Rightsizing and Management of Prototype Vehicle Testing at Ford Motor Company

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The prototype vehicles that Ford Motor Company uses to verify new designs are a major annual investment. A team of engineering managers studying for master's degrees in a Wayne State University program taught at Ford adapted a classroom set-covering example to begin development of the prototype optimization model (POM). Ford uses the POM and its related expert systems to budget, plan, and manage prototype test fleets and to maintain testing integrity, reducing annual prototype costs by more than $250 million. POM's first use on the European Transit vehicle reduced costs by an estimated $12 million. The model dramatically shortened the planning process, established global procedures, and created a common structure for dialogue between budgeting and engineering.

In 1903, Henry Ford founded the Ford Motor Company with an initial investment of $100,000. In 1910, Ford opened a large factory in Highland Park, Michigan, to meet the growing demand for the Model T. Here, Henry Ford combined precision manufacturing, standardized and interchangeable parts, division of labor, and, in 1913, a continuous moving assembly line. The introduction of the moving assembly line revolutionized automobile production by drastically cutting assembly time per vehicle and thus lowering costs. Ford's production of Model Ts made his company the largest automobile manufacturer in the world at that time. Today,

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Ford Motor Company is the world's second largest manufacturer of cars and trucks with 111 manufacturing plants in 38 countries and more than 350,000 employees worldwide.

From its inception, Ford Motor Company has carefully designed its vehicles to meet and, in many cases, exceed customer expectations. These designs are time consuming and extremely expensive to produce, partly because each design must be painstakingly verified. For some verification tests, Ford must construct prototype vehicles so that it can examine the interactions of systems in their operating environment. The cost of building a prototype routinely exceeds $250,000. Complex vehicle programs commonly require over 100 full-vehicle prototypes and sometimes require over 200 in the course of product development.

Product Development at Ford Motor Company

Developing a new vehicle or even a moderately modified vehicle requires capital, time, and resources. Product development (Table 1) begins at the macro level with definitions of vehicle descriptions, target markets, and costs. At this level, planners identify target markets and vehicle use—such as family sedan, sport utility, pickup truck, or commercial van. The overall plan includes vehicles with no modification, new vehicles, and all levels of change in between. Planners develop this *cycle plan* in an iterative process, determining the capital and resources required to deliver all the strategic wants, prioritizing the resources needed, and setting final targets and budgets. Once complete, the cycle plan is not static. Planners can modify it to meet changing customer demands or market needs or to balance one program's expansion by reducing another.

In the second stage of the product-development cycle, teams assigned to the vehicle use the initial product intent and marketing strategy to define in detail customer wants, vehicle configurations, and strategies to ensure customer satisfaction. They refine the product, developing its general direction, sense, and feeling. Designers start work on computer and physical models and establish vehicle dimensions, including length, width, height, and wheelbase.

Designing a line of vehicles is complicated by the need to meet customers' demands for a wide variety of options. The number of combinations of features in a complex vehicle can number in the billions. To reduce the number of combinations, designers define the buildable combinations, that is, what combinations of features will be available to consumers.

Once management approves the overall plan, the vehicle team must deliver the product. The product-development cycle moves into the design, build, and test stages (stages 3 and 4 in Table 1). Designing the vehicle requires testing each individual component, the systems containing these components, and the vehicle as a whole. Design engineers determine how to test components and systems to prove out their design parameters, and they prepare the design-verification plan (DVP). After this, the team decides what specific configurations—of the billions of potential combinations—to build as prototypes to test and evaluate.

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Stage	Planning corporate cycle plan	Defining products in detail	Planning vehicle testing and building prototype fleet	Iterating through design, testing, and building	Ramping up manufacturing to full production rates
Deliverables	Corporate budget, vehicle-line budgets	Market demands, detailed budgets	Finalized test plan, prototypes ordered and built	Validated vehicle designs	Vehicles
Tool	POM-Predictor	POM-Predictor	POM	POM	

Table 1: During the five stages of product development at Ford Motor Company, the tools enabled by operations research helped produce various deliverables.

Prototypes can be very costly to produce because most of the parts and the manufacturing and assembly processes are unique. The tools that would be used during mass production do not yet exist, and each vehicle is specially built to prove out designs, processes, and vehicle performance. Since the costs for prototype vehicles depend solely on the number built, the goal is to build as few vehicles as possible to perform the testing and evaluations required.

