Building Large Dynamic Models for Fun and Profit

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Abstract

Building large dynamic simulation models of an industry requires sound organizing principles and appropriate tools combined with a thorough understanding of the industry being modeled. In this paper I will describe how we build a simulation model for a client's business to answer the client's key strategic questions.

The models are large because they are based on physical, observable phenomena in the industry. They must take into account the stocks and flows of product and money, as well as represent managers' decision-making processes and the key variables that impact each producer's decisions. Most corporate decisions are based on physical or financial parameters, so the model structure is clearly understandable to the final user.

At Federal Group we use an effective methodology for building large-scale structural dynamic simulation models to address the real-world problems of business decision makers. This paper presents how we have successfully constructed such models for oligopolistic, capital-intensive industries. However, our methodology can be generalized to a broad range of other business environments.

Building Large Dynamic Models for Fun and Profit

Introduction

Simulation models are useful for many reasons. They improve one's understanding of historical, current, and future situations, allow running "what-if" scenarios, and are a self-consistent reflection of reality that keep track of complex relationships. They are an extension of decision makers' mental models, capable of correctly and completely computing the multi-faceted effects of any change. Federal Group's physically-based structural computer models are aimed at supporting decision makers in complex capital-intensive businesses. The models reflect the critical aspects of the business environment, as well as the effects of competitors' strategic decisions on producers and consumers. The models are as complex as is necessary to accurately reflect the business environment, but are designed to be transparent and understandable to the client users.

Federal Group has built models costing $100,000 or more, mainly for managers of Strategic Business Units (SBUs) within Fortune 500 companies, as well as for companies' general management. The models generate both industry pricing and capacity, which are the main determinants of current and future profitability. The principles, tools and procedures we use are outlined in this paper.

1. Modeling Principles

The principles behind all Federal Group methods can be divided into three broad areas: what is being modeled, how it is modeled, and the model's structure.

1.1 What to Model in an Industry

1.1.1 The Question

The first issue confronting a client and a model builder is to decide on a specific question that can be answered in a definable way by a model. The nature of the answer may be unknown at the outset, but the question will define the broad boundary of the model. For many industrial clients, the most general strategic question is: “given the industry structure, what can I do to improve the performance of my business in a variety of economic and demand climates?”. However, models built to answer more specific questions are also common.

1.1.2 The Boundary

Some people think that a model of the entire world that could answer all possible questions would be *the* solution to their problems. But if the fundamental question is, "what can we as industry participants do about our situation?" a well-defined model that accurately represents the structure of the business of interest will serve. Using exogenous time series for the macroeconomy, product demand, and other factors which are not under the client's control will make it possible to answer the question thoroughly for significantly less effort.

The boundary surrounds a closed system, with full accounting for all material inputs and outputs. A closed system forces actions to have reactions: it shows the feedback relationships. The boundary must be broad enough to include the variables that are under the client's control, but should be narrow enough to allow the model to be as simple as possible.

1.1.3 Level of Detail

A typical business model developed for an SBU client includes all of the producers of a product in the world. The most important (including the client company) are explicitly defined; the rest are aggregated. Worldwide product demand is also included. Frequently, the feedstock or other raw material inputs are exogenous. The system can include multiple production technologies, or encompass a group of similar, competitive products. Some products may be modeled as a chain of processes, in which the output of one production process is the input to a downstream plant.

A major determinant of modeled detail is composition: the breakout of an industry into producers, processes, regions, product grades, and end uses. Here the key is the specific question(s) that the model needs to answer. However, an important limiting factor on composition is data availability. If there is no data on a detail, or at least a qualitative assessment of its importance and impact, it is probably pointless to model it. Differentiation is another consideration: if there are no major behavioral or other differences among the pieces to be broken out, there is less reason to do so. In some cases, a product may not need to be modeled on a worldwide basis: some regions may not use the product, or it may be difficult or expensive to transport and trade.

Most strategic management questions can be answered with a ten year forecast period. This period covers two 4 to 5 year business cycles, and shows the 6 to 8 year commodity cycle that results from decisions that have delayed effects. The model output is shown at quarterly or annual intervals. The long forecast period also forces a reality check of the model structure and data.

