineering. But this was different. I shared my experience with a BMW engineer. He told me, "At BMW, manufacturing would not question the design for two reasons. First, they would respect the engineers and have confidence in their design and the reasons for it. Second, they would accept the challenge and find a way to manufacture it. They would never say, 'We cannot do it.'" He continued, "Those problems are unheard of for a BMW engineer."

—Chrysler Engine Block SE Team Member

In early September 1997, Jack Smith was trying to decide how to resolve an impasse between the product design engineers and advanced manufacturing engineers. Ten months earlier, Smith had become the project leader for Chrysler's joint venture with BMW. The joint venture, known as Tritec, was responsible for developing a new 1.6-liter family of engines. Tritec was a high profile development project with a projected \$525+ million investment.

The deadlock involved the selection of an engine block sealing design. Product engineers had originally designed a lower tie bar for the cylinder block, a design never before used at Chrysler on a small engine. They believed their elegant design would not only entail lower capital investment, but also provide a superior seal that would reduce the risk of oil leaks. This design had already been incorporated in 23 prototypes built as part of the early design phase. Advanced manufacturing engineers, however, who joined the team after the early designs had been completed, subsequently pointed out that the design was not appropriate for high-volume production. Without a robust design, in terms of manufacturability, they argued, the project could not achieve its quality targets. The product engineers proposed alternative seal designs, including a bedplate design used in Chrysler's 2.0-liter Neon engine and a rear retainer design. Selection of one of the three designs—the tie bar, bedplate, or the rear retainer, involved many tradeoffs, including the engine's weight, fixed investment cost, variable costs, impact on the project timing plan, and estimated warranty costs. None of these tradeoffs could be precisely evaluated at this stage of the project, however.

Although the Tritec team had developed processes and guidelines for resolving problems, Smith felt he needed to become directly involved. While this was one of many hundreds of product or process design decisions made in a project of this scope, it was particularly critical to meeting program cost, performance, quality, and timing goals. Smith realized that failure to resolve the issue quickly could cause cascading delays in the project and lead to a late product launch. The issue had already attracted the attention of Frank Ewasyszyn, Vice President, Advanced Manufacturing, and could easily escalate onto the agendas of other corporate leaders if not quickly resolved. Smith pondered, "What is the best block sealing choice? And how should I resolve the problem so that we can improve our capability of working together?"

Professor H. Kent Bowen and Post Doctoral Fellow Courtney Purrington prepared this case. Names, performance data, financial figures, and other data for the Tritec project have been disguised. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

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Evolution of Chrysler in the 1990s

Under CEO Lee Iacocca (1979-92), Chrysler had twice courted bankruptcy. With the exception of the minivan, Chrysler products, such as the “K” car, generated little consumer appeal. Product development was done sequentially in functional departments known as silos or chimneys. According to Robert Lutz, “Our designers worked pretty much in a vacuum, conceiving a product and ‘throwing it over the wall’ to engineering in the next building, which would then do the same to procurement and supply, and down the line.”¹ In the latter half of the 1980s, Honda and Toyota had a commanding advantage over Chrysler in major platform projects (new car designs). They were 40 percent faster (36 months versus 60 months) in terms of cycle times, 100 percent more productive (1.4 versus 3.1 million engineering development hours), and were rated much higher in terms of quality (conformance and design). An internal study of Honda and external studies of the auto industry subsequently led Chrysler to change its structure and processes for new product development.

After Robert Eaton became CEO and Robert Lutz became president and COO (**Exhibit 1**), Chrysler began to make dramatic improvements in profitability, market share, award-winning designs, and J. D. Power ratings (**Exhibit 2**). *Forbes* selected Chrysler as its “1996 Company of the Year.” Executive VP Tom Gale’s design organization created award-winning designs, like minivans and cab-forward cars. EVP Francois Castaing led the creation of five cross-functional platform teams (i.e., large car, small car, minivan, jeep/truck, and power train) that “toppled the chimneys.” The company’s functional resources were funneled into these platforms, which essentially operated as five mini-companies. Some senior executives were given two job titles—one functional and another cross-functional. All the functions were also collocated at Chrysler’s new Technology Center. Finally, Chrysler pioneered the use of CATIA software in the automotive industry. This software, created by Dassault Systemes in partnership with IBM, made possible the testing of thousands of product and process designs without building a single prototype model and helped reduce the amount of time needed to launch a product.

By 1997, the platform teams had launched multiple generations of products and derivatives (**Exhibit 3**) and had acquired formal and informal mechanisms for managing projects. “Tech Clubs,” or informal associations of engineers with specific technical knowledge, were created to facilitate cross-platform learning. Product Assurance Planning (PAP) was also implemented to shorten the time required to develop new or derivative products and improve quality and customer satisfaction. A PAP handbook, over 300 pages in length, guided each project team in the “responsibilities, tasks, deliverables, quality and reliability methods, tools, and measurements necessary to meet development milestones” (**Exhibit 4**).

Other improvements were initiated in manufacturing and procurement. Tom Stallkamp, EVP Procurement and Supply, led changes in corporate procurement practices to lower costs and bring suppliers into the new product development process sooner. Over 70 percent of Chrysler’s components were procured externally. The Supplier Cost Reduction Effort (SCORE) asked suppliers to submit annual cost-savings suggestions equal to 5% of their annual business with Chrysler. In 1996, the company estimated it derived \$1 billion in savings from the effort. To narrow the quality gap between Chrysler and benchmark Japanese competitors further, Dennis Pawley, EVP Manufacturing, instituted the Chrysler Operating System (COS). Based on the Toyota production system, COS introduced a systems approach to manufacturing and received plaudits for revolutionizing how Chrysler manufactured products.

¹ @ Issue, “Chrysler’s Robert A. Lutz on Design,” p. 2.

Creation of a Joint Venture

Pre-Project Efforts to Design Small Engines

In October 1995, David Ludlow, a senior power train product engineer, was serving on a task force given the mandate to explore building a B-class car, a small car with a small engine. Jim Holden, EVP Sales and Marketing, had assembled the team, which included Bob Marcell, head of the small car platform, as well as manufacturing, finance, and international specialists. Future growth opportunities for low-cost engines ranging in size from 1.0-1.6 liters were believed to be strongest in emerging markets in Asia and Latin America. While a number of feasibility studies had been conducted, no vehicle project was ever initiated. The main task force subsequently disbanded after corporate priorities changed. Nevertheless, a perceived need for Chrysler to develop small-car capabilities remained. Development of a power train was viewed as the first step toward that end.

A smaller team, including Ludlow, made several more proposals, including one describing the engine and unit cost for a low annual production of 100,000 engines. Corporate management responded that the proposal would require too much capital and directed the team to find a partner to share the costs of developing and producing the engine. Before the team approached any other companies, however, Bob Eaton arranged a meeting with BMW. Team members were not told why BMW was chosen. They speculated it was because a joint venture would allow both parties to explore "the potential benefits of building a longer-term relationship."

Joint Venture Explorations with BMW

In January 1996, the Chrysler team held its first meeting with BMW in Munich. BMW, which had acquired Rover from British Aerospace in 1994, disclosed that it planned to design a new engine for its Rover Mini. The new Mini, a "retro style" car, was critical to BMW's marketing strategy of moving Rover's model range up-market and restoring profitability at the company. In addition, BMW committed to upgrade productivity at Rover by making significant plant investments and rationalizing production. It also planned to lower costs by using common suppliers, transferring significant component purchases out of the UK, and reducing Rover's traditional supply base.

At a subsequent meeting in Michigan, both sides discussed their future small engine development plans. BMW revealed that it intended to invest in a new engine plant in either Germany or Britain, and it planned to manufacture a single overhead cam, 1.6-liter engine with an aluminum block. The Chrysler participants disclosed their intention to build a 1.6-liter engine plant in Brazil using a cast iron block. Chrysler had decided on Brazil after earlier studies revealed other emerging markets were too risky. No in-depth study of Brazil's market potential was made. The manufacture and export of engines in Brazil, however, would build export credits used to import Chrysler vehicles into Mercosur nations. Chrysler also had no definite plans for what car(s) would incorporate the new engine.

Both sides held several more meetings in February and compared estimated costs for their engines. BMW's engine was projected to cost roughly \$400 more to produce. Its anticipated level of investment was also significantly higher at a similar volume of production. BMW projected its annual demand to be about 200,000 engines. During discussions, it became mutually evident that a partnership would allow the companies to reduce their investment costs by at least 50 percent. BMW would also be able to learn how to design and produce a low-cost engine. While 200,000 engines were twice its projected demand, Chrysler believed it could design an efficient engine plant with a capacity of 400,000 units/year. The company also hoped to learn engine durability and reliability testing for a "European-type" market from BMW.

In April, a Chrysler team led by Francois Castaing held a major technical meeting with BMW. The Chrysler side gave a very detailed presentation, including 3-D models showing the engine design, as well as performance, cost, and timing projections. BMW's presentation was less detailed. Dr. Wolfgang Reitzle, Rover Chairman and the BMW Board Director responsible for R&D, was impressed enough with Chrysler's proposal and analysis that he implicitly endorsed a collaborative venture and cited BMW's need to learn low-cost design and manufacturing.

For much of the rest of 1996, Chrysler and BMW engineers disagreed over a range of design issues. Chrysler engineers believed BMW's designs would have made the engine more expensive to develop and manufacture. In June, when it seemed that explorations of a partnership were about to flounder, Dr. Reitzle overruled his own engineers and decided to accept most of the elements in the Chrysler proposal. At an early November meeting, both sides subsequently agreed to sign a joint venture agreement. Several weeks later, the Chrysler team met Rover engineers for the first time. Rover explained the new Mini's strategic importance for the company. BMW turned technical development of the engine over to Chrysler and Rover. The small Chrysler team then started working with Rover on the design.