In the fourth stage of the product-development cycle, the vehicle team does testing. The results may lead to design modifications. The team may make improvements and changes to provide desired features, to meet market demands, and to satisfy test parameters. This stage can include several design iterations, retesting, and rebuilding vehicles.

The fifth and last stage of the product-development cycle is the final manufacturing prove out and full vehicle launch and introduction. During this stage, Ford increases vehicle production to full volumes and then maintains the production system at a steady-state rate. Success in this stage depends on flawless execution in the earlier stages of the product-development cycle.

The Engineering-Management Masters Program

The engineering-management masters program (EMMP) at WSU is a three-year master's program Wayne State University developed specifically for Ford Motor Company as a technical alternative to an MBA degree [Chelst, Falkenburg, and Nagle 1998]. Engineering and business faculty designed the program to teach students to integrate engineering and business issues in their decision making and management. A committee of Ford executives, WSU faculty, and class representatives oversees the program.

Students maintain their regular jobs, taking classes that start in the late afternoon two days a week for 10 months a year. They come from diverse parts of the organization and have, on average, 10 years of experience in automotive engineering. Graduating students have a network of contacts throughout the company that further enhance their ability to get things done.

At the end of the program, students form teams to work on large-scale projects suggested by executives and students. The oversight committee receives project proposals, and students must find sponsors to fund their projects at $50,000 to $100,000, which insures the sponsor's interest and the projects' value to Ford. Between 1994 and 2000, 300 students participated in over 50 leadership projects, gaining academic knowledge, practical experience, and valuable contacts throughout the company.

Four of us were directly involved with the EMMP. Kenneth Chelst is the operations research instructor in the program, while Jeffrey Lockledge teaches information systems. John Sidelko is a member of the class of 1996 and was directly responsible for POM's transfer from his team's project to a working system within Ford. Dimitrios Mihailidis was a PhD candidate working with the student team to develop and implement their model in GAMS.

Complex vehicle programs commonly require over 100 full-vehicle prototypes.

The Prototype Optimization Model

We developed the prototype optimization model (POM) to reduce the number of prototype vehicles Ford needed to verify the designs of its vehicles and to perform all the necessary tests. Historically, prototypes sat idle much of the time waiting for various tests, so increasing their usage would have a clear benefit. The barrier to sharing these idle prototypes among design groups and thereby increasing their usage lay in determining an optimal set of vehicles that could be shared and used to satisfy all of the testing needs.

Ford's planning with respect to prototypes can be broken into two phases: (1) strategic predictions of the fleet size during cycle-plan development, and (2) tactical planning of specific prototype requirements for vehicle design and testing. These two phases are tied together by the assumptions concerning the vehicle line under development and the budget established for prototypes during strategic planning. With POM and the related expert-system modules, planners and designer base all their decisions on similar assumptions and have a mechanism for tracing the testing requirements from the engineers' level through strategic planning.

In discussing the role of POM, we start with Phase 2 since we built the model to help the firm to deal with the tactical planning during vehicle design and testing. The model guides the planner in developing a fleet of prototypes and assigning tests to specific vehicles. In Phase 1, the preliminary strategic-planning phase, the model is an integral part of an expert system called POM-Predictor. Its primary purpose is to estimate the size of the prototype fleet and the costs for different scenarios of the strategic product cycle. In this, POM provided the conceptual structure for developing the expert system that forecasts the budget.

The Math Model

The prototype planners must determine the specific characteristics of the fleet and schedule all tests to that fleet. In the language of mathematical programming, their objective is to minimize the number of vehicles built subject to the constraint that every test be completed on an appropriate vehicle by a specific deadline. The test planners' primary input to the model is a description for each test of the