The level of detail in the model reflects the above time frames. Details that change on a daily or weekly basis, such as spot prices and daily warehouse deliveries, are not modeled, since they do not affect longer term decisions. Monthly and quarterly changes, such as contract pricing and average inventory and production levels, are included, as they form the basis of observable and recorded industry behavior. Capacity planning and building, which usually takes one to three years, is shown explicitly. To ensure that the model reflects these time frames, and to keep computations simple by having many small and understandable adjustments, the internal time step is set to 16 or 32 per year, so each decision interval encompasses 1.5 to 3 weeks.

1.2 How to Model an Industry

1.2.1 Physical and Financial Structure

Physical and financial flows are represented in a natural way in a structural simulation model. This mapping is very important, for it verifies that no physical impossibilities occur, such as negative inventory, or shipments that are negative or exceed production and inventory levels. A physical model also conserves mass, which ensures that two producers are not both supplying a single customer and that all demand is met (subject to capacity and inventory limitations). Modeling the delays encountered in building and starting up a plant enables logistical reality to be accurately represented: for example, no one can construct a plant overnight.

Modeling the financial flows allows the product price to be accurately determined in the model. Variable production costs, which are (almost) always recovered in the price, are separated from the fixed and indirect costs, which may not be recovered if the market is weak. Knowing prices and costs makes it easy to calculate cash flow and profitability for each producer and process. Accounts payable and accounts receivable are modeled as explicit stocks, permitting accurate determination of working capital requirements.

All flows are in physical and financial units (tons, pounds/year, $/ton, etc.) which are natural to the business modeled. This makes the model results transparent and familiar to both the model builder and the client. It also simplifies error checking.

1.2.2 Generic Building Blocks

All of our models are built up from generic pieces. For example, standard inventory stock and flow structures are used for the feedstock, the product, and the production capacity. Capacity is simply an inventory of the product of an engineering firm that builds process plants. Pricing structures for a region, a product grade, or end use are similar, because all prices are influenced by production costs and by the supply-demand balance. Since the generic pieces are used in multiple models, they have been thoroughly tested in many environments.

In a model, each equation is replicated for each producer, region, and/or grade by the use of subscripts (arrays). This ensures that the structure for each is the same when this is appropriate, saves a lot of equation writing, and simplifies understanding and working with the model. Differences among producers, regions, or grades lie mainly in equation parameterization, reflecting our observation that many elements in an industry are often subject to the same types of influences.

1.2.3 Behavior

Decision making and other observable behaviors by managers in companies can be modeled. Behavior simply consists of day-to-day actions, and is ultimately based on the physical and financial information available to those managers. The model's physical and financial substructure clearly depicts the manager's environment, making the inputs to decisions explicit and quantifiable.

The basic form of a company's response to varying business conditions does not change greatly over a 10 to 20 year period. These reactions form part of the company culture with which newly hired MBA's (and the competitors!) become rapidly familiar. A company tends to continue to be an innovator, price leader, niche player, or commodity grade producer.

As long as a behavior is sensible in the limiting situations, it is not difficult to judge its form under intermediate conditions. For example, the severity of producer discounting increases as utilization goes down, but in most situations the discount offered will not go below production costs.

The form of behavior is similar for all producers: no one will increase prices as their utilization goes down. The detailed parameterization may vary, however, and can be determined from qualitative knowledge of the competitors, and from observing their historic behavior.

The easy way to discover how a detail should be modeled is to ask the decision makers. How have competitors reacted to a situation in the past? How do price negotiations with major customers take place? Which factors influence a producer's decision to expand? How long does it take to translate a perception of profitability into expansion plans? How long does the board of directors then take to approve the expansion? These types of questions cover physical, financial, and behavioral aspects of a model. We turn to the "back of the book" whenever possible, instead of relying on complicated regressions or other techniques that try to make up for a lack of understanding of the causes behind observed phenomena. Our models reflect the real world.

1.3 Structure of a Model

A typical business model's basic structure is shown in Figure 1. About 25% of the code is taken up by the physical flows section (bottom left), another 25% is used for financial flows (bottom right), and 20% is occupied by business environment and demand inputs (top). The remaining 30% controls the behavior of the competitors in the industry. The hard data requirements for the behavioral section are small, although qualitative information is extremely important here.