Overview of the Joint Venture

Under the terms of the joint venture signed in January 1997, Chrysler and BMW agreed to design an engine, build a 400,000-unit annual capacity engine plant, and manufacture a family of 1.4L-1.6L engines. Each would own 50% of the venture, located in Campo Largo, Brazil. The \$525+ million investment for plant, equipment, research and development, and launch was to be equally shared. Important decisions were to be subject to the review and unanimous approval of a steering committee (**Exhibit 5**). Each side had the right to terminate the venture, if any material dispute could not be resolved. The agreement could be terminated upon one year's notice, but not before June 30, 2006, unless there was a breach of the agreement, deadlock on a key issue, insolvency of either party, or one of the parties became owned (>25% interest) by a competitor.

Staffing the Organization

The Project Manager

Jack Smith joined the project in November 1996. One year earlier, at the age of 33, he had been selected to run Chrysler's van assembly plant in Windsor, Canada, despite his limited experience running large, complex operations. Known as a talented manufacturing manager, Smith had advanced degrees in mechanical engineering (combustion science), materials science, and management. After 11 months at the plant, however, he was told by senior Chrysler executives that they were looking for someone to create a new 1.6L engine, design a plant that would implement COS from the ground up, launch the product, and run the plant. Smith was highly surprised by the offer. It represented a major career change and meant uprooting his family. He had expected to continue as the plant manager for two or three more years. Smith's initial reply was: "I don't know very much about product development from a practical experiential basis. Are you sure I'm the person you want?"

In response to Smith's concern about his inexperience in managing new product development, Francois Castaing and Dennis Pawley promised to provide whatever resources were necessary. Smith recalled them saying: "We'll surround you with some of our best people. Trust us Jack, you'll be able to get this done." On the basis of this promise, he accepted the offer. At an early November

1996 meeting in Germany, Smith met several BMW executives in order for them to decide if they would be comfortable having someone of his age and background leading the project.

Smith was given a mandate to create a business. He was instructed to “take the concept that the vice presidents had agreed to with BMW, fill in the blank spaces, organize the project, and get the business running.” His span of coordination responsibilities was extensive. He was given direct responsibility for all work “from cradle to grave” for the project. The considerable executive support Smith enjoyed provided him the organizational leverage necessary to accomplish tasks in a timely manner, even though he did not outrank the functional managers who would provide many team members to the project. He reported to senior Chrysler executives, including those on the joint venture’s steering committee. His executive sponsor was Francois Castaing. Beyond the broad parameters given him, Smith was not given an explicit charter that established project objectives.

Early Dedicated Staffing

Before Smith was selected to lead the project, David Ludlow began recruiting a small nucleus of product engineering specialists, who had worked with him on the 2.0-liter Neon engine. Some had also participated in the early concept phases of the 1.6-liter project. In early November 1996, this small team of product engineers and designers was working full-time on the project. At the time, Ludlow was uncertain about Smith’s role during the design phases of the project. But he thought it was a great idea to bring some of the plant people on board early, “so they could understand the design process and own it.” This had not been his previous experience at Chrysler.

Ludlow sought to create a cross-functional platform team, with dedicated people from engine engineering, advanced manufacturing engineering, supplier quality, procurement and supply, and finance. His initial request was “rather conservative in terms of numbers” because he thought he would “never get the people he wanted.” Castaing helped provide most of the necessary resources, however. According to Ludlow, “a champion at that level was highly unusual for a development project of this scale.” Ludlow regarded the presence of an executive sponsor as vital. He compared his “dream experience” on this project with prior experiences:

On other projects we would have deployed product engineers who had worked on the 2.0 liter and were available. Advanced manufacturing support would have initially consisted of 3–4 part-time engineers. Over time, it would have ramped up to 10-20 people, but with only five dedicated on a full-time basis. No one from procurement would have been dedicated full-time to the project.

Smith and Ludlow both sought outstanding people inside and outside Chrysler with the requisite skills. They wanted tenacious, talented, and outspoken people, who could tolerate complexity, work in a foreign setting, and still demand support from their functional departments. They also preferred to hire managers who had significant plant manufacturing experience (**Exhibit 6**). Except for his managerial staff and some advanced manufacturing personnel, Smith was not directly involved in most hiring decisions. Some managers joined the project after their engineers were on board. These managers included Ron Stone, Engine Engineering; Tomas Morales, Advanced Manufacturing Program; and Frank Simon, Procurement and Supply. Ernst Schmidt was selected by BMW as Chief Financial Officer.

By June 1997, staffing for the design phases was nearly complete. The project team (**Exhibit 7**) comprised about 120 members (mostly dedicated full time). Despite an emphasis on “choosing experienced talent with a good reputation,” nearly half of the team was new to Chrysler. Tritec was projected to be two-thirds the investment of Chrysler’s recently launched 4.7-liter engine program, but had 16 more advanced manufacturing engineers. On a normalized investment basis, Tritec employed

more than twice the number of manufacturing engineers (54 versus 26). The upfront, dedicated staffing of advanced manufacturing engineers (and future plant staff) was done to ensure that a problematic design would not simply be thrown over the wall—as a Tritec manager explained had happened in the past: “After we found that the design didn’t work very well, we would then get into a panic mode of finding ways to fix it, adding costs, adding manpower, and making the equipment late for delivery to the plant floor. Or maybe we would take the problem to the plant floor because the supplier couldn’t get it fixed in time.”

By having so many fully committed manufacturing engineers on board early, more time was spent reviewing manufacturing processes, plant and machine layout, gauging and tooling. Each full-time advanced manufacturing engineer cost about \$125K per year, however. There was also a shortage of advanced manufacturing employees because of a large number of ongoing power train programs. This led to the hiring of contract engineers. Although many were young and inexperienced, Ludlow observed: “They don’t carry old baggage and consider new ways of doing business.”

Due to the challenge of hiring contract engineers, advanced manufacturing was the last function to become fully staffed. Even then, product engineering was unaccustomed to a strong manufacturing voice so early in the product creation process. One product engineer, while acknowledging the benefits of early manufacturing involvement, nevertheless nostalgically recalled the days when “AME [Advanced Manufacturing Engineering] was not looking over our shoulders.” Another complained, “AME is too strong and demanding.” But Smith believed the manufacturing engineers should have been added to the project about six months earlier “in order to get full alignment, full clarity about strategy, and full orientation of people.”

Aligning the Organization

Leadership

Smith’s perception of what constituted effective leadership generally coincided with the way project team members described him. He believed leaders should be trustworthy, sincere, reliable, predictable, and competent. He believed relationships with his team members should be based on trust with open and sincere communication. Team empowerment came from giving team a clear direction and guidelines on how to achieve its mission. He characterized his managerial style as “open and results-oriented.” Finally, he believed that alignment of the organization’s strategy, structure, systems, and metrics was critical.

Smith was especially concerned with alignment in an organization, where he discovered “many people had tacit knowledge of how to create a product, but there existed no Chrysler development system” *per se*. He was surprised to learn that each Chrysler platform team conducted product development somewhat differently. Tacit knowledge was often lost and not transmitted even within the platform to the next generation when leadership changes occurred. He found himself wondering, “How can I tap into that knowledge and share it with other members of my team?” This led him to discussions with a university mentor in December 1996. The professor recommended that he study state-of-the-art literature on new product development (best practices) and use modest external resources to coach him and his team. Smith also enlisted the services of several Chrysler retirees.

Within the team, there was a range of perspectives on Smith’s efforts to bring in outside experts, as well as his continued efforts to develop better approaches to product development. One manager commented, “He believes everything is broken and needs to be fixed.” Others felt that when he brought in coaches, it represented “a lack of trust for the team to do its job.” Still others believed he

did so, in order to fill in “gaps in his knowledge, because he was on a career fast track.” Many were also initially skeptical about the “value-added” outside specialists could provide.

Smith championed a number of concepts for the team. One was that the engine design should be “simple and proven,” as should the manufacturing process, given the many risks and uncertainties already inherent in the project. He characterized himself as a “strategic problem solver.” According to Smith, “I spend my time on those items where I can help the team lay a foundation and move forward.” He emphasized training his staff on how to resolve conflicts themselves. When his intervention was required, however: “I make sure everyone is heard and we get all the issues on the table. Hopefully, the groups can then resolve the issue themselves. If not, I will then interject some philosophy or some guidelines in order to expedite resolution of the issue.”

Collocation of Team

While assembling the team, Smith and Ludlow decided to collocate all team members in the same suite at the Chrysler Technology Center. They believed this would improve understanding between functional experts, increase cross-functional flows of information, foster team building, facilitate the creation of a shared vision, and expedite decision-making. While such proximity of team members was not uncommon for Chrysler’s vehicle platform teams, it was unusual for the power train projects, whose team members typically conducted most of their work within the geographic confines of their own functional community.

Advanced manufacturing was not collocated with the team, however. Union bargaining unit rules prohibited contract workers from working at a Chrysler facility. Faced with the choice of moving the entire team off-site, or dividing his team, Smith decided to locate all manufacturing engineers at a facility three miles away, which became known as “the AME building.” This was because he was concerned that moving the entire team offsite would isolate it from the rest of the Chrysler organization. One product engineer, however, pointed to the ramifications this had for organizational dynamics: “You lose the coffee pot interaction. During the early design phases, a component design can change four times in a day. But you can’t just drop by someone’s desk when they are a 30-minute commute away. On the other hand, had manufacturing been collocated, the product engineers may have been even more overwhelmed.”

