PLANETS: A Modeling System for Business Planning

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The Production Location Analysis NETwork System (PLANETS) was developed to provide General Motors with the capability to evaluate complex quantifiable business decisions. Originally implemented in 1974, PLANETS has evolved into a flexible framework for scenario description and analysis. It is now supported by Electronic Data Systems Corporation. Individuals with no prior computer or mathematical programming background use PLANETS to decide what products to produce; when, where, and how to make these products; which markets to pursue; and which resources to use. PLANETS also provides detailed shipping allocations and capital spending schedules. PLANETS' worldwide use throughout General Motors has contributed to the understanding of business problems. Usage of PLANETS in-site selection and tooling allocation studies has resulted in substantial cost avoidance.

Multinational planning is complex. In the automotive sector alone, this involves the manufacture and distribution of thousands of products supported by hundreds of facilities worldwide. In order to guarantee timely delivery at competitive prices, these facilities have to be properly designed, tooled, and situated. Lead times for tooling and facility changes can be three years or

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FACILITIES/EQUIPMENT PLANNING

more and routinely involve capital expenditures in the tens or hundreds of million dollars. Errors in implementing and changing facilities can be costly. The planning departments are continually evaluating new alternatives.

While the business planning organizations of most large multinational corporations are well organized and structured, the actual planning processes are unstructured and multipurposed. Some planning may be unstructured in that complete overhauls of all or part of a business plan can occur at any time that competitive pressure dictates. Ad hoc management studies of product mix, site selection, or divestiture can occur at any time. In addition, routine planning tasks must be satisfied, including quarterly business plans, annual budgets, and five-year business plans. The planning horizon varies from study to study and can range from months to years.

Planning is multipurposed since both corporate and divisional objectives must be satisfied and can involve any of the functional areas of business (engineering, finance, logistics, management, manufacturing, marketing, and purchasing). The scope of an analysis frequently depends upon how and where in the organization the study originates.

The Technology Need Evolves — PLANETS Is Born

In late 1973, General Motors decided that it needed a system of mathematical models to assist management in determining the best strategies for placing facilities to support new products in new overseas markets. Responsibility for this effort was assigned to a corporate management science support staff. In evaluating the type of decision support system required (for example, simulation, optimization, or spreadsheet scenario), this group compiled a list of over 300 probable decision variables and factors (labor availability, flexible capacity, local content regulations, and so forth) which might have to be considered by a model. A survey of GM managers worldwide was conducted to solicit their input and to order these factors by priority. Involving the managers in this survey turned out to be crucial for the ultimate acceptance of PLANETS by corporate and divisional management.

During the survey, the scope of the requested modeling capabilities expanded substantially as the economy changed. Management now wanted to evaluate whether to

— Buy or build new facilities (location and timing to be determined);
— Expand capacity at existing plants, (when, where, and how);
— Use a nonallied manufacturing source (when, who, how much);
— Reallocate products among existing plants (when, where, how, what volume); and
— Introduce a new product (go/no-go, when, where, how).

Furthermore, senior management wanted the modeling capability to use standard business terminology to facilitate expression of business scenarios to the system. They also wanted the system to be available for use by managers worldwide.

Not all managers wanted to trust in an optimization model. Some wanted only a tool that would quickly evaluate the financial, production, or marketing impact

of specific scenarios. As with prior manual studies, these managers would set all variable values and use the model as a big calculator. Others, who already trusted the concept of optimization, wanted the capability to have every business factor float to satisfy some paramount objective.

The possible objectives included
— Maximize profit,
— Maximize market penetration,
— Maximize facility utilization,
— Maximize exports,
— Maximize production,
— Maximize sales,
— Minimize costs,
— Minimize losses,
— Minimize investment, and
— Minimize imports.

The management science group realized that traditional approaches to mathematical model building would not adequately support, on an ongoing basis and in a timely manner, the quantity and variety of scenarios to be evaluated. Skilled management science resources were not available in sufficient quantities. Conventional model development was too slow. Models did not use business terminology and did not include enough real-world interactions. Therefore, what resulted was not just a system or collection of mathematical models specific to some proportion of the automotive business, but rather, PLANETS: a sophisticated, yet easy to use, flexible model-building system applicable to any industry (Figure 1).