Super Duty F-350 Chassis Cab		8 ft. Stake/Platform	8 ft. Dump	9 ft. Statke/Platform	9 ft. Dump	9 ft. Utility	8 ft. Dump w/ Back Pac	10 ft. Stake/Platform	10 ft. Dump	10 ft. Van	11 ft. Utility	12 ft. Stake/Platform	12 ft. Van	Catering	Wreck - Roll Off	Wrecker - Boom Type	Wheelbase/CA	GVWR (lbs.)	Max Payload (lbs.)
Regular Cab	4 X 2 SRW (F34)	■		■		■								■			141/60	9900	5050
	4 X 4 SRW (F35)	■		■		■								■			141/60	9900	4615
	4 X 2 DRW(G) (F36)	■	■	■	■	■										■	141/60	11200	5840
	4 X 4 DRW(G) (F37)	■	■	■	■	■										■	141/60	11200	5380
	4 X 2 DRW(D) (F36)	■	■	■	■	■										■	141/60	12500	6620
	4 X 4 DRW(D) (F37)	■	■	■	■	■										■	141/60	12500	6150
	4 X 2 DRW(G) (F36)						■	■	■	■	■	■	■			■	165/84	11200	5740
	4 X 4 DRW(G) (F37)						■	■	■	■	■	■	■			■	165/84	11200	5265
	4 X 2 DRW(D) (F36)						■	■	■	■	■	■	■			■	165/84	12500	6500
	4 X 4 DRW(D) (F37)						■	■	■	■	■	■	■			■	165/84	12500	6030
SuperCab	4 X 2 SRW (X34)	■		■		■								■			162/60	9900	4760
	4 X 4 SRW (X35)	■		■		■								■			162/60	9900	4325
	4 X 2 DRW(G) (X36)	■	■	■	■	■										■	162/60	11200	5550
	4 X 4 DRW(G) (X37)	■	■	■	■	■										■	162/60	11200	5135
	4 X 2 DRW(D) (X36)	■	■	■	■	■										■	162/60	12500	6300
	4 X 4 DRW(D) (X37)	■	■	■	■	■										■	162/60	12500	5895
CrewCab	4 X 2 SRW (W34)	■												■			176/60	9900	4495
	4 X 4 SRW (W35)	■												■			176/60	9900	4050
	4 X 2 DRW(G) (W36)	■	■	■	■	■										■	176/60	11200	5300
	4 X 4 DRW(G) (W37)	■	■	■	■	■										■	176/60	11200	4840
	4 X 2 DRW(D) (W36)	■	■	■	■	■										■	176/60	12500	6055
	4 X 4 DRW(D) (W37)	■	■	■	■	■										■	176/60	12500	5600

Figure 1: Ford uses this chart to show consumers the possible configurations for a Ford F-350 Super Duty Truck with a chassis cab.

—requisite vehicle characteristics,
—the number of hours of testing, and
—the deadline or due date for completion.

A separate input is a list of every realistic vehicle configuration, called the buildable combinations matrix (BCM). This is necessary because some combinations of features are incompatible, for mechanical or esthetic reasons (for example, the largest engine may not be in the same vehicle with the smallest transmission).

The BCM reflects reduced product complexity that is a byproduct of the early decision-making process in the cycle-planning process. It describes the combinations of major components (drive trains, body styles, and so forth) that are intended to serve specific market segments. For example, in the F-350 truck series (Figure 1), the regular cab is the only cab style available in many of the specialized configurations. This isn't because a dump truck with a crew cab is impossible but because the market for one would be so small that it would never be profitable. Other combinations may not be available because the components would be mismatched. For example, the Ranger pickup is offered with 2.5, 3.0, and 4.0 liter engines. The smallest engine is not powerful enough for four-wheel drive and is therefore available only in a two-wheel drive

Engines			Transmission		Body style		
V8	4 Cyl	6 Cyl	Automatic	Standard	4-door	Coupe	Wagon
0	0	1	1	1	1	1	0
1	0	0	1	0	1	0	1

Table 2: Each row represents compatible components for the various features that can be combined to make buildable vehicles.

version.

In POM, the BCM is represented as a spreadsheet with ones and zeroes indicating the available combinations (Table 2). Each row corresponds to a set of possible combinations with all compatible components marked. Thus, one row may indicate a large number of vehicles. Multiple rows may represent the same configuration. While this is redundant information, planners judged it acceptable, because the people who specify the configurations are used to thinking in overlapping product segments. Users found this representation compact and much more natural than entering a row for every available combination, especially as potential combinations may number in the tens of thousands.