The Contract Book

In late March 1997, Smith spent a day with his university mentor to better understand the strategy and best practices for leading a product development project. Upon his return to Chrysler, Smith assigned Len Ramsey, a management trainee, to begin work on a Tritec contract book. This formal document was designed to specify the measurable objectives of the project, the processes used to achieve them, and to help team members understand (and agree on) the overall strategy and relate it to their daily work activities.

The first draft was about 100 pages. It was presented at the June town hall meeting, where management staff led small breakout groups to facilitate communication, to elicit feedback, and “to foster organizational learning.” The initial reaction from some team members, irrespective of function, was somewhat negative. This was partly related to the initial size of the document. A typical response was “I don’t have time to read this. What relevance does this have for my job?” Some managers did not encourage team members to read it.

The document required several more revisions and critical input from outside experts. The final document was eventually 47 pages long and defined both the program’s goals and how to

accomplish them (**Exhibit 8**). The entire team eventually signed the contract book, which contained the following statement: "The mission of TRITEC Motors, the Chrysler/BMW Joint Venture, is: To develop a family of high quality, strong performing 1.6 L engines, and to build the world's lowest overall cost engine business in the city of Campo Largo, Brazil by July 2000."

Achieving this mission would depend on five critical success factors: 1) high quality, equal to any engine in the world; 2) low overall cost; 3) execution of a world-class product development process; 4) implementation of the Chrysler Operating System at the plant; and 5) continuous learning. The metrics used to define success included certain performance, productivity, investment, quality, and cost targets. Target values used to define world-class performance were calculated by benchmarking other engine plants. High quality depended on achieving three attributes: function, reliability and variability. Function required that the product perform in a manner that met customer needs under all operating conditions. Reliability meant that the product was durable under all anticipated duty cycles. Minimal variation meant that processes were in COS terms, "robust, capable, and in-control," so that all engines functioned as designed and with the design reliability sought. A warranty assessment was used as a principal measure of product and process quality.

By signing the contract book, team members agreed that these project goals would guide all their key decisions. Smith hoped that this would not only encourage individual ownership of project goals, but help the team arrive at more timely decisions and with a clearer understanding of the tradeoffs involved. He regretted that completion of the contract book was so protracted, since it therefore had less impact on some of the early design decisions. Although the contract book also contained a section on senior management involvement, the Chrysler-BMW steering committee was not approached about signing it. Some staff members believed this was a tactical mistake.

Product Assurance Teams and SE Teams

The guidelines in the PAP Manual emphasized the central role performed by cross-functional, Product Assurance Teams (PAT's). Over 30 of these teams at Tritec managed the process for designing, developing, testing, and manufacturing of dozens of components procured externally. Advanced manufacturing was generally not involved in the process. Product assurance teams were generally led by a product engineer and typically included a supplier quality specialist and 2-3 representatives from the supplier. Believing Chrysler already managed its product assurance teams well, Smith did not focus much on these teams in 1997.

Smith instead viewed Simultaneous Engineering (SE) Teams as the critical nexus for product and process integration. Unlike Product Assurance Teams, SE Teams focused on a small number of critical engine parts to be designed, machined and assembled by Tritec. These teams were responsible for the integration of manufacturing process, layout and tooling, and supplier selection (process equipment) with the engine design. SE Teams were the primary vehicle for interaction between advanced manufacturing and product engineering specialists and were structured to ensure that the engine and its critical components were designed for manufacturability, assembly, and serviceability (**Appendix**). He hoped that cross-functional expertise would decrease the number of late design changes in the project. Finally, he wanted "everyone to wear two hats, his functional hat and the team hat. And everyone should see his career as inextricably linked to the project's success."

Seven SE teams were created in May 1997: Connecting Rods, Cylinder Head, Crankshaft, Camshaft, Cylinder Block, Cylinder Head Assembly, and Engine Assembly. The SE teams included product engineers, engine designers, advanced manufacturing engineers (tool, process, and gage), and support functions (when needed) like procurement and finance. External machine and raw material suppliers also participated. Each team was co-led by an advanced manufacturing engineer

and product engineer. Both were in charge. According to Ludlow, the composition of the SE teams was different from his prior experiences:

In the past, because of manpower constraints, there would have been one senior product engineer, one product engineer, one designer, one AME person if we were lucky, probably assigned part-time, and no one representing the plant. You would have had a casting supplier and a machine tool specialist. But it was an engineering-driven SE process. And the product engineers were always the SE team leaders.

Formalized procedures were created by Tritec managers for running and managing the SE teams. It was believed that those used by Chrysler's platform teams were inadequate. SE teams met weekly or biweekly. Attendance was mandatory. According to one staff member, "Attendance was not always required at other Chrysler projects." SE teams were also made responsible for tracking quality, cost, timing, and weight for their components in a SE team notebook. One purpose of the archival notebook was "to avoid second-guessing by the downstream team in Brazil of upstream design issues and changes." The notebook indicated what was decided and why. Each SE team also held progress review meetings regularly with Smith and his core staff at SE steering committee meetings. These meetings provided a forum to address outstanding issues and ensured that each team had a clear understanding of its objectives, the tools and methods used to achieve the objectives, and timeline and deliverables. SE team co-leaders were also regularly trained for their roles by Ludlow, Stone, Morales, and a Chrysler retiree.

While the SE Teams were designed so that the product engineers and advanced manufacturing engineers did not operate solely within their own functional perspectives, both groups found it difficult at times to communicate and resolve differences. Advanced manufacturing engineers wanted a manufacturable design and were concerned with issues like engine reliability, manufacturing defects, scrap, and production assembly flow. Product engineers also had strong functional objectives. They were concerned with meeting demanding performance targets, such as torque, horsepower, and fuel economy. They often thought in terms of geometric dimensions, tolerances, and confidence levels expressed numerically. They believed their "exact science" utilized a methodical, systematic approach to problem solving, whereas manufacturing people were accustomed to a "fire fighting" or "just-fix-it" approach at the plant floor. One product engineer complained: "AME overburdens us with endless questions. Does the design have enough socket clearance? Can an assembly operator see the O-ring? Are you certain we can assemble the part within the takt time?" He added, "We are making too many concessions. We can't allow functionality to be sacrificed." Corporate organizational development specialists were enlisted to teach conflict resolution techniques to the SE teams, beginning in June 1997.

Team Meetings and Interactions

Smith spent significant time preparing for and holding meetings. He did so because of the importance he attached "to alignment of the organization, getting the strategy right and looking ahead for the needs of the project team." Smith initially held a weekly staff meeting typically lasting about 1½ hours. Later, there were two weekly staff meetings, one focused on engine design and another on factory-related issues. One purpose for these meetings was to encourage cross-functional ownership of issues. According to one staff member: "These meetings were different. Open communication about problems was encouraged and cross-functional input was solicited."

The entire Tritec team also participated monthly in town hall meetings. Their purpose was to inform the entire organization of the project's status, near term goals and provide a forum to facilitate working-level feedback and "strike fear out of the organization." Some meetings lasted 4-6 hours.

About 20 training workshops were also held on various topics, including several on how the Chrysler Operating System would influence the project.

Many project members were perplexed by the need for so many meetings. According to Smith, "Staff members frequently could not understand why I was so worried about alignment." Some team members complained about the frequency and length of the meetings. "Some of the engineers get a little frustrated with the workshops and half-day meetings," noted one manager, "They would rather be working than sitting in meetings."

Smith himself had little time to familiarize himself with some of the disciplinary skills and the language of the product engineering community. He regretted that his work aligning the team did not allow more interaction with working-level team members. When he was the Windsor plant manager, he spent much more time walking the shop floor. At Tritec, he relied on key staff members like Ludlow and Stone to serve as translators. It was easier to stay involved in the manufacturing community, since he "understood their issues" and would "ultimately go to Brazil and run the business." In order to remain accessible to all his team, however, he maintained an open door policy.

Coordination with Senior Executives

Smith also met with the joint venture steering committee on a quarterly basis. Executive project sponsors from Chrysler and Rover/BMW typically attended the meetings (**Exhibit 5**). In addition to a program review meeting about every two months with Ewasyshyn, he also had private meetings periodically with Castaing and Pawley.

Assessment Measures

Several tools were used to assess progress toward achieving the project's mission and goals. One tool was a "12 panel chart" that summarized the key program objectives and tracked their status (**Exhibit 9**). The Chrysler specifications came from detailed analyses of anticipated customer needs and were also based on past performance data from the Neon. Some financial goals were stretch targets. The Rover engine objectives were based on extensive marketing analyses of what it would take to turn the new Mini into a "cult car" image of the old Mini. The JV Steering Committee subsequently approved the targets. A second tool used were "spider charts," which provided a comparison of major program objectives and their process and product benchmarks. The Tritec joint venture sought to become the best-in-class engine benchmark for torque, power, quality, and cost. To accomplish this, AME staff members took four weeklong trips to study the world's best engine producers. A trip to Toyota resulted in ideas on how to reduce the engine block line from 26 to 5 workers per shift. A third tool used was "integrated program timing charts" (**Exhibit 10**). The timing chart identified key program milestones and specified "who was to do what and when." It also identified key project handoffs. A Work Plan, 8-10 pages in length, provided supporting detail for this chart.

While the 12 panel, spider, and integrated program timing charts focused primarily on measuring progress toward meeting project goals and timing issues, a one-page "program dashboard" was designed to provide a "real-time" visualization of the status of key activities, tasks, and processes (**Exhibit 11**). The dashboard focused attention on what issues required urgent attention. A dashboard review eventually became a centerpiece of Smith's weekly staff meetings.