An Overview of PLANETS' Capabilities

The basic premise of PLANETS was that if people could be taught how to evaluate a business problem and reformat it into a mathematical program, then a computer system could be "taught" to do the same, only faster. Long before *expert systems* became a widely used term, the first version of PLANETS (1974) provided business planners with a comprehensive network of computer programs to facilitate the following tasks, which had previously required the direct involvement of management science model builders:

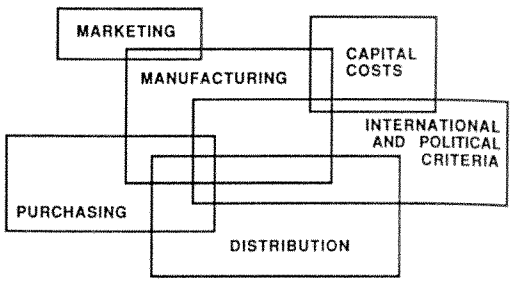

Figure 1: Production Location Analysis NETwork System.

(1) *Define a Business Environment.* PLANETS provides a structure with which a business planner can communicate conversationally to develop a working outline of various business situations using standard business terminology and data estimates. The PLANETS building blocks that form the basis for this structure are shown in Figure 2. In addition to providing a structured approach to defining business problems, PLANETS handles all file manipulation so that the planner needs only to specify new, changed, or deleted data. PLANETS will then update the data structures accordingly and provide a review of the information.

(2) *Define Specific Business Analysis Assumptions.* Through user friendly dialogue, the business planner can

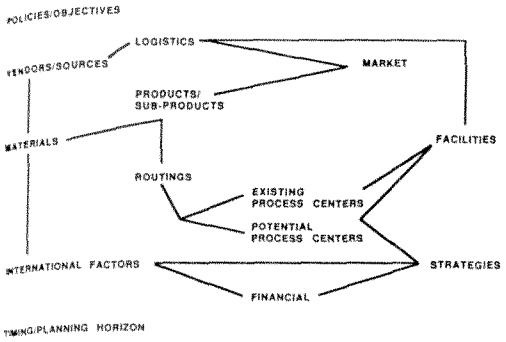

Figure 2: PLANETS building block framework. Most business situations can be structured by using combinations of the available PLANETS building block categories, which act as either sources and/or sinks in the business flow process. Underlying this problem network are quantifiable management objectives and policies that can be imposed over some definable planning horizon.

design specific what-if scenarios. These scenarios are a hybrid of the data provided and the business analysis assumptions and options. PLANETS combines all this information to build a model specific to the problem at hand. Using PLANETS, the business planner can quickly and efficiently define an unlimited number of scenarios from a single set of base data.

(3) *Automatic Feasibility Check of Any Potential Scenario.* PLANETS automatically analyzes each scenario or "English model" to be evaluated or optimized for inherent mathematical and logical structure, data completeness and integrity, and then performs a premodel feasibility check.

(4) *Automatic Mathematical Model Generation and Solution.* PLANETS interprets the problem database and model specifications for each business scenario and builds a mixed-integer programming model to solve that scenario. PLANETS creates input files for commercially available solution tools like MPSX and SCICONIC. A typical problem has in excess of 10,000 variables, including over 100 integer variables. Formulating and generating the input deck for MPSX or SCICONIC takes approximately one to two minutes. The same task done manually would typically take weeks and would require an operations research analyst. PLANETS automatically generates a job deck and then submits a job that will run the solution tool (MPSX or SCICONIC), which then solves the problem.

(5) *Automatic Mathematical Model Interpretation and Business Report Generation.* After the problem is solved, PLANETS interprets the MPSX or SCICONIC output of the model run and integrates this information with the problem data and modeling options to generate business reports. The business planner can select from a menu of standard business reports similar to those listed below.

The Basic Reports

The Process Center Utilization Report identifies by facility each process center, its activity, variable cost, fixed cost, total cost, and utilization percent by timestage.

The Process Center Graphical Report is a histogram of capacity utilization for each process center by timestage.

The Strategy Implementation Report identifies which strategies were implemented by the model. Strategy costs are represented by facility, asset category, and pre-

tax investment.

The Material Usage Report identifies the materials used by facility including transfer products. Specific detail for timestage, volume, material cost, inbound freight, and tariffs are included along with a total cost.

The Product Cost Allocation Report identifies for each product which routings were used by timestage. The process centers associated with the routings are shown with volume, unit cost, and total cost by timestage.