Each vehicle-configuration type is defined as vector of features, with elements drawn from a restricted set of values for each feature. The vehicle features are typically grouped into a limited number of major categories. For example, on the Transit vehicle program the categories were (1) vehicle variant (body style), (2) engine, (3) roof height, (4) transmission, (5) rear closure, (6) gross vehicle weight, (7) wheelbase, and (8) right or left hand drive. The test requester specifies which combinations of features need testing and identifies which features have no bearing on the test. For example, in an altitude-drivability test (to determine whether a vehicle will perform acceptably at high altitude), the test requester will generally specify a vehicle with the highest gross vehicle weight (GVW), the smallest engine, and an automatic transmission to examine the worst-case vehicle configuration. For this test, the vehicle variant, roof height, rear closure, wheelbase, or which hand drive would be insignificant factors.

Step 1: Set Covering—Minimum Set of Uniquely Configured Vehicles

We determine the optimal (or near optimal) fleet size in three steps. In the first step, we use as input just the required vehicle characteristics for each test and the buildable-combinations matrix. For now, we ignore the test duration and deadlines. We formulate a classical set-covering problem whose goal is to determine the minimum number of unique vehicle configurations needed to cover all the tests (Appendix). In this first step, an actual example could start out with more than a thousand possible vehicle configurations. The Transit vehicle program began with a list of 38,880 combinations, and the model identified a minimal subset of 27 unique vehicle configurations that were needed for all of the tests in the design-verification plan. (The total optimal vehicle count exceeded 100 vehicles.)

We aligned this first step to match the way the planner thinks about constructing the fleet of prototypes. It can cost much less to build two identical prototype vehicles than to build two distinct prototypes. If the two vehicles differed in body style, the savings could be in the $100,000 range because of the high cost of stamping dies for body panels.

Steps 2 and 3: Optimal Test Allocation

The model assigns tests to individual vehicles in two steps because of computational issues with integer programming. In step 2, the model assigns tests to groups of identical vehicles considering only the group's total testing capacity. This provides a lower bound on the minimum number of prototype vehicles of each unique configuration. In step 3, the model schedules tests to individual vehicles, making sure that no test is split across two identical vehicles.

We solved two small test problems with steps 2 and 3 combined into a single step, and the solutions were the same as those with two separate steps. In large problems, however, it is not possible to determine whether separating the solution into steps 2 and 3 causes the solution to be suboptimal. However, in our context, we can use another criterion to judge the quality of the model's optimal solution: the percent utilization of each vehicle. In addition, an experienced, knowledgeable planner uses the solution for guidance but has ways to improve it.

Model Development and Design Assumptions

Our first assumption in developing the model was that we had smart users. Software developers often assume that users do not realize or consider the impact of their actions and must be protected from themselves. Hence, software is typically full of checks and double checks that increase development costs. POM users are meticulous engineers who understand the process. We therefore designed only a primitive interface that was implemented in Excel.

Our second assumption was that the optimization model was only a guide whose results users could modify. The team adopted John Little's [1970] definition of the role of a model, to "update the intuition of the decision maker." We did this for three reasons: (1) The model did not take all issues into account (in particular, it did not schedule tests into testing facilities), so that human intervention was necessary to meet constraints that the model didn't consider, (2) the design engineers had never used OR models and had little faith that the results would work; and (3) the engineers would have to modify the actual schedule to accommodate unanticipated results from the testing program. The model's results were accepted only after experts who had traditionally developed the fleet had inspected and approved them.

Between 1994 and 2000, 300 students participated in over 50 leadership projects.

Phase Two: Model Run—Beating the Optimal

We run POM after collecting the DVPs from all the design engineers to find the minimum number of vehicles necessary to cover all the tests they contain given the vehicle features each test requires. However, the fleet the model identifies as optimal can be insufficient in two ways: (1)

Some of the prototype vehicles will be used very little, and (2) the proposed fleet may exceed the budget. In either case, the test planner identifies the underused vehicles by looking at the POM to see what tests are assigned to each vehicle and then discusses them with the design engineer. The planner frames the discussion around the following questions:

(1) Can you perform these tests effectively through computer-aided engineering models, a bench test, or other means?

(2) What specific characteristics are important to this test?

(3) If the test is seasonal, can you reproduce conditions in a lab?

(4) What is the final deadline for this test?

(5) Can the test be shortened or performed simultaneously with another test?

(6) Is the test likely to be successful, and did engineers perform a preliminary analysis?