1.3.1 Physical and Financial Operations

Modeled physical stocks and flows are analogous to the actual stocks and flows in a plant. In each time period product is produced, limited by the amount of capacity in place, feedstock availability, and policy decisions. Product is stored in and shipped from inventory. Capacity can be in the process of being built, or may be shut down, restarted, or dismantled during each time period.

The financial flows, such as operating costs, fixed costs, and capital costs, are calculated along with the physical flows, and form the basis for the policy decisions.

1.3.2 Policy and Behavior

The policy/behavior component of a model is divided into three decision categories. The first is capacity and production planning. These actions are only indirectly influenced by competitors' decisions. They include decisions to add, restart or shut down capacity. Production decisions involve determining and maintaining a desired level of inventory and plant utilization. Both types of decisions can be made quickly in response to perceived changes in market conditions, but capacity decisions can have implementation delays of up to three years.

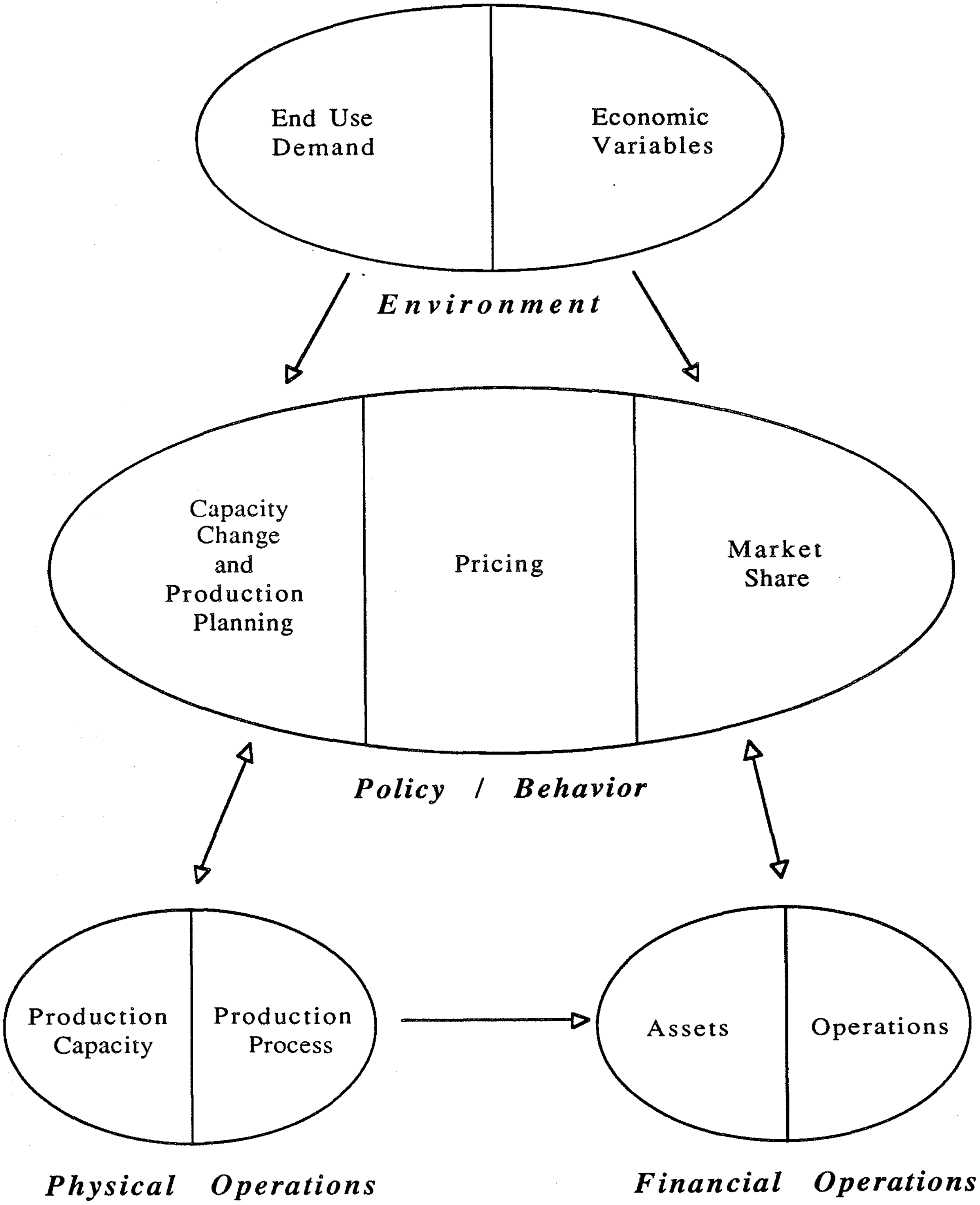
The second policy/decision area is market share determination. Market share assignments depend on product availability, price offered by producers, and other end user preferences. A producer's ability to ship product, which is determined by market share decisions, affects actual inventory levels and utilization. Market shares may change within a month of changes in end user perception of producers' pricing and availability.