The Product-Shipment-by-Facility Report enumerates each product and the market that it is shipped to by timestage. Volume, price, total revenue, freight, and tariffs are included with each market and timestage combination.

The Financial Reports

The Investment Summary Report shows investments by asset type, facility, and timestage, as well as an investment grand total.

The Revenue Summary Report shows revenue by product and by facility for each timestage as well as a total for all timestages.

The Expense Summary Report shows facility, freight, and tariff costs by timestage. Facility costs are broken into variable and fixed, direct and indirect. The freight costs are enumerated by type of freight (that is, inbound and outbound).

The Facility-Revenue-and-Cost Report shows sales by product and costs by process center for each facility. Information is shown by number of units and value by timestages.

The Facility-Income-and-Cash-Flow Report shows for each facility an income statement consolidating the information from the facility revenue and cost report.

The Consolidated-Income-and-Cash-Flow Report provides a summary of all the facility income-and-cash-flow reports.

The Investment Detail Report provides investment data by asset type showing pretax cost and depreciation by timestage.

The Infeasibility Report is used to help the analyst determine why a feasible solution could not be found.

The Sensitivity Report provides information as to the amount that a variable in either the objective function or the RHS may vary before the solution will change.

The PLANET system does not simply take input data and fill in data matrices for a canned linear program. It is not a model but a highly elastic model-building system that can automatically generate unique mathematical models to support large and small, simple or complex business scenarios. Because actual problem formulation and data input are facilitated by PLANETS through the use of standardized "building block" terminology, PLANETS has been referred to as an

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open-end scenario and model building language for business planners. It keeps track of which business information is mandatory for any valid or feasible scenario description; in addition to this mandatory information, the user can include other optional business descriptors. There are 11 basic building block categories; each has its own specific attribute data, which are maintained via conversational dialogue and full-screen editors.

The first of these, *Timestage*, is a mandatory building block that defines the financial and productive planning horizon as well as permissible periods during which decision activity can take place. *Timestages* can correspond to calendar or budgetary time periods (for example, individual months or years) but more often represent decision periods which can be multiples of calendar time.

The *Facility* building block is also mandatory and represents geographic location and the availability of resources that are location dependent (for example, labor skills, floor space types, public utilities, and default area efficiency and work environment). *Facilities* are commonly used to represent plant shells. The attribute productive capacity is never applied to *Facilities*. Buildings or locations (*Facilities*) have no capacity; however, things that go into buildings (*Process Centers*) do have capacity.

The mandatory building block *Process Center* represents people, equipment, or any other resources that can have productive capacity. *Process Centers* must be assigned to a *Facility* with a status of either existing or potential. *Process Centers* represent resource requirements (for example, labor skills, and floor space type) and resource dependent fixed and variable costs as well as efficiency.

Strategy building blocks are optional and represent potential investment alternatives that can add, modify, combine, or remove *Process Centers*. Within any business problem, *Strategies* can interact and be mutually exclusive, dependent, contingent, or additive. This building block incorporates the details of financial amortization schemes and the timing options of expenditures. In the resulting mixed-integer mathematical formulation, *Strategies* are represented by integer variables.

The optional *Materials* building block represents purchasable commodities required by *Product-Routing* combinations. (For example, *Product* A produced via *Routing* 1 may require five pounds of *Material* X, a plastic compound; however, if *Product* A is produced via *Routing* 2 then three units of *Material* Z, a metallic alloy, would be required since the *Process Centers* referenced by this *Routing* 2 use totally different processing.) The *Material* building block also incorporates *Vendor* purchase plan availability and pricing options.

The *Vendor* building block of PLANETS must be referenced if the *Material* building block category is utilized. *Vendors* typically represent external sources for *Material* having a sourcing location. This building block can also be used to define inventories in scheduling models.

Market is an optional building block that represents potential external demand locations for a *Product*.

Product is the mandatory keystone building block that ties everything in the "English model" together. *Products* represent the marketable output of the business process being modeled. *Products* specify *Market* demand at various pricing levels for a given *Timestage*; this demand can have lower and upper range values, either of which may be forced into the solution by the user. The *Product* building block also defines *Product-Routing* combinations specifying permissible production options, *Material* requirements, and any

internally produced material needed. (*Transfer Product*).