They try to move tests assigned to the underused vehicle to other testing mechanisms or to other proposed vehicles. In considering the first question, they try to establish whether the engineer can perform the test in a computer simulation or through the use of a partially constructed vehicle. (These are known as bench tests or buck tests, depending on how much of the vehicle is needed.) Either is less expensive than using a prototype. The remaining questions all concern running the test on other proposed vehicles.

For example, in the test for noise, vibration, and harshness (NVH), passengers make qualitative judgments while riding in a vehicle. Initially, the engineer has specified a combination of engine, wheel base, transmission, wheels, and tires. On running POM, the planner may find a vehicle dedicated to this one test. Confronted with this result, the design engineer may be willing to forego the specified wheels in that any of the steel wheels would be adequate. Assigning the test to another vehicle that had spare testing capacity would reduce the test fleet by one.

The process of running POM, finding the fleet, negotiating changes, and rerunning POM can take several iterations. During this time, POM functions as a tool to facilitate negotiation, “to update the intuition of the decision maker.” Only in the final iteration is the fleet close to its optimum. The test-fleet planners must still be aware of other hard-to-quantify issues that constrain sharing of vehicle prototypes. Keeping this in mind, they use the fleet POM suggested to begin scheduling the testing on the vehicles and reserving time in the test facilities.

Phase One: Strategic Planning and Budgeting

We developed a system for strategic planning and budgeting based on the techniques we used in POM. Ford personnel use this system, POM-Predictor, in predicting the costs associated with prototypes in a potential vehicle program.

In the early stages of Phase 1, the vehicle program consists of a set of rapidly changing expectations concerning the eventual product line. These expectations relate to the target markets vehicles need to serve and the number and types of body styles, engines, and other major components. The combination of body style, engine, and other components is called the vehicle’s content. A vehicle’s content can be the same as that for the previous model year, or it can include an existing component brought over from another vehicle line or completely new components. Changes in existing components can vary from very small, primarily cosmetic modifications to a complete transformation. Each content expectation carries a price tag for design and for testing. The POM-Predictor uses the degree of change in the major components to estimate how many prototype vehicles will be required for the product line. While creating prototype vehicles is not the only expense for a new vehicle line, it is a major line item in the budget and must be estimated accurately.

Frequently the initial planned changes in content are too elaborate and too expensive. Managers then go through an iterative process (Figure 2) in which they estimate the cost for the expected content, modify the content, reestimate, and so forth. They spell out the details for each product line separately but can make trade-offs between programs to keep total resource requirements (for example, investments, capital, and engineering) within preset levels while achieving targeted profits for different vehicle segments. They must make estimates simultaneously for all of the company's vehicle programs, a lengthy and difficult task.

The POM-Predictor model used in this phase is a collection of eight expert-system modules, each targeted at creating a generic DVP at one of the major testing activities (for example, NVH, vehicle dynamics, and emissions certification). By predicting what tests will be needed to verify the new-vehicle content, the system can estimate the number of prototypes required.

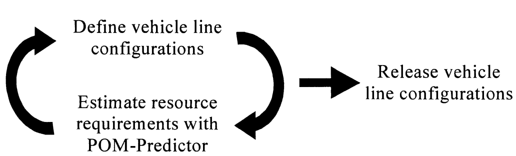

Figure 2: To determine the configuration of a vehicle line, Ford planners repeatedly propose potential configurations, estimate their resource requirements, and assess their feasibility with regard to available resources.

The unifying ideas behind this system of modules were concepts and data structures we created when we developed POM for the fleet planner, including the BCM and methods for specifying tests. While the expert systems vary in their approaches, they all depend on the buildable combinations of the vehicle program and produce test specifications for tests that proposed vehicles will most likely need to pass.

The expert systems contain rules that specify conditions that indicate tests are needed. These conditions are expressed as change levels that are carefully defined, escalating levels expressing the extent of modification of an existing vehicle program. The highest level is a completely new vehicle program, and the lowest is a program in which all components will be carried over from the previous model year. Planners use these change levels to decide whether to perform testing and for how long. An example expert-system rule is the following:

If the power train's change level is greater than P3 and the body's change level is greater than S2 then the test will be performed for five days.

Greater change levels will necessitate longer tests; smaller change levels may result in the test being dropped.