The third area of policy and behavioral decision making is pricing. There are usually two types of price determination. A base price for the commodity grade depends strongly on the cost structure of producers in the region and on the regional perceived supply/demand balance. The minimum possible price is usually the variable production cost. A higher price can be charged if the market will bear it. Each producer may offer discounts from the base price to attempt to increase share or improve utilization, or may try to extract a premium from its customers if demand is higher than normal. Pricing for premium grades is derived from commodity pricing, subject to supply/demand sensitivities and other factors. Pricing generally responds quite quickly to cost and demand changes.

The model keeps physical phenomena and perceptions of these phenomena carefully separated. Perceptions are based on past physical reality and drive decision-making in each area. Physical reality constrains implementation of decisions by enforcing building delays, conservation of mass, and the need to maintain non-negative capacities and inventories.

The physical, financial, and business environment sectors form the machine which is controlled by the behavioral component. This representation closely approximates the working environment in which a manager must make decisions. The model keeps track of all decisions made and shows the logical consequences of decisions made by each producer in the system. Because the system is closed, nothing is forgotten, and because it is based on physical, observable phenomena, nothing that is physically impossible can occur.

Figure 1: Model Design



2. Modeling Tools

To build the type of models described in Section 1, appropriate hardware and software tools are needed. At Federal Group we use MicroVAX and Macintosh computers, and have developed proprietary software, similar to Pugh-Roberts' Dynamo III/F, to deal with the specialized issues that arise from building large dynamic simulation models.

2.1 Hardware

For most industries that Federal Group has modeled, a microcomputer is not suitable because of speed and memory constraints. Most models require over 1000 lines of subscripted code in a language such as Dynamo, which is equivalent to 10,000 or more spreadsheet rows. A practical alternative is an engineering workstation, as it is well suited to large number-crunching tasks.

2.2 Software

Software is far more important than hardware. The software needs fall into three categories: model processing, input data control, and output data manipulation. At this time there is no package that meets all three needs while being able to handle the large models described here.

2.2.1 RatDyn

Federal Group has developed a precompiler for model processing called RatDyn. It generates Fortran code similar to Dynamo III/F, but with several significant enhancements. These are in unit checking, error checking, simplified coding, readability and documentation. External functions for some specific modeling needs have also been added.

RatDyn's unit checker requires that every variable or constant be declared in the source code, preferably close to the defining equation, with correct units and a text definition. The unit checker verifies that all equations have consistent units on both sides of every operator. This prevents data input in percent from being used as a fraction, and ensures that variables given in tons/year are not summed with those whose units are cents/lb. A similar analysis is done on the subscript domains.

RatDyn error checking ensures that no syntactic errors are deferred to Fortran. It also checks that all equations are defined for all appropriate subscripts. Simultaneities, in both initializations and active equations, are discovered and reported. RatDyn also determines whether the equation typing is appropriate. For example, it redefines an auxiliary that is not used in any other active equation as a supplementary. This optimization reduces the model's running time.

Model coding is simplified and clarified by permitting long variable names (up to 31 characters) and any combination of upper and lower case letters. Equations can be continued over multiple lines, and indented to any desired column. Spaces and tabs may be included in the equations to improve readability. Timescripts have been eliminated. Subscripts are enclosed in square brackets, while parentheses and braces are used in the other parts of the equations.