The mandatory *Routing* building block represents alternative operating plans for producing a *Product*. *Routings* contain a sequence of existing or potential *Process Center* references with specific capacity attributes. Typically, more than one *Routing* is specified for a *Product* (otherwise no process selection is performed by the resulting model). *Routings* can also be mutually exclusive, dependent, or directly tied to a specific *Market* demand.

The *Freight* building block is optional and represents inbound, interplant, intraplant, and outbound logistic planning options, including cost and mode of transport.

The *International/Geopolitical* building block category is a collage of policy options. These can represent constraints dependent on country or economic community that concern tariffs, local content, balance of trade, trade complementation, or other specific policy. This category specifies volume or monetary limits, penalties, ratios, and exclusions. In addition, inflation and exchange rate can be specified by country and *Timestage*.

PLANETS can be used by management to evaluate the following questions, either independently or simultaneously:

— What to make,
— When to make it,
— Which markets to satisfy,
— How to make it,
— Whether to make or buy,
— Where to ship,
— Where to make, and
— How to purchase.

While the capability exists in PLANETS to evaluate all the preceding what-if questions simultaneously, not all problems or scenarios will be set up in this manner. For example, raw material and vendor selection are often not factors, or perhaps the processing sequence is already fixed and only logistics variables need to be evaluated. Any of the preceding criteria or sets of variables can be included or eliminated.

The direct financial benefits from the PLANETS model-building process are the reduction in procurement, manufacturing, and distribution costs achieved by taking advantage of the following:

— Differences in direct labor and fixed and variable burden rates,
— Increased equipment utilization,
— Optimal volume production,
— Best use of capital expenditure options,
— Higher volume purchasing and vendor pricing schedules,
— Reduced transportation costs,
— Elimination of low-profit and capacity-inefficient products,
— Optional market pricing/volume considerations, and
— Difference in currency exchange rates.

Since 1974, PLANETS has been used for over 80 major corporate studies as well as numerous divisional and plant studies. Figure 3 provides a percentage breakdown of the problem types that have been addressed using the PLANETS technology. Most of these modeling applications were performed by planning analysts who had little or no prior background in operations research.

Planets in Action — A Case Study

We will now describe a representative

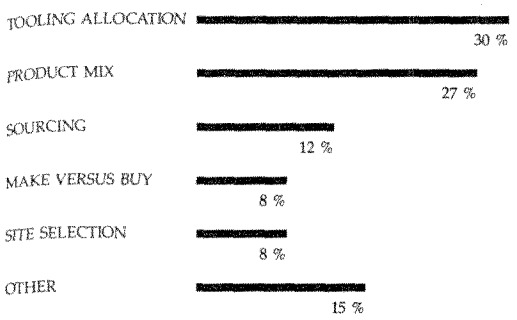

Figure 3: A breakdown of 80 major PLANETS studies by type.

case study that demonstrates many of the types of planning issues that can be evaluated with PLANETS. Most of the 80 major studies (Figure 3) were of the size and complexity of this case study. This example demonstrates that PLANETS models can be used for ad hoc and recurring applications.

This case study also provides a glimpse of the PLANETS philosophy or discipline that we suggest for each major study (Figure 4). We have found that at least 50 percent of the effort of the planning analyst should be devoted to working with management to properly define the scope of the problem in business terms.

In this particular study, management and the analyst jointly defined the following problematic situation:

— A new vehicle is planned for introduction in the marketplace in four years.
— Totally new major components will be required.
— Existing facilities do not have the capability to manufacture these components.
— New tooling, and possibly new facilities, will have to be procured.
— Tooling purchase and installation often require lead times of two to three years.
— New facility construction, if required, could involve more than three years effort.

The actual study involved 14 major automotive components. However, for simplicity we will focus on engines and transmissions only.

The issues that management wanted to optimize were

— How many facilities are required?
— What is the ultimate size of each facility?
— Which engine and transmission design or designs should be selected for each market?
— What is the best sourcing and distribution pattern for each component, in each year?

These issues had to be optimized for the following management objectives:

— Minimize the 10-year corporate cost;
— Adhere to export/import requirements; and
— Satisfy mangement's noneconomic constraints.