Engine Block Sealing Dilemma

The initial cylinder block design, drawn up by a small group of product engineers in late 1996, incorporated a design concept called a “deep skirt, lower tie bar” with five separate main bearing caps. While several auto companies manufactured chain-drive engines using an upper tie bar, no mass-produced engine used a lower tie bar to seal the lower part of the engine. Deep skirt designs were common on Chrysler’s four cylinder engines, but occasionally had oil leaks beyond 24-36 months of intense usage. Chrysler’s 2.0 and 2.4-liter engines used a bedplate design.

The product engineers selected a lower tie bar design because of lower anticipated warranty costs, which were based on three-year projections. Oil leaks were especially a major concern of the power train engineering organization. Warranty issues were also important to BMW. The product engineers believed this design would be more reliable. It was also believed to require a much lower fixed investment in manufacturing equipment and have lower variable costs. Over 20 engine prototypes were eventually produced using the lower tie bar.

The earliest discussions between AME and the product engineers on the tie bar design took place in late May 1997. Mark Fielder, a senior advanced manufacturing engineer, informed Carl Sands and other product engineers on the Cylinder Block SE Team (**Exhibit 12**) that the lower tie bar design would be problematic for high volume production. In a July 15 memo, the manufacturing engineers detailed their concerns. Fielder worried that a lower tie bar would necessitate reinventing part of the machining process. He argued that such manufacturing complexity would make it impossible to achieve certain tolerances. The lower tie bar required the machining of several surfaces deep down in the block to very accurate tolerances within a 30-35 second cycle time:

You would machine the crankshaft main bearing half round, each side of the bearing cap walls (bulkhead), and the lock notches that locate the main bearings. These steps would be done with an arbor tool, a long spindle tool with multiple cutters, that simultaneously would cut the sides and the lock notches, and bore the half-round. While doing this, however, the tie bar would obstruct the milling operation, because milling that flat would require a big spindle, at least 100 millimeters long.

Fielder further argued that this machining challenge would strongly impact productivity. While machining the tie bar with multiple stations and tools was a possible solution, it would reduce the number of engine blocks per hour and also require a larger fixed investment. A second major concern was quality assurance. The design was argued to be “not robust” in terms of consistency of machining. A product or process was not robust if it did not work well despite some inevitable variation. The manufacturing engineers believed that as much as 25 percent of all the cylinder blocks would need to be scrapped. A third major concern was “chatter,” which was a surface condition resulting from the vibration of the metal during the cutting operation that created an unacceptable surface finish. All the prototype parts, which had been machined, had exhibited chatter. A rough surface finish would impact on the sealing capability of the gaskets, making oil leaks more likely. Finally, tool life was a concern. Given these challenges, Fielder demanded a design change. He was also concerned, however, about making major design changes after a machine tool supplier was selected the following month: “Chrysler might get its pocketbook picked by the supplier if we make major changes after we have contracted for the machines.”

The product engineers responded one week later to the memo by reiterating why they had designed the lower tie bar. According to one product engineer, “The primary issue was we had a innovative design that we felt would work well. We believed that manufacturing should figure out a way to make it.” An advanced manufacturing manager responded: “The product engineers are used to being gurus and kings. But on this project they don’t rule.”

The debate between the manufacturing and product engineers soon escalated beyond the Tritec team. At an August 27 program review meeting, Ewasyshyn raised the issue with Smith. He expressed concern that the tie-bar design might impede quality and productivity targets and suggested a more detailed analysis be made to ensure the tie bar was manufacturable. Following the meeting, Smith directed the Block SE Team to come with several design alternatives.

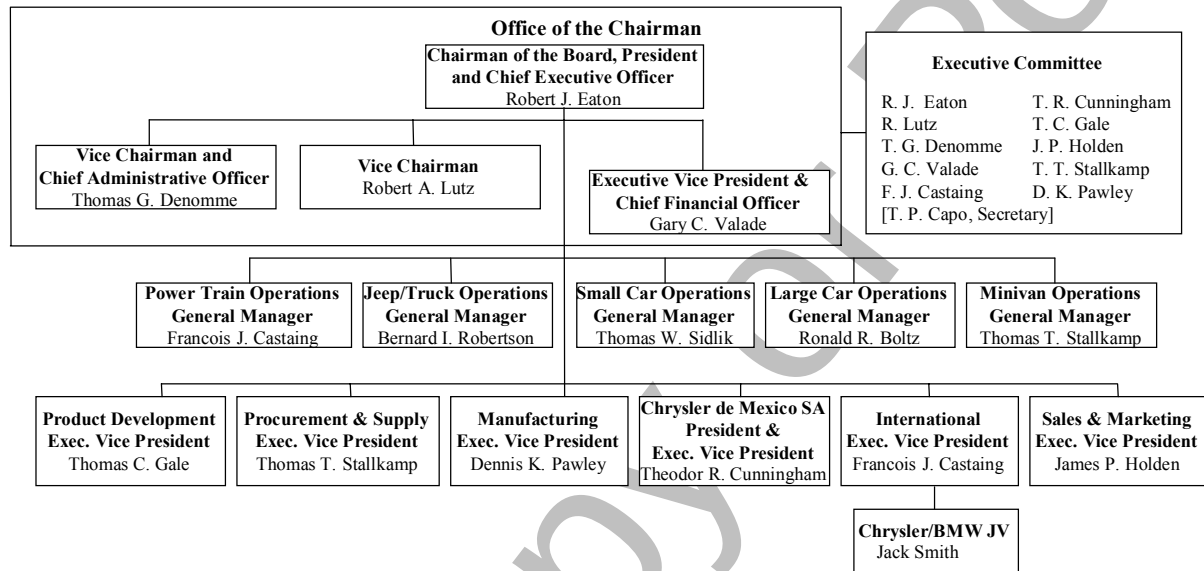
The product engineers submitted two basic alternatives to the lower tie-bar design: a rear retainer style joint that used four T-joints and a bedplate design. Some advanced manufacturing engineers favored a rear retainer style design, arguing this design had the fewest machining challenges and would be cheaper to manufacture. The product engineers, however, believed this design was highly risky, because of the high potential for engine leaks and Chrysler's inexperience with this design.

A bedplate design had several pros and cons. One advantage was that the plant could use conventional machine tools. Furthermore, a bedplate was a proven design used on the 2.0-liter engine. Finally, there were product benefits, including noise vibration harshness (NVH) and a more rigid structure that would allow Tritec to manufacture a high performance derivative engine. One shortcoming was that it would require two more metal cutting machines and complicate the assembly line. Three lines would be required instead of one: one line to machine the cylinder block, another to machine the bedplate, and another line to complete the machining of the combined bedplate and cylinder block. A second disadvantage was related to overall project timing. The team would need to redesign the lower end of the engine block in a very compressed, four-month timeframe to meet the January 5 "OK to tool milestone." Choosing a new design this late in the development process could delay the project by two-three months, create a lot of overtime, or necessitate a transfer of resources from elsewhere in the project. A third drawback was that simultaneous engineering with the supplier would be shortened by about one month, in order to meet pilot/launch schedules. A fourth concern was that the bedplate would require a much larger fixed investment. The cost of the additional block machines, assembly stations, and factory floor space was estimated to be \$10 million. This would possibly leave only \$5 million in reserve for any other product and process changes.

The SE Cylinder Block Team studied the various risks and tradeoffs associated with each alternative. It conducted a preliminary cost, investment, and weight analysis (**Exhibit 13**), as well as warranty impact estimates (**Exhibit 14**). The product engineers conducted a Design Failure Mode and Effects Analysis (**Appendix, Exhibit 15**). The advanced manufacturing engineers conducted a Process Failure Mode and Effects Analysis (**Appendix, Exhibit 16**). A summary chart reviewing the impact on timing, design and manufacturing workload, assembly, and service was also created (**Exhibit 17**). Finally, a worksheet on the anticipated impact on the project's 12-panel goals was made (**Exhibit 18**). A SE Cylinder Block Team review meeting examined the alternatives, but could not reach a decision.

Time to Decide

As Smith considered the cylinder block design impasse, he wondered, "What decision-making process should I use to resolve the issue?" Program timing requirements made it difficult to postpone a decision. One option was to make the decision himself, and present it to his organization as a *fait accompli*. A second was to call a meeting of his senior managers and reach a consensus. A final option was to call a general meeting, which included the Cylinder Block SE Team, his senior managers, and any other interested members of the Tritec team.

Exhibit 1 Chrysler Organization Chart (September 1997)

Revised December 22, 2003.