The model may be split over multiple files, allowing separation of equations from data, and, for example, splitting physical, financial, and behavioral phenomena. Dividing code into modules in this way permits making changes to a (variant of a) module, and recompiling without changing any of the other modules. The RatDyn Cross Reference Analyzer cross-references variables by both equations and modules, simplifying the determination of key feedback links across modules.

RatDyn includes additional external functions not found in Dynamo. For example, several functions ensure that any excess demand for a producer's product is reallocated to the other producers, if they have available capacity, reflecting the real marketplace. An additional table function format ensures that accumulated input or averages over a period (e.g. a quarter or year) are treated as such, so that the accumulation of output point values over the same time period equals the input for that period. Several other functions have been added to improve tracking of discrete events, such as capacity building and dismantling, which can only occur in large "lumps", and for keeping track of linear averages.

Figures 2 and 3 show some of the differences between Dynamo code and RatDyn code using a subscripted epidemic model (Richardson and Pugh 1981, 379). Both versions can be compiled.

Figure 2: Dynamo III/F Epidemic Model

```
* EPIDEMIC MODEL WITH THREE AGE GROUPS
NOTE
C   CHLDRN=1
C   ADLTS=2
C   ELDRLY=3
FOR A=CHLDRN,ELDRLY
NOTE
L    SUSC.K(A)=SUSC.J(A)+DT*(-INF.JK(A))
NOTE     SUSCEPTIBLE POPULATION (PEOPLE)
N    SUSC(A)=ISUSC(A)
T    ISUSC(*)=1980/980/695
NOTE    INITIAL VALUES OF SUSC
R    INF.KL(A)=TSICK.K*CNTCTS.K(A)*FRSICK(A)
NOTE     INFECTION RATES (PEOPLE/DAY)
NOTE
A    TSICK.K=SUM(SICK.K)
NOTE     TOTAL SICK (PEOPLE)
L    SICK.K(A)=SICK.J(A)+DT*(INF.JK(A)-CURE.JK(A))
NOTE     SICK POPULATIONS (PEOPLE)
N    SICK(A)=ISICK(A)
T    ISICK(*)=10/5/5
NOTE     INITIAL VALUES OF SICK
T    FRSICK(*)=.05/.01/.03
NOTE     FRACTION SICK (DIMENSIONLESS)
A    CNTCTS.K(A)=TABLE(TABCON(*,A),SUSC.K(A)/TOTAL(A),0,1,.2)
NOTE    SUSCEPTIBLES CONTACTED PER INFECTED PERSON
NOTE    PER DAY (PEOPLE/PERSON/DAY)
T    TABCON(*,CHLDRN)=0/2/3/3.5/3.8/4
T    TABCON(*,ADLTS)=0/1.5/2.3/2.6/2.85/3
T    TABCON(*,ELDRLY)=0/1/1.5/1.8/1.93/2
NOTE    TABLES FOR CONTCTS
N    TOTAL(A)=SUSC(A)+SICK(A)+RECOV(A)
NOTE    TOTAL POPULATIONS IN EACH AGE GROUP (PEOPLE)
NOTE
R    CURE.KL(A)=SICK.K(A)/DUR(A)
NOTE    CURE RATES (PEOPLE/DAY)
T    DUR(*)=7/8/10
NOTE    DURATION OF DISEASE (DAYS)
L    RECOV.K(A)=RECOV.J(A)+DT*CURE.JK(A)
NOTE    RECOVERED POPULATIONS (PEOPLE)
N    RECOV(A)=IRECOV(A)
T    IRECOV(*)=10/15/0
NOTE    INITIAL VALUES OF RECOV (PEOPLE)
NOTE
NOTE    CONTROL STATEMENTS
NOTE
SPEC   DT=.5
SPEC   LENGTH=50
SPEC   PRTPER=0
SPEC   PLTPER=1
```