The planning horizon criteria are embodied in the PLANETS *Timestage* building block. While a standard 10-year financial analysis was needed, the actual decision timestages representing the planning horizon are four and add up to 12 years. The first *Timestage* represented three calendar years spanning the actual investment timing and the initial start of production. The next two *Timestages* represented the next two years of the plant capacity acceleration and modification. The final timestage represented seven business years, during which no tooling decisions were planned (Figure 5).

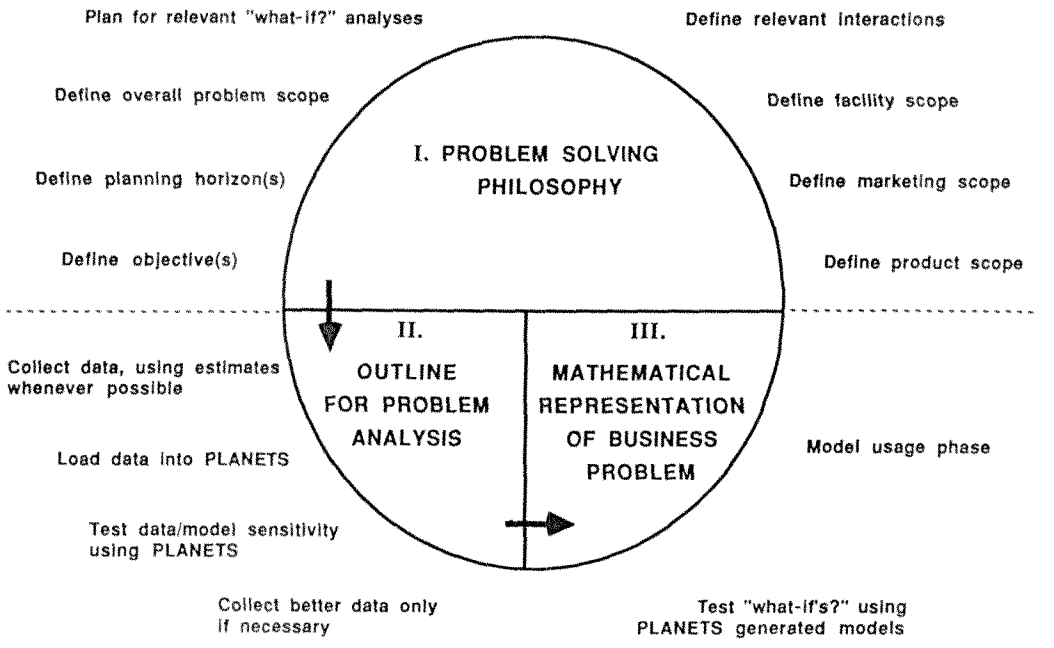

Figure 4: PLANETS discipline. The initial 50 percent of a typical project effort utilizes PLANETS problem structuring philosophy and terminology without actually accessing any PLANETS software. This involves defining overall business problem scope, planning horizons, and objectives. In the second stage, the user begins accessing the Planet System software to construct a database outline of the business problem. The completion of the project effort (final 25 percent) involves interacting with the system to perform automatic model generation and analysis.

There were two engineering designs for both engines and transmissions that could be marketed, each represented by a PLANETS *Product* building block. The locations where these components could end up on finished vehicles were worldwide and would be represented by the *Market* building block.

Eight locations were possible for new engine facilities and almost as many for the transmission facilities. The *Facility* building block contains information pertinent to location, such as floor space and the availability of public utilities.

The final size of each new facility was also a variable. Historically, tooling to manufacture the components was purchased and installed in modules with finite economies of scale. One-half a module may have one-half the capacity of a full module at two-thirds the cost. One-half, one, or two modules could be combined to create facilities of several different sizes at each potential location. Each module representation conformed to a *Process Center* building block specification. These *Process Center* building blocks are utilized by *Product Routing* building blocks.