Exhibit 2 Chrysler's Revenues, Market Share, Pretax Earnings

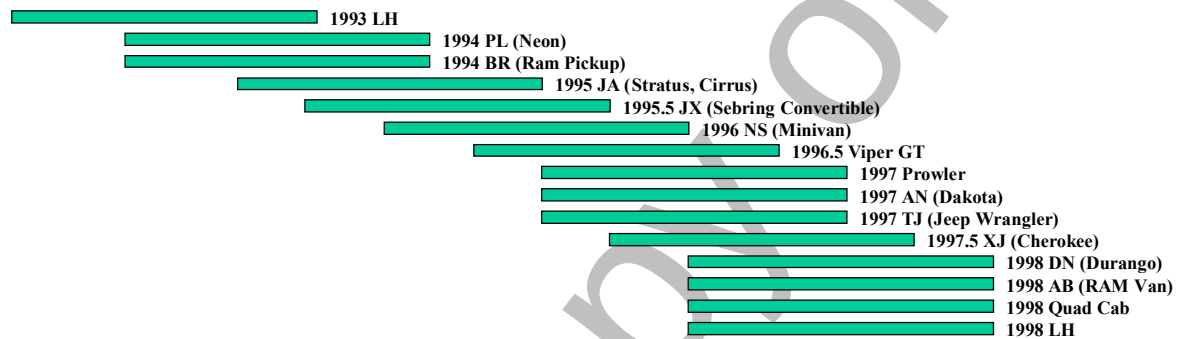
Year	Retail Market Share (North America Cars & Trucks)	Revenues (billions)	Pretax Earnings (millions)
1992	13.4%	\$36.9	\$ 34
1993	14.0	43.6	3,838
1994	14.7	52.2	5,830
1995	14.7	53.2	3,449
1996	16.1	61.4	6,092

Exhibit 3 Chrysler New Product Launches (based on PAP manual)

Improvements in Product Development Leadtimes: Months from Project Approval to Program Launch

1993 Intrepid/Concorde/Vision (LH)	39 months
1995 Stratus/Cirrus/Breeze (JA)	35 months
1996 Minivan (NS)	32 months
1997 Dakota (AN)	30 months

Major Vehicle Projects at Chrysler: Actual and Proposed Launches (Model Year 1993-98)

**Exhibit 4** Product Assurance Planning Milestones (based on PAP manual)

Major Milestones:	Concept Approval	Program Approval	Program Vehicle (F1 Build)	Pilot PO Build	Launch (V1 Build)
Product Assurance Plan Phase:	Concept	Approval	Program Vehicle	Pilot	Launch
Concept Approval					
Management authorization to continue development activities and develop a plan for Program Approval.					
Milestone is defined as of the date of the Senior Management Meeting					
Program Approval					
A commitment by the platform or project team to complete the product program and all activities to the approved plan, and a commitment by senior management to provide the identified resources.					
Milestone is defined as the date of the Senior Management Meeting.					
Program Vehicle (F1 Build)					
Verification that the product design and manufacturing process intent for components, systems and vehicles meets objectives, and that the program is on time with limited risk.					
Milestone is defined as the start of F1 Build.					
Pilot (PO Build)					
Verification that the components, systems and vehicles meet objectives, and that the program is on time with limited risk.					
Milestone is defined as the start of first Pilot (PO) Build. (PO Pilot Vehicles are complete running vehicles built to plant scroll with parts provided from hard tooling. Used to verify manufacturability.)					
Launch (V1 Build)					
Manufacture of production products to program goals at planned volumes, and management approval for distribution and sale.					
Milestone is defined as the start of V1 Build (1st volume production vehicle).					

Exhibit 5 BMW/Chrysler Joint Venture Steering Committee Members (September 1997)

Francois Castaing, EVP, International Operations, and GM, Power Train Operations, Chrysler
Thomas C. Gale, EVP, Product Development, Chrysler
Tom Stallkamp, EVP, Procurement and Supply, and GM Minivan Operations, Chrysler
Volker Doppelfeld, Finance Director, BMW
Walter Hasselkus, Rover CEO and BMW Board member
Dr. Wolfgang Reitzle, BMW Board member

Exhibit 6 Profiles of Tritec Managerial Staff (Names Disguised)

David Ludlow, JV Platform Executive. 25+ years experience in power train engineering at Chrysler. Managed engineering departments (e.g., Small Car Platform Engine Engineering and Lead Engine Engineering.) Involved in many new engine launches. Various responsible engineering positions in Engine Design, Engine Development, Engine Performance, and Fuel Systems. Experience with international programs, engine plants, and suppliers. B.S., Mech. Engineering, Lawrence Technological University. M.S., Mech. Eng. and Business Management, University of Michigan.

Ernst Schmidt, JV Chief Financial Officer. Educated in Germany at a Gymnasium for Math and Science. Served in the German Army. As an undergraduate, studied Business Management, Law and Information Systems. Received a MBA in Business Management and Law, and a pre-degree in Information Systems. Joined BMW in 1984. Manager trainee for 18 months. Worked on an international project (financing). Next was Sales Manager in Financing. Subsequently held many international executive level positions.

Tomas Morales, 18 years of manufacturing experience (processing and launching new engines and transmission programs). Spent 4 years at Chrysler Kokomo plant and Chrysler Technology Center, and 14 years in Chrysler's Mexico power train plants. Has Industrial Engineering Degree.

Juan Luis Angeles, Tool and Process Manager. 20 yrs. experience in manufacturing engineering. 27 years of supervisory and managerial experience. Spent 18 years at the Saltillo, Mexico engine plant in various departments (Maintenance, Facilities, Manufacturing, Operations, and Engineering.) Formerly a College Professor. B.S., Electrical Engineering, Master's degree in Business Administration.

Ron Stone, Engine Engineering Manager. B.S., Mechanical Engineering, Wayne State University; M.S. Mech. Engineering, University of Michigan (Dearborn). 26 yrs. of experience in automotive design, development, and manufacturing (22 yrs. at Chrysler). 13 yrs. in supervisory positions, all in the engine area. Holds 3 engine-related patents. Formerly engineering manager at Mound Road Engine Plant.

Frank Simon, Procurement and Supply Manager. B.A. Materials & Logistics Management, Michigan State University. M.B.A., Wayne State University. Worked for 12 years at AMC/Chrysler in various P&S areas (logistics, production control, specs & releasing, launch coordination, purchasing).

Dan Henry, Quality Manager. 29 yrs. experience in manufacturing (mostly in quality area). Spent 18 years at Trenton Engine Plant. Last assignment: Operations Manager for three years. B.S., Management.

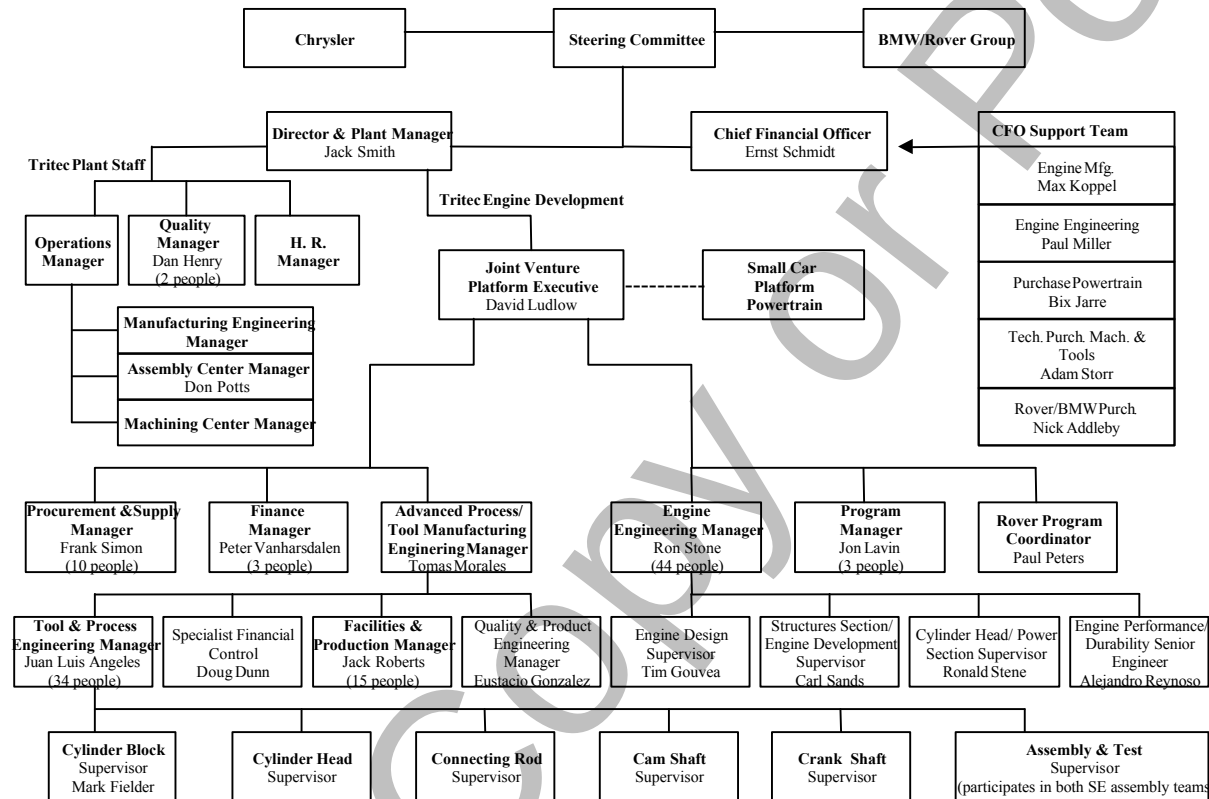
Peter Vanharsdalen, Finance Manager. Joined Chrysler in 1987 as a finance trainee. Since has held a series of increasingly responsible positions in the finance organization. Prior to joining Chrysler, he worked for Ford and General Motors in engineering and manufacturing. B.S., Mech. Engineering, University of Waterloo; MBA, University of Windsor.

Don Potts, Assembly Center Manager. Studied Mechanical Engineering at Ohio State. B.S., Cleveland State. M.S., Central Michigan. Worked at Chrysler for 15 years. Formerly worked with the COS group. Worked at General Motors for 13 years and Volkswagen for 3 years.

Jon Lavin, Program Manager. Joined Chrysler in 1987. Worked at Trenton Engine Plant, starting as a First Line Supervisor in Connecting Rod Machining and worked his way through positions of increasing responsibility in Product and Quality Engineering during three major new engine launches. In January 1995, became Supervisor of Resident Engineering at Trenton Engine Plant. Joined Tritec in May 1997. B.S. in Mechanical Engineering, Michigan State University. M.S., Mech. Engineering, University of Michigan.