Figure 3: RatDyn Epidemic Model

```
* "epidemic model with three age groups"
i       children = 1
i       adults = 2
i       elderly = 3
for pop = 1,3
d       children        = people        "population of children"
d       adults          = people        "population of adults"
d       elderly         = people        "population of elderly"
d       pop             = people        "population types"
#
l  susceptibles[pop] = susceptibles[pop] + dt * ( -infected[pop] )
n     susceptibles[pop] = isusceptibles[pop]
t       isusceptibles[*] = 1980 /  980 /  695
a  infected[pop] = tsick * contacts[pop] * fraction_sick[pop]
#
d       susceptibles     =  people      "susceptible population"
d       isusceptibles    =  people      "initial value of susceptibles"
d       infected         =  people/day  "infection rate"
#
a  tsick = sum(sick)
l  sick[pop] = sick[pop] + dt * (infected[pop] - cured[pop])
n     sick[pop] = isick[pop]
t       isick[*] = 10 /  5 /  5
t       fraction_sick[*] = .05 / .01 / .03
#
d       tsick    =  people      "total number of sick people"
d       sick     =  people      "number of sick people"
d       isick    =  people      "initial values of sick people"
d       fraction_sick = number  "fraction of contacts leading to sickness"
#
a  contacts[pop] = table{tabcon[*,pop],
                 (susceptibles[pop] / total_in_group[pop]), 0, 1, .2}
t       tabcon[*,children] =   0 / 2   / 3   / 3.5 / 3.8  / 4
t       tabcon[*,adults]   =   0 / 1.5 / 2.3 / 2.6 / 2.85 / 3
t       tabcon[*,elderly]  =   0 / 1   / 1.5 / 1.8 / 1.93 / 2
n     total_in_group[pop] = susceptibles[pop] + sick[pop] + recoveries[pop]
#
a  cured[pop] = sick[pop] / duration[pop]
t       duration[*] = 7 /  8 / 10
l  recoveries[pop] = recoveries[pop] + dt * (cured[pop])
n     recoveries[pop] = irecoveries[pop]
t       irecoveries[*] = 10 / 15 /  0
#
d       contacts         =  number/day   "susceptibles contacted "_
                                         "per infected person per day"
d       tabcon           =  number/day   "table for contacts"
d       total_in_group   =  people       "total population in each age group"
d       cured            =  people/day   "cured rate"
d       duration         =  day          "duration of disease"
d       recoveries       =  people       "recoved population"
d       irecoveries      =  people       "initial value of recoveries"
#
spec  dt = .5
spec  length = 50
spec  prtper = 0
spec  pltper = 1
n     time = 0
d       1        = number ## tells RatDyn the name for pure numbers
d       dt       = day   "time period for calculations"
d       length   = day   "time model runs to"
d       prtper   = day   "print period for output variables"
d       pltper   = day   "plotting period for output variables"
d       time     = day   "current model time"
```

2.2.2 Input Data Control

RatDyn can directly extract data from a spreadsheet saved in SYLK format, and convert it into RatDyn statements for tables and constants. This process eliminates the need to rekey client input data, which often comes on diskettes. The spreadsheets allow direct consistency checking and graphing of input data. It is also much easier for the client to understand spreadsheet data than the semi-mysterious table and constant statements in model source code.

2.2.3 Output Data Manipulation

Dynamo III/F's runtime package has been modified to accept the longer variable names used in RatDyn, and can also accept named subscripts and ranges. Accuracy of the runtime's command parsing has been improved, so that undocumented and possibly confusing shortcuts are no longer accepted. The runtime symbol table has been unpacked, increasing efficiency and speeding up model runs by up to 30 percent.

At present, we have found the Apple Macintosh to be the best environment for capturing and analyzing Dynamo output. The Macintosh running MultiFinder allows the user to switch between several programs with consistent, user-friendly interfaces, and permits easy data transfer between programs. The Mac is connected to the processor running Dynamo, printed output is captured in a text file, and this data is imported into a spreadsheet such as Microsoft Excel for graphing and analysis. In this way presentation quality plots can be made, and comparing multiple model runs is quite easy.

2.2.4 Future Enhancements

Federal Group plans to continue RatDyn development. Non-contiguous FOR statements and subscripted subscripts will simplify generating the coupling equations needed to link producers to the appropriate regions and grades. Separate compilation of modules, similar to Pascal's Units, will greatly speed up making modeling changes and testing model structures.