In this study, six weeks elapsed as we defined the problem scope, issues, timing, and objectives with management using the PLANETS building block specifics and terminology. Once this information was in hand, the PLANET system was accessed, and the second half of the study

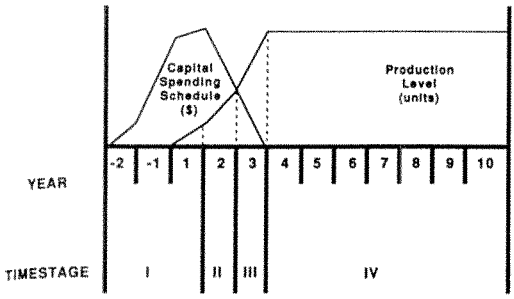

Figure 5: The case study planning horizon of 12 Years. The entire business planning horizon is predefined by using the TIMESTAGE building block category. Each TIMESTAGE segregates binary decision points. For example, each potential increase in production capacity levels is a decision point that would be represented by its own TIMESTAGE designation. The four production levels, while spanning 12 years, can be represented by four TIMESTAGES. Capital spending schedules of one or more years do not have to be represented by single TIMESTAGES since each TIMESTAGE can have a variable planning horizon length associated with it and any financial discounting would be handled accordingly.

effort began (Figure 4).

The types of data used in this study are listed in Table 1. This information was supplied by the user through a conversational dialogue specific to each PLANETS building block. Given this input, PLANETS generated the relevant interactions, and the stage was then set for the final what-if phase of the study (Figure 4).

In addition to "free run," (nonpolicy-constrained) economic optimizations, over 40 what-if management prerogatives were also modeled. Of these scenarios, only 10 were originally planned; the remaining 30 were the result of ideas spawned by management after reviewing the scenario output as it progressed, and they led directly to concepts which avoided projected costs of hundreds of millions of dollars.

Had the PLANETS study not been performed, management would have proceeded with capital appropriation requests derived by traditional manual analysis methods. The reduced expenditure projections provided by PLANETS were readily compared to this baseline.

The output determined the number of new facilities required, their locations, the size and tooling requirements of each facility, facility start-up timing, and specific product volume allocation and distribution patterns. This entire study effort, including the non-PLANETS portions, took approximately three months.

Further proof of the acceptance of this PLANETS analysis approach by management was the fact that these optimization results were fully implemented. In addition, this specific application did not end with the completion of this ad hoc study; it led directly to further usage. Three years after the site location study and once the facilities had been built, a PLANETS model focusing on engine variants only was used regularly to optimize the purchase and allocation of tooling sets to optimize shipping schedules and to optimize product mix allocations.

As this case demonstrates, planners have used PLANETS to determine what products to make, when to make or introduce a product, and where to base production. They used it to decide which markets to satisfy, where and how to ship, whether to make a product instead of purchasing it, how to make or process a product, and which vendors and purchasing strategies to use. No mandatory policy requires the use of PLANETS;

planners have used and continue to use PLANETS because they want to. By using PLANETS, they are able to evaluate these issues simultaneously, whereas in the past they could not.

What We Have Learned — 12 Years of PLANETS Experience

In the course of applying PLANETS technology worldwide, a number of lessons have been learned that have caused General Motors and EDS to adapt their game plan for implementing MS/OR technology to the changing environment. Here is what the past 12 years of implementing PLANETS have taught us.

Managers as Direct System Users

PLANETS was designed to capture the quantitative MS/OR expertise required to formulate, model, and solve complex business-planning problems. The original objectives of the PLANETS development and implementation effort were to minimize end-user dependence on MS/OR practitioners and to maximize the benefits of transferring mathematical modeling technology to business planners. We originally intended PLANETS as a decision support tool that management would use directly; we learned early on that analysts, not management, would be the hands-on users.

Management works through the analyst, and all the expert systems and user friendliness that we could possibly design into the system will not appreciably change that. Senior mangagement prefers to concentrate on managing the enterprise and to delegate hands-on analysis to analysts.

The Importance of Optimality

Experience has also demonstrated that managers frequently do not require optimal solutions. They have used the quantitative optimal results less than 10 percent of the time. The rest of the time they choose a less than optimal solution that satisfies qualitative criteria not incorporated in the model. PLANETS calculates

CASE STUDY INFORMATION

PROBLEM SCOPE

14 Potential Products
2 Engineering designs per product
7 Market areas
11 Potential facility locations
66 Basic tooling options per product
40 Economic scenarios

DATA

— Inbound, interplant, and outbound freight costs and modes
— Variable cost, capacity and efficiency per tooling option
— Fixed and variable burden cost
— Effect of shift differentials and overtime
— Fixed expenses for facilities and tooling
— Investment timing, options, schedules and amortization schedules
— Engineering compatibility of component designs
— Flexible capacity interference losses
— Local content requirements
— International trade complementation options
— Minimum export level requirements
— Balance of trade factors
— Vendor material availability and material costs
— 10-year product forecast by market
— Product transfer pricing options by market
— Penalties for lost sales