Jack Roberts, Facilities and Assembly Manager, Advanced Manufacturing Engineering. B.S., Engineering, Lawrence Technical University. Prior to joining Chrysler in 1997, he worked in 3 industries. Spent 8 years in automation equipment; 4 years in electrical assemblies/power supplies; and more than 10 years in power train components. Various job assignments, but all positions were related to plant engineering, purchasing and production control. Significant interaction with international sources for most of these positions.

Exhibit 7 Tritec Staff Organization (Names Disguised)



Part of the advanced manufacturing organization under Juan Luis Angeles is shown to illustrate how it participates in the seven SE teams.

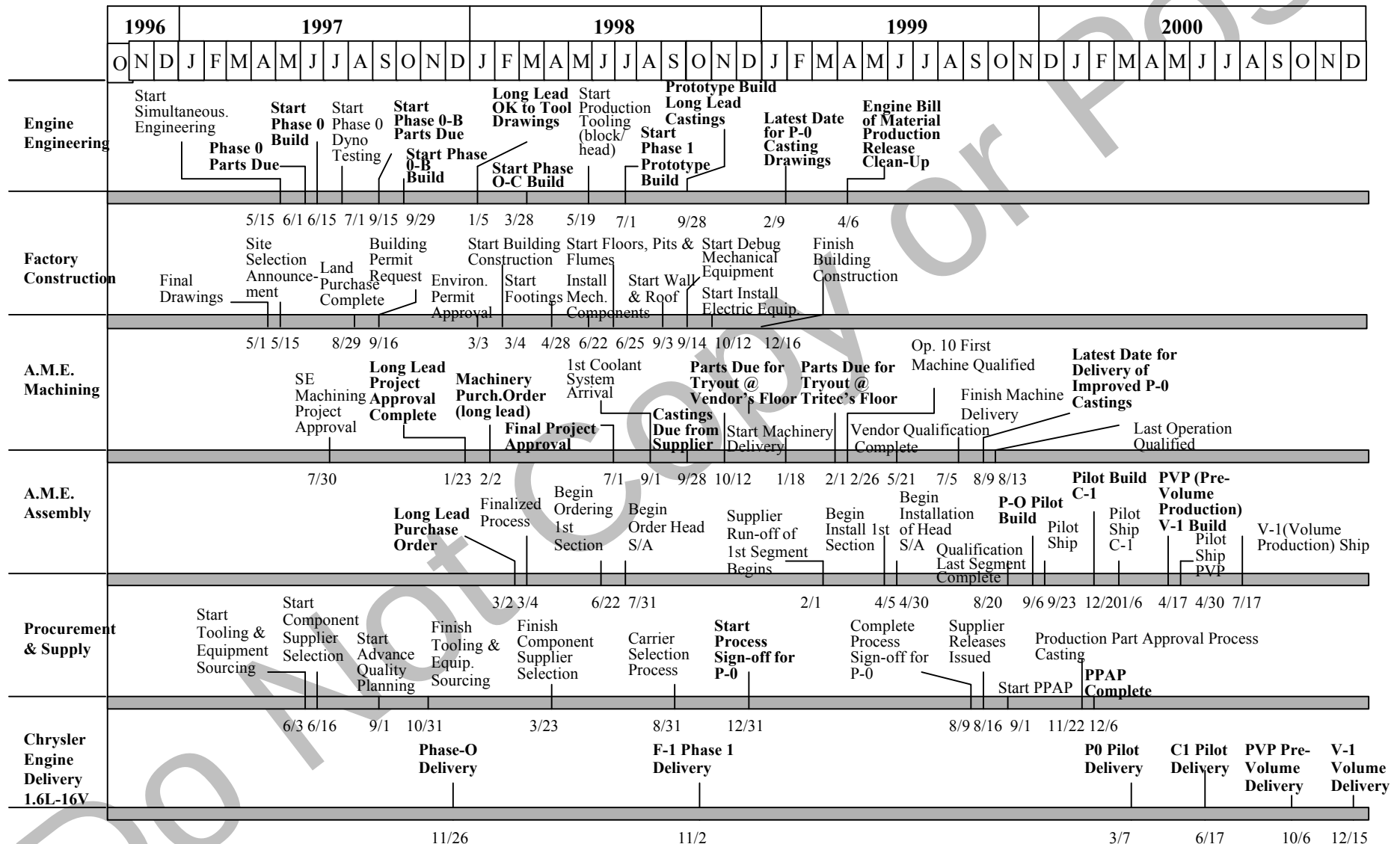
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Exhibit 9 Tritec 12-Panel Program Objectives 14 August 1997 (Data Disguised)

ENGINE PERFORMANCE							FUEL ECONOMY				
1.6L-16V		Chrysler Contract		Rover Contract			Chrysler and Rover				
		Target	Status	Target	Status	1.6L-16V		1.6L-8V			
6VMax Power (Hp@RPM)		105@5600	N/A	114@6000	109@5500	Fuel Economy					
(Kw@RPM)		78@5600	N/A	85@6000	81@5500	gm/lbm/Hp-hr (gm/Kw-hr)					
Max Torque (lb.- ft.@RPM)		109@2800	N/A	110@4500	110@4500	Target		Status	Target	Status	
1.6L-8V (Rover Only)						1600 RPM/35 psi (2.4 bar)		.561 (341)	.590 (359)	.582 (354)	N/A
Max Power (Hp@RPM)		N/A	N/A	90@5500	N/A	2000 RPM/29 psi (2.0 bar)		.625 (380)	.640 (389)	.653 (397)	N/A
(Kw@RPM)		N/A	N/A	67@5500	N/A	3200 RPM/97 psi (6.7 bar)		.444 (270)	.420 (255)	.473 (288)	N/A
Max Torque (lb.-ft.@RPM)		N/A	N/A	101@4000	N/A						
EMISSIONS							NOISE LEVEL				
Chrysler & Rover Emissions		1.6L-16V		1.6L-16V			Per SAE J1074				
gr/Hp-hr (gr/Kw-hr)		Target	Status	Target	Status	Measured in decibels @					
1600 RPM/35psi (2.4bar)						Chrysler and Rover		1.6L-16V & 1.6L 8V			
Hydrocarbons (BSHC)		3.5 (4.7)	2.9 (3.9)	3.5	N/A	Wide Open Throttle		No Load			
Nitrogen Oxides		10.4 (14.0)	10.0 (14.0)	10.4	N/A	Target		Status	Target	Status	
2000 RPM/29psi (2.0 bar)						1000		N/A	67	N/A	
Hydrocarbons		3.5 (4.7)	2.9 (3.9)	3.5	N/A	2000		N/A	75	N/A	
Nitrogen Oxides		10.4	8.5 (11.3)	10.4 (14.0)	N/A	3000		N/A	79	N/A	
3200 RPM/97psi (6.7 bar)						6000		N/A	94	N/A	
Hydrocarbons		2.2	2.15	2.2	N/A	OIL CONSUMPTION					
Hydrocarbons		15.0 (20.0)	13.0 (17.3)	15.0 (20.0)	N/A	Chrysler and Rover 1.6L-16V & 1.6L-8V					
Nitrogen Oxides						1400cc Max for 72 hours of Chrysler END 16 schedule (oil economy test).					
						Start test after engine run-in per schedule SRN 16.					
VOLUME							WEIGHT				
Model Year		2000	2001	2002	2003	2004	Chrysler and Rover (Base Engine)				
Chrysler		0	63	98	98	98	1.6L-16V		1.6L-8V		
Rover		0	72	113	151	180	Target		Status	Target	Status
Total		0	135	211	249	254	240.34		253	234.85	(N/A)
Dec. '96 Projection		0	137	267	325	375	(109.02)		(115)	(106.53)	
TIMING							QUALITY				
		Rover		Chrysler			Chrysler and Rover 1.6L-16V & 1.6L-8V				
		1.6L-16V	1.6L-8V	1.6L-16V			C's (conditions)/1000				
Phase O Delivery		08/15/97	12/15/97	11/26/97			Launch		2002Model Yr.		
Phase I(f-1) Delivery		08/15/98	11/11/98	11/02/98			12K miles/12 months		2003 Model Yr.		
P-0 Pilot Tritec		09/07/99	11/01/98	01/07/00			14K miles		10		
Car Assembly		10/07/99	12/07/99	03/07/00			24K miles/24 months		18		
C-1 Pilot Tritec		01/06/00	02/10/00	04/23/00			28K miles		22		
Car Assembly		02/17/00	04/06/00	06/17/00			PPM@ vehicle plant		2000		
PVP Tritec		04/30/00	06/15/00	08/12/00					800		
Car Assembly		06/11/00	07/30/00	10/06/00					600		
V-1 Production Tritec		07/17/00	08/21/00	10/21/00			Chrysler audit/BMW QZ TBD				
Car Assembly		08/28/00	10/15/00	12/15/00			targets & correlation D&R,				
							R90 C90 testing per contract (reliability 90%, confidence 90%).				
INVESTMENT							IDLE QUALITY				
\$ (Millions @ 1996 economics)		Target	Status	Risk			Chrysler and Rover				
NOTE: 250K/yr. Capacity		@constant					1.6L-16V & 1.6L-8		Target	Status (Chrysler)	Status (Rover)
Mfg. Building		\$78	\$58.4				Idle Stability C.O.V.		<12%	6%	12%
Mfg. Equip./Plant tooling		250.9	222.6				(Coefficient of Variance				
Supplier tooling		30.5	31	9			of Gross Indicated Mean				
Material handling/support		15	4	20			Effective Pressure %)				
Change Provision		15	15				750 RPM Dyno Disconnected SAE Conditions				
Cost of Launch		45	45	10							
Program Reduction (13 Jun 97)		(20)									
Total		\$414.4	\$376.0	\$58							
Product Engineering R&D		40	40								
Manuf. Engineering R&D & Other		38	38								
Total		\$492.4	\$454.1	\$58							
Total Program (current status + risk)			\$512.1								
COST											
NOTES: Costs shown are @ 400K per yr..											
Base engine content differs on Chrysler											
and Rover versions.											
Variable Cost		Chrysler		Rover							
		1.6L-16V	1.6L-8V	1.6L-16V	1.6L-8V						
		Target	Status	Target	Status						
Material		\$744	\$755	\$680	\$733	Target		\$688			
Labor and Burden		118	118	118	114	Status		N/A			
In Bound Transportation		23	23	23	23	Target		N/A			
Total Variable Cost		\$885	\$896	\$821	\$870	Status		N/A			
Boxing & freight on imported components*		21	21	21	21	Target		N/A			
Total cost		\$906	\$917	\$842	\$891	Status		N/A			
Fixed Cost											
Salary fringe		\$45	\$45	\$45	\$45	Target		N/A			
Other Manufacturing Expenses		4	4	4	4	Status		N/A			
Fixed Burden		24	24	24	24	Target		N/A			
Mfg. Engineering R&D		30	30	30	30	Status		N/A			
Total fixed cost		\$103	\$103	\$103	\$103	Target		N/A			
Total engine cost		\$1,009	\$1020	\$945	\$994	Status		N/A			