Once a test is to be performed, the test planner determines which vehicle configurations to test by considering the worst case for the proposed vehicle. The worst case varies greatly, however, depending on the test and the buildable combinations. The worst case can be dependent on a single component, on the cross-product of two or three components (with one or all of the vehicles defined by the cross-product considered worst case), or on a handful of special cases (for example, the combination expected to have the greatest sales volume). In the example rule, the worst case is found by selecting one vehicle from the cross-product of body styles with suspensions, one from engines crossed with suspensions, one from drives and suspensions, and the worst suspension configuration (if it hasn't been covered by one of the earlier cross-products). This will likely result in three tests to be performed on three different buildable combinations of the vehicle.

Managers estimate the cost for the expected content, modify the content, reestimate, and so forth.

POM represents these cases in tables that delineate which rules and combinations apply to each test: they form a compact template planners and engineers can work from. Planners compare the vehicle configuration against these test templates to prepare a preliminary test plan. In many cases, this preliminary test plan is easy to assign to vehicles because the tests are few and simple. When the tests are so numerous and complex that optimization is required, planners use POM in its original form to optimize the number of vehicles the preliminary test plan will require. As the system is currently implemented, the results of two of the eight expert systems are run through POM.

When the vehicle expectations have stabilized, planners hand the preliminary test plan to the test engineers who can use it in preparing their DVP. The test engineers know a great deal more than the expert system, and they usually modify the test plan once they see the final vehicle configuration. However, the continuity that POM provides allows the test requesters to see how the budget was created and where their tests fit into the overall plan.

Our major motivation for incorporating a high level of detail in these expert-system modules was to build credibility and bridges between the budgeters, the so-called bean counters, and the engineers downstream who run the vehicle program within the budget set earlier. The experts we interviewed to develop the modules are the same ones who later manage the development of actual test plans. The expert system also allows the budget to escape the bias that existed in the earlier, regression-based model since it makes its estimates independent of historical data. The number of prototypes used in the previous model year is irrelevant to the current method of estimation. In addition, each expert speaks to a very narrow range of issues, and the modules use their opinions to build aggregate estimates of budget requirements.

Chronology of Model Development and Hurdles

In 1994, a team of engineering managers in a master's program developed by

Wayne State University for Ford Motor Company [Chelst, Falkenburg, and Nagle 1998] were taking a course in deterministic modeling. They observed a conceptual analogy between set covering and the problem of developing a prototype fleet to cover a set of required tests. They decided to tackle the prototype-planning problem as their team project for the final year of the program. This first team, class of '95, succeeded in creating a small hypothetical data set and demonstrated to engineering directors the potential of a model to answer a wide range of what-if questions. Students in the succeeding class picked up where this first team had left off. This second team had more experience in prototype planning and built a broader base of support. They drew on their own experiences and developed a comprehensive example that they could use for show and tell.

After completing their degree program, members of this second team continued to make the rounds of the various vehicle-development programs to educate them about the tool. It was a time of tremendous transition within Ford with heavy time and cost pressures. Consequently, vehicle-program managers felt they could not afford the luxury of using a new concept that had yet to be proven with a real test under actual working conditions. One vehicle program, however, saw no way of meeting its deadlines and budget without a breakthrough methodology for managing the prototype-planning process.

Implementation of the Existing Model Begins

In June 1996, we began working with the Transit vehicle team. Chelst, Lockledge, and Mihailidis took responsibility for creating the OR models and software for the system while Sidelko worked to overcome organizational barriers. Two months later, we had a fully functioning model that the planners could use on their own with little or no guidance. During these two months, we accomplished three things simultaneously: (1) we developed software in Microsoft Excel to gather the needed data, prepare it for input to the model, and present the model's output in a format useful to the test planners, (2) we coded the model in GAMS, and (3) we obtained feedback from test planners at least once per week. Because of the test planners' feedback, we restructured the model from a mixed-integer model to a strictly integer-programming one. (The original model could split tests among two or more vehicles. Test planners thought such solutions would be a logistical nightmare and were unacceptable, even though they might be technically feasible.)

When we first ran the model, the results indicated that the number of prototypes required was almost twice the number estimated by the old regression model. The test planners were devastated. However, we reviewed the data input to the model and discovered a misunderstanding. Test requests frequently listed a duration of 180 or 365 days for tests that should not take that long. The design engineers were still stating what vehicles they wanted and how long they'd like to keep them instead of defining the attribute-testing requirements. As we cleaned up the test specifications, the number of prototypes dropped. In the end, the model designed a fleet that was 25 percent smaller than originally estimated by the regression model. The savings were estimated to be $12 million.