Table 1: While many different variables were included, the resulting models were not sensitive to all the data. Whenever possible, easily collectible range estimates (with some plus or minus variance) were input as opposed to difficult-to-collect, highly accurate point values. This study was typical in that 85 percent of the original data range estimates remained valid, while only 15 percent of the data needed refinement (greater accuracy).

the quantitative impact of these qualitative decisions. For example, management may override the PLANETS investment options in favor of their preference, while using PLANETS to optimize the remaining logistics and product-mix alternatives. Because optimization capability is guaranteed behind the scenes, management can now establish benchmarks for decisions. PLANETS is a form of decision makers' insurance. One divisional general manager said that he liked the PLANETS approach because he now knew the cost of going with a decision based on his "qualitative feel," compared to the quantitative or economic optimum. Because of such use, since 1974, we have added many more scenario evaluation and direct management controls to PLANETS.

Faster Algorithms Versus Scenario Manipulation

Since most of the recurring planning models are generated only three or four times a year or as needed to support ad hoc studies, such as facility site selections, turnaround times of one hour to one day are entirely satisfactory. Therefore, the mathematical solution algorithms currently available commercially are more than adequate to satisfy users . Further substantial improvement of the solution turnaround would generally provide minimal benefit to the business planner. Our assessment is based upon the content of requests for the development or enhancement of user-specified systems. Repeatedly, such qualities as solution integrity and input/output understandability rank higher than faster solution turnaround.

We have learned that the capabilities to evaluate and optimize specific scenarios must co-exist. A blend of solid MS/OR and simple scenario evaluation gives the planning analyst a sense of control and comfort. PLANETS has made a quantum leap in applied management science capability; problem formulations that used to take weeks or months now take days; models and matrices that would have taken days or weeks to generate even using commercial mathematical programming packages now take a couple of minutes; and mathematically optimized solutions are only minutes or hours away. In accomplishing this, MS/OR expertise has been leveraged, and in many cases replaced, by MBA skills.

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Supporting PLANETS

As is often the case, unexpected side effects accompanying a new technology overshadow the original objectives. While PLANETS helped us solve most of the quantitative puzzle, its ease of use created new organizational problems.

- How does management prevent the tool from being misused?
- How will the MS/OR activity adapt to user demands for training?
- How can competent PLANETS use be maintained when the successful business planners get promoted elsewhere?

In order to better support the development and implementation of PLANETS and other MS/OR technologies, the various management science and applica-

tions support staff functions involved were consolidated into what is now the Decision Technologies Division of EDS.

A blend of MS/OR practitioners, MBAs and explanners provides the nucleus of expertise that promotes PLANETS' use. This strategic analysis services group also provides professionally developed training programs at a variety of levels. A management appreciation course exposes financial and planning managers to business situations that would be good candidates for PLANETS applications. The PLANETS course for planning analysts is designed to accomplish true technology transfer and end-user independence.

Supporting this formal classroom instruction are professional documentation materials such as capabilities guides, user guides, and an overview of the system mechanics and mathematics.

Benefits — The Value of PLANETS

The benefits of using PLANETS have involved projections of significant monetary cost avoidance. A handful of the 80 major PLANETS applications are projected to have resulted in over $1 billion in documented cost avoidance. While the remaining studies were not fully documented or had no cost projection benchmarks, we estimate that PLANETS use results in at least two to three percent savings in overall capital expenditures.

Another effect of PLANETS is that more scenarios can now be generated and analyzed reliably. This has both tangible and intangible benefits; more scenarios analyzed should guarantee that less expense or more profitability are likely; as more scenarios are evaluated, the risk associated with scenario selection decreases.

Because PLANETS is ideal for evaluating scenarios with little more than estimated variables, less time is now required for each analysis. Even though PLANETS can review more variables simultaneously, less overall study time is typically required.

Finally, one of the best benefits of all is the satisfaction of knowing that PLANETS has successfully transferred MS/OR technology to planning analysis.

PLANETS has provided a means of taming the dynamic elements of the planning process. Electronic Data Systems Corporation is proud to provide professional planning technologies like PLANETS, which complement the overall planning procedures encountered in business.

Acknowledgments

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