Exhibit 10 1.6L Engine Program Timing Chart (details for 1 of 3 engine launches) (Data Disguised)



Bold indicates critical path items

Exhibit 11 Program Dashboard (Data Disguised)

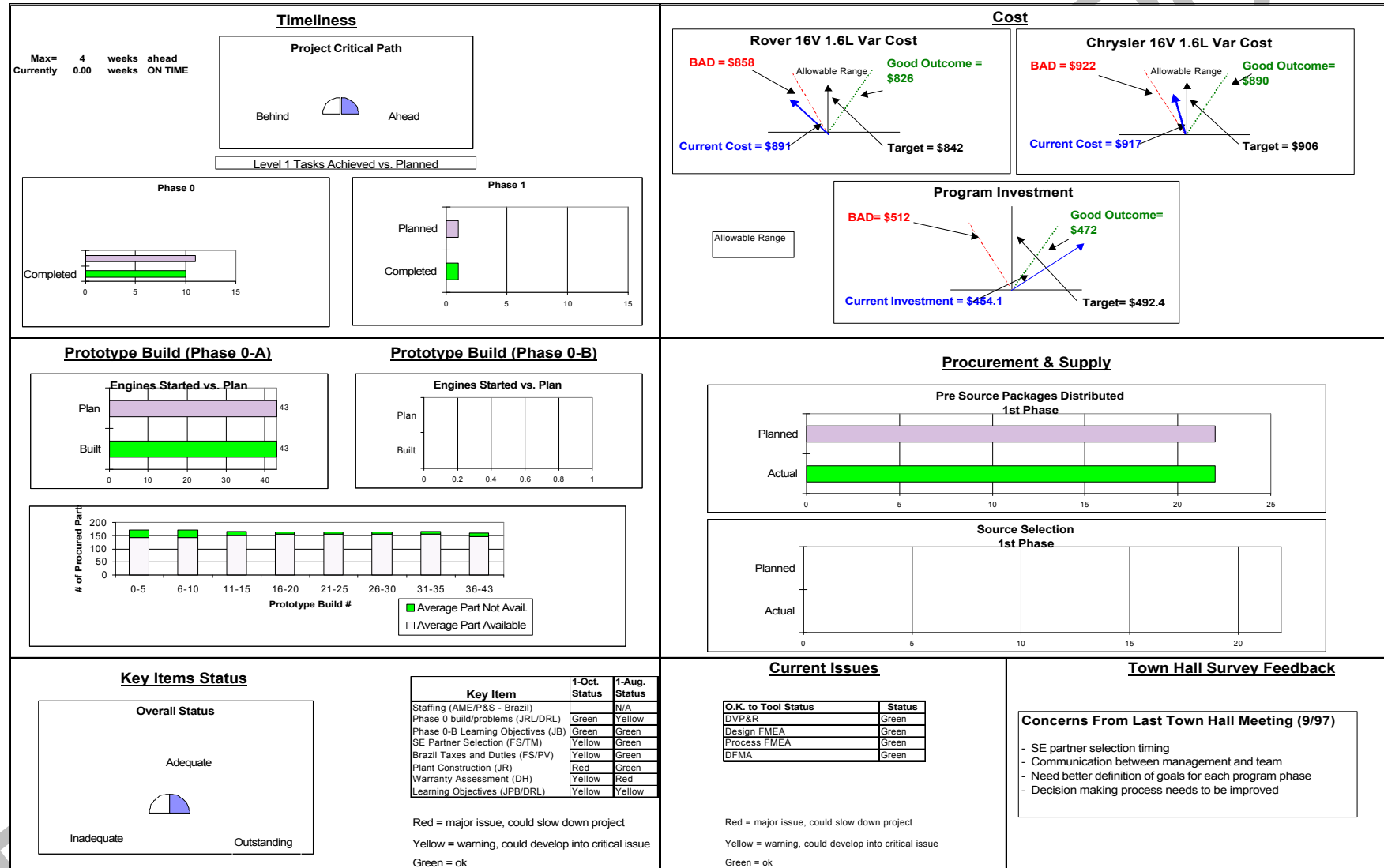


Exhibit 12 Members of the Block S.E. Team (summer 1997) (Names Disguised)

Luke Landeau: Lead Engineer/Engine Engineering, SE Co-Leader (Engine Engineering)
 Carl Sands, Senior Engineer, Engine Engineering (Engine Engineering)
 Jeff Koerner, Engineering Technical Specialist (Engine Engineering)
 Larry Carmen, Casting Specialist (Engine Engineering)
 Fred LaBataglia, Cylinder Block Plant Engineer, SE Co-Leader (AME)
 Mark Fielder, Cylinder Block Supervisor (AME)
 Rich Wang, Tool and Process Engineer (AME)
 Stanley Zhang, Tool and Process Engineer, Facilitator (AME)
 Kevin Payson, Cylinder Block Specialist (AME)
 Eric Lowery, Block Line Plant Engineer (AME)
 Steve Moore, Block & Head Controls Engineer (AME)
 Gene Cleary, Finance Support (Finance)
 Supplier representatives from Comau (machine tool builder), and Teksid (raw castings supplier)

Exhibit 13 Cost and Weight Comparison of Design Alternatives (Data Disguised)

	Bed Plate	Cast-in Tie Bar	Rear Retainer Style
Variable Cost (unit)			
Total Material	\$59.70	\$59.02	\$59.52
Total labor and variable burden	\$121.40	\$118.04	\$118.04
Total material and labor	\$181.10	\$177.06	\$177.56
Investment (000)			
Manufacturing T&F	\$57,900	\$57,900	\$57,900
Bedplate machining	8,000	--	--
Block machining	19,800	19,800	19,800
Supplier Tooling	TBD	307	307
Total	\$85,700+TBD	\$78,007	\$78,007
Weight (total lbs.)	95.3lbs.	90.8lbs.	90.5lbs.

Exhibit 14 Engine Engineering Warranty Assessment: Estimated Conditions (C's) Per Thousand (Data Disguised)

	Best Case	Most Likely	Worst Case
Cast-in Tie Bar			
Oil Pan Group	4.0	4.5	12.0
Crank Group	1.0	2.1	6.0
Total C/1000	5.0	6.6	18.0
Bed Plate			
Oil Pan Group	3.6	4.1	5.0
Crank Group	0.9	1.4	4.0
Total C/1000	4.5	5.5	9.0
Rear Retainer Style			
Oil Pan Group	5.5	6.2	30.0
Crank Group	1.0	2.1	6.0
Total C/1000	6.5	8.3	36.0

Exhibit 15 Engine Engineering Sealing Design FMEA Summary Sheet (Data Disguised)

Potential Failure Mode	Potential Cause(s) or Mechanisms of Failure	(RPN) ^a
Cast-in Tie Bar		
(1) Insufficient Compression on the Oil Pan Gasket	Torque loss on fasteners or incorrect re-install torque during service.	120
(2) Tensile fracture of the oil pan gasket at the T-joint (cylinder block, rear seal retainer, oil pan interface)	Thermal expansion of the mating components due to dissimilar materials creating movement.	144
(3) Abrasion of the oil pan gasket at the T-joint (above)	Thermal expansion of the mating components due to dissimilar materials creating movement.	144
(4) Fatigue fracture of the oil pan gasket at the T joint (above)	High vertical or horizontal dynamic loading at the T joint due to engine strut mount, crankshaft runout, accessory drive or engine vibration	120
	Thermal expansion of the mating components due to dissimilar materials creating movement	144
(5) Insufficient compression on the oil pan gasket at the T joint (above)	Dimensional stack of the rear seal retainer to cylinder block creates a transition in the sealing surface flanges.	144
	Thermal expansion of the mating components due to dissimilar materials creating movement	144
Bedplate Design (shares same failure mode, cause, and RPN as #1 of Cast-in Tie Bar)		
(2) Fatigue fracture of the anaerobic material at the interface between cylinder block & bedplate	High vertical or horizontal dynamic loading at the T joint due to engine strut mount, crankshaft runout, accessory drive or engine vibration.	144
(3) Insufficient surface contact between cylinder block/bedplate bore and rear crank seal	Rear crankshaft seal misalignment in bore	180
Rear Retainer Style (shares same failure modes, causes, and RPN's as #1-#5 of Cast-in Tie Bar)		
(6) Tensile fracture of the oil pan gasket at the T joint (cylinder block, front cover, and oil pan interface)	Thermal expansion of the mating components due to dissimilar materials creating movement.	180
(7) Abrasion of the oil pan gasket at the T joint (above)	Thermal expansion of the mating components due to dissimilar materials creating movement.	180
(8) Fatigue fracture of the oil pan gasket at the T joint (above)	High vertical or horizontal dynamic loading at the T joint due to engine strut mount, crankshaft runout, and accessory drive or engine vibration.	150
	Thermal expansion of the mating components due to dissimilar materials creating movement.	180
(9) Insufficient compression on the oil pan gasket at the T joint (above)	Dimensional stack of the front cover to cylinder block creates a transition in the sealing surface flanges.	144
	Thermal expansion of the mating components due to dissimilar materials creating movement.	144

^aRPN: Risk Priority Number. See **appendix** for how this value is calculated.