After planners developed the original fleet plan, they used POM to redesign the prototype fleet when a major new engine was added to the Transit vehicle program. In the past, developing a new plan for testing and determining a new-prototype-fleet specification could have delayed the program six months. Using POM, planners performed this task in a matter of weeks. This led to one test planner's nickname for the system: The Prototype Optimization Miracle.

Despite POM's success, we still faced major barriers to making the model a standard corporate practice. The model required more preliminary planning and data structuring than managers were accustomed to. One prototype planner, Alex Przebienda, who had knowledge of OR and programming saw the potential of the tool and began working with it within the truck organization. When he accepted the job of managing the prototype-prediction process, he began institutionalizing POM and encouraging its use in other areas. He developed linkages with other parts of the company's computer system to facilitate the transfer of data into and out of the model, and he took the model to a new level. With the help of test planners and experts in resource requirements for design personnel, he created the POM-Predictor model for use in strategic planning.

The development and implementation of POM and POM-Predictor was always a bottom-up process begun as a student project. Along the way, we had to overcome more than our fair share of barriers, including

(1) the negative image of a project initiated by students,

(2) different fleet-planning and management processes across vehicle-design and testing centers in the US and Europe,

(3) no track record for optimization models serving as decision aids at Ford,

(4) lack of knowledge about OR models and their potential to improve the management of product development,

(5) computational issues as the constraint set grew by a factor of five to meet the planning needs in Europe,

(6) issues that were impossible to capture in a model without a major investment of time and money, neither of which were available, and

(7) lack of information systems to provide data for the model.

Impact

Ford uses POM-Predictor to plan for prototype budgets for all the vehicle programs of Ford, Lincoln, Mercury, and Jaguar and will use it for Volvo as soon as it is better integrated into the Ford Motor Company. POM, the tactical planning model, has been run for Taurus, Windstar, Explorer, and Ranger vehicle development programs and for a series of small vehicles being developed for Europe and South America. In total, Ford has used POM, for more than 10 complex vehicle-development programs.

The Taurus program presented an interesting opportunity to use POM to increase the number of prototypes. Ford decided to move the launch of the Taurus three months ahead of the original schedule. This would require it to compress the test time. Planners used POM to estimate the number of additional vehicles required, something that would have been unimaginable with earlier tools.

The vehicles mentioned above are all quite complex. In contrast, a program such as that for the Thunderbird, which has only one body style and a very limited number of configurations, does not have to use the Phase 2 POM to design the fleet. Nevertheless, planners used POM to show that Ford would need to build only one configuration.

Over the past several years, Ford has established aggressive cost-reduction targets to increase overall profitability. The prototype budget with its $1 billion price tag was one of many targeted for reduction. POM-Predictor and POM worked at opposite ends of the spectrum to help Ford budget, plan, and manage prototype test fleets to make huge reductions. In 1995, the costs for prototypes was over $1 billion per year and that was reduced by more than $250 million by 2000. During the same period, Ford increased its yearly offering by more than 20 percent.

The model designed a fleet that was 25 percent smaller than originally estimated.

POM-Predictor enabled top management to explore and revise its assumptions about vehicle programs so as to develop a realistic plan for saving 25 percent. POM, the tactical-planning model, facilitated increased sharing of scarce prototype resources to achieve the budget target. In some instances, POM introduced the practice of sharing vehicles between vehicle-design groups. Because strategic and tactical planning were based on the same business and vehicle-program assumptions, Ford achieved these budget reductions while maintaining the integrity of its design, verification, and testing processes.

Product-design verification takes place throughout the product-development cycle and crosses organizational boundaries. Full-scale prototypes are the final testbed for proving out systems integration and total vehicle performance. The model and its associated systems that structure this core process have had broad organizational impact:

—They have propelled US and European test planners toward global best practices.
—They have eliminated the bias of past forecasting models that implicitly rewarded past inefficiencies.
—They have motivated and facilitated increased sharing of prototype vehicles.
—They have instigated and facilitated early planning of product-design verification.
—They have cut the time for planning a prototype fleet from months to weeks.
—They have moved Ford product developers towards consistent thinking about the attributes of vehicles, a concept aligned with customers' views of vehicles.
—They have provided a structure that helps experienced fleet planners and test requesters to discuss alternative test plans that can reduce the size of the prototype fleet.
—They have enabled planners to answer strategic what-if questions realistically.
—They have provided for consistent budget planning, revising, and negotiating.