Exhibit 16 Advanced Manufacturing Engineering Process FMEA Summary Sheet (Data Disguised)

	Machining Operation Features	Cast-in Tie Bar		Bedplate		Rear Retainer Style	
			RPN		RPN		RPN
1	Milling Main Bearing Cap Seats	Spindle bearings compromised in order to avoid interference with tie bar	210	No problems—block & bedplate can be processed using proven methods. No tie bar interference during drilling	30	Ideal-block can be processed using proven methods. No tie bar interference during mill pass	30
2	Drilling the #1 Oil Feed	Drill needs to be longer in order to clear tie bar. Deflection and tool breakage results. Bushing plate designs not clean.	147	(same as above)	42	(same as above)	42
3	Milling Bulkheads	Questionable arbor milling results. Possible deflection of tool	210	No problems—block & bedplate can be processed using proven methods. No tie bar interference during milling	120	(same as above)	30
4	Ball Milling Half Rounds	Unacceptable tool life; plant capacity constrained by excessive tool changes	280		N/A	Would use proven arbor milling techniques	0
5	Arbor Boring Half Rounds	Arbor mill deflection possible, resulting in unacceptable parts	175	No problems-block & bedplate can be processed using proven methods. No tie bar interference during mill pass.	70	Ideal-block can be processed using proven methods. No tie bar interference during mill pass	70
6	Rough & Finish Milling of the Oil Pan Face	At production feeds & speeds, tie bar unable to withstand predicted machining forces without excessive breakage or surface defects (chatter)	280	No problems-block & bedplate can be cast using proven methods. Tie bar on bedplate can be strengthened to an acceptable level	90	Ideal-sealing surface would be integral to either oil pan or front cover	25
7	Rough & Finish Milling of the Front Face.	(Same as above)	280	(same as above)	90	Ideal-sealing surface would be integral to either oil pan or front cover	25
8	Arbor Milling Lock Notches	Arbor mill deflection possible, resulting in unacceptable parts	150	No problems-block & bedplate can be cast using proven methods	50	Ideal—Would use proven arbor tooling methods	50
9	Crank Bore Locating	Excessive breakage of clamping locating details near #1 main	240	Review 4.7L designs for feasibility	^a	No problems-block can be cast using proven methods. No tie bar interference during locating	30
10	Casting Process Feasibility	Questionable scrap rates during shake out of casting. Solidification of metal may result in tie bar warp or cracking	343	No problems-block can be cast using proven methods.	120	No problems-block can be cast using proven methods	120
11	Broaching Half Rounds & MBC Seats	Possible	75	Acceptable-single broach could machine both features with acceptable tolerances	70		0

^aPending 4.7L comparison of bore centers and access issues.

Exhibit 17 Cylinder Block Sealing Design Review, 8/29/97 (Data Disguised)

Alternative	Sealing	Manufacturing	Assembly	Investment	Variable Cost	Service	Structural	Budgeted Work Standard	Design Workload	Summary Total
Weighting Factor	9	8	7	6	5	4	3	2	1	
(1) Cast Iron Bedplate Anaerobic sealant bedplate to block Reduced height possible	5 Proven concept. No seal retainer. All T-Joints metal-metal and machined.	3 Requires bedplate machining line.	5 2.0L proven concept eliminates 5 main caps and rear seal retainer adds bedplate dowels.	1 Approx. \$8M.	2 Saves: retainer caps. Adds: bedplate, screws and dowels.	5 Elimination of all T-joints.	5 Increased rigidity.	1 New bedplate line.	1 No design 2.0/4.7L experience.	158
(2) Cast-in Tie Bar (Original Design)	4	1 Two-pass machining	3	2 Block Machining Effect	4 4 retainer caps	4	3	4	5	135
(3) Oil Pan-Oil Pump (Rear Retainer Style): Uses "wings" on the block. No fasteners between oil pan and pump. Dowels added to pump/block interface	3 4 T joints. Bar to block sealing. 2 wet fasteners.	4 Added machining of wings and dowels.	2 Oil pan assembly last. Requires rotation.	4 Minor machining effect.	4 Less than \$0.50.	1 Requires oil pan removal to service oil pump.	2 Inability to attach motor mount strut to oil pan (Chrysler version).	4	2 Concept started.	137

(Rating method: Best to Worst, 5 to 1; Weighting factors: 9 to 1, linear; Summary: Total of individual ratings x weighting factors. Budgeted Work Standard is the sum total of the amount of manpower time that each assembly operation takes.)

Exhibit 18 Impact on 12-Panel Objectives: Comparison of Bedplate & Rear Retainer Style Versus Original Tie Bar Design (Data Disguised)

Bedplate			Rear Retainer	
	Impact	Comments	Impact	Comments
HP/ Torque	+	Strong enough for high-performance derivative, supercharged 150-170 hp.	0	Neither may be strong enough.
Fuel Economy	0		0	
Emission	0		0	
Noise Vibration Harshness	+	Significant improvement detectable by unskilled observer	--	Slightly worse
Oil Economy	0		0	
Weight	--	3-5 lbs. heavier	0	
Timing	--		?	
Quality	+	0.5c/1000 Best, 9.0c/1000 Worst	--	1.5c/1000 Best, 18.0c/1000 Worst
Investment	--	\$8-11 million	--	(\$2 million risk)
Idle Quality	0		0	
Variable Cost	--	\$2-4	--	\$.50
Volume	0		0	

(+) advantage; (0) neutral ; (--) disadvantage compared to original design.

Appendix of Key Terms²

Design for manufacturing integrates the design of the product with the design of the manufacturing equipment (simultaneous engineering) to ensure ease and consistency of manufacture without compromising the product performance and focuses on:

- Using proven high-quality manufacturing methods
- Identifying concepts for products that are inherently easy to manufacture
- Evaluating the component design for ease of manufacture

Design for assembly is utilized when the process involves assembly and focuses on:

- Reducing the number of parts
- Ensuring that parts are easy to assemble

Design for serviceability is an engineering process designed to optimize the design of the component or system to enable serviceability after launch. During the design phase, the design engineer must be cognizant of the serviceability requirements of their individual parts and the effect their part has on the serviceability of the entire vehicle. This activity requires close coordination and cooperation between the designer and the service organization. Important considerations include diagnosability, accessibility, maintainability, washability, remanufacturability, liftability, towability, cost of ownership, and the need to avoid using special tools.

Design Failure Mode and Effects Analysis (DFMEA)

Purpose: A Design Failure Mode and Effects Analysis (DFMEA) is a systematic, detailed analytical procedure used to identify potential design related failure modes, root causes, and consequences, in order to eliminate or minimize their effects through product design changes. Once these problems have been identified, they can be prioritized and steps can be taken to eliminate them by feeding back the corrective actions identified into the design. All this occurs before the build of the prototype products.

Description: A DFMEA is used early in the design development process to discover potential problems in the design of a component, subsystem, or system that may result in reliability problems. The DFMEA includes:

- Identifying potential effects of the failure on the customer
- Assessing the potential effects of the failure on the customer
- Identifying the possible causes of the failure mode and the effectiveness of the current controls to detect the causes of the failure mode
- Establishing risk based on: Severity of effect (consequence); Probability of occurrence; Probability of detection/non-detection

The failure modes and causes identified are then prioritized on the basis of relative risk. This can help to enhance the effectiveness of the design validation activity by ensuring the proper items (higher risk) get addressed first. The considerations of severity, occurrence, and detection are assigned values ranging from 1-10, with higher numbers implying higher risk. Once values are assigned to each consideration for each failure mode, they are multiplied together to yield a Risk Priority Number (RPN).

Process Failure Mode and Effects Analysis (PFMEA)

Process capability analysis evaluates the inherent ability of a manufacturing process to perform within requirements, usually requirements related to a specification tolerance. It is closely related to Statistical Process Control (SPC). Statistical control charts assess the stability of a process. A stable process has a consistent, predictable amount of variation, but may or may not meet specifications. A capability analysis evaluates the ability of the process to meet specifications. Stability is generally a prerequisite for calculating capability.

Process Failure Mode and Effects Analysis (PFMEA) is used to identify potential process causes of part and process failures. It also identifies the effects of these failures, not only at the part level, but also in other “downstream” processes. After failure modes and causes are identified and prioritized, a RPN is calculated in the same manner, and using the same considerations, as the DFMEA.

² Appendix is taken from materials found in *Product Assurance Planning Manual*, 2nd Edition, Chrysler Corporation, 1995.