KISSm—Keep It Simple and Smart

The POM EMMP leadership project established another precedent at Ford. It established the paradigm for managing the development of an OR model as part of a leadership project and transferring the tool to the mainstream organization when the project ended. The EMMP program developed by Wayne State University produces educated consumers of OR models. Such consumers can lead the OR modeling process by (1) defining the modeling opportunity, (2) clarifying the modeling framework, and (3) planning and assisting in the model transfer. However, they are not skilled OR model builders. The POM project made clear the need for doctoral-student support to address the technical modeling issues.

The eight months available for carrying out a leadership project is tight, especially given that the Ford engineering managers who are students maintain their regular 50-hour workweek jobs. The student team must plan the model, help develop it, collect data, document its potential with one or two cases, sell the concept to the broader organization, and start training people to use the model. The POM project defined the modeling strategy, Keep It Simple and design for the Smart User (KISSm). If you can assume that the end user is experienced and has good analytic skills, a lean approach to model building is effective and efficient. There is no need to simplify input and output formats; nor is there a need to invest in preventing input errors.

MAUT and Mustang

Later leadership projects followed similar processes to build and apply OR models successfully. In one project, students used multiattribute utility theory (MAUT) to evaluate alternative enhancements to engines in the Mustang product line. Since then, Ford has adopted MAUT as the formal mechanism for rank-ordering all enhancements to the Mustang line. The model has taken emotion out of decision making. It separated the roles of experts and decision makers. It enabled different organizations within Ford to contribute equally to decisions and develop acceptance of the end results. The Thunderbird and Windstar vehicle lines are considering adopting a similar process.

Optimization Plus Simulation and Flexible Assembly Plants

Ford had been struggling for more than a decade to develop a process to use to justify investing in manufacturing flexibility. One leadership team focused on assembly-plant flexibility. It adapted an optimization model developed at MIT [Jordan and Graves 1995] and coupled it within a simulation inside an Excel spreadsheet. It used the model as part of a comprehensive process to study two cases. In one case, the team found that flexibility was justified and in the other, not. The team applied the concept of option pricing to rate the flexibility of every assembly plant. At the end of the project, Ford budgeted several hundred million dollars for flexibility and prioritized a list of projects. Ford has been implementing these plans and spending the money during 1999 and 2000.

Decision Trees for Late Design Decisions—Norfolk Assembly Plant and Econoline

In another leadership project that drew

on the POM paradigm, a team built decision-tree software to help engineers make late design decisions before and during launch of a product. The original concept of using a tree to make a late design decision came from a small homework assignment in the decision-analysis course. The team identified the key issues that are common to most late design decisions. It also defined a number of default assumptions that the decision makers could use or modify depending upon the context. Running the model is now a standard requirement in the change-control process at Norfolk's assembly plant. Ford has officially declared the model a "best practice," and it is offering training in the model's use to a broad audience of engineers. The Econoline vehicle line will be the first product group to apply the model.

In working on these modeling efforts, student teams followed the POM strategy of KISSm, and respected the knowledge and experience of the end-users of the model. In all of these instances, the driving force was not an OR group but rather a leadership team of engineering managers who were educated consumers of operations research. They were, however, experts in making things happen. Ford and Wayne State University are educating them to become systems thinkers with new analytic and organizational skills and planning for them to be forceful leaders for change.

Conclusion

From its modest beginnings as a student project, the POM project overcame many hurdles to make it an integral part of Ford's tactical and strategic planning of product development. Along the way, the team cut the time for planning and created new processes that have become global standards. The POM project also opened the door for other working-student teams to bring OR techniques to bear on a wide array of critical decisions and processes at Ford.

Executive summaries of Edelman award papers are presented here. The complete article was published in the INFORMS journal Interfaces [2001, 31:1, 91-107]. Full text is available by subscription at http://www.extenza-eps.com/extenza/contentviewing/viewJournal.do?journalId=5