A new runtime package is being developed which will be able to generate the standard emulated graphics of the Tektronix 4010, rather than character plots. The new runtime will also simplify transferring data to spreadsheets and comparing output from multiple runs.

RatDyn is written in RatFor, a Fortran preprocessor, which enhances its portability across Unix workstations and 386 machines. Eventually, it will run in a Unix, Macintosh MPW or DOS Extender environment, as well as under the current VMS.

3. Modeling Process

The modeling process is interactive between the model builder and the client company. The model builder interviews people within the client company and works with them to gather quantitative and qualitative data. The model is then built and calibrated against observed historic data. A base forecast and scenarios are generated with the client's exogenous input data, and the results are presented to the client. The client is educated about model contents and applications, and the model is updated annually. New scenarios and additional detail are added whenever needed.

"The client" consists of people at many levels in the client company, who are involved with the model in a variety of ways. Senior management authorizes the project and has ultimate oversight. A senior staff member is frequently the main contact and information conduit, directing questions to appropriate departments, providing extensive background knowledge, determining who should be interviewed, and developing a thorough understanding of the workings of the model. This person usually has both business and planning experience. We work directly with experts in various functions to collect and analyze data. Interviewees contribute additional information and insight when needed.

3.1 Interviews and Data Gathering

Every industry has many unique features. Both to gather the qualitative inputs needed and to build interest in and support for the model, extensive client interviews are extremely important. Since all aspects of the business must be covered, people from production, marketing, sales, finance, planning, materials/logistics, and input acquisition are included. Suppliers, customers, and competitors can also be interviewed if the client feels this is relevant. Questions cover the following general topics:

- What is your function and what are your major concerns on a monthly to quarterly basis?
- What are the main business issues and events you need to know about, both within the company and in the business environment, in order to perform your job properly?
- How do you compare your company with the competitors, both in terms of your function and in general?
- What do you see as the main issues facing your company and industry?

The data needs depend on the level of detail in the model, but fall into the following categories:

- Historical industry prices.
- Historical capacity data for each competitor.
- Current cost structure data for each competitor.
- Historical and forecast input material price series.
- Historical market share data.
- Historical cash margin or cash flow data.
- Historical macroeconomic and demand data.
- Forecast macroeconomic and demand data for a base case forecast.

Data is invariably incomplete, and sometimes may be inconsistent. The advantage of a structural dynamic model is that these inconsistencies are found rapidly and can then be corrected. The model forces the creation of a consistent database for the client. Clients tell us that if they are not already tracking this data, they ought to start doing so!

3.2 Calibration

Model calibration is a data consistency check and validates the model by comparing its output to the past ten years of history. As the historical period almost always includes both strong and weak demand periods, and the model generates both price and capacity, each producer's response to various conditions can be determined. The calibration process also leads to insights about the industry being studied, since this is frequently the first time that all the data and historic observations have been subjected to a consistency check of this extent and intensity.

Calibration proceeds in several major stages. In the first stage, an "empty model" is built. This model has no active behavioral components, and is used to check the consistency of the input data. The environment, feedstock costs and availability, cost structure, and end use demand inputs are checked to ensure they are both plausible and consistent.

The second stage adds historical price as an input, and enables the capacity and market share behavioral components. Qualitative behavioral information that differentiates producers is also entered at this stage. Then capacity changes are calibrated to history. Capacity change is a function mainly of price and of business environmental conditions, especially demand. Additions, shutdowns, and restarts must be generated by the model at this stage.

In the third stage the roles of capacity and price are reversed. Capacity becomes an input, pricing behavior is enabled, and price must be calibrated given the known historic supply/demand balance. A main source of qualitative input is the knowledge that price response is monotonically increasing as the supply/demand balance gets tighter. Unique forces in the industry that affect pricing are also taken into account in this stage.

In the last stage, the observed price and capacity are both disabled, and the model must generate price and capacity. If the capacity calibration in the second stage was good, this calibration can be used in place of observed capacity and the third stage can be skipped. The observed historic data does not include construction start-ups and planning stages, which are really implicit in the data, and are calculated by the model. The model can thus ensure that what was observed (or thought to have been observed) is physically feasible.

Gaps in data become obvious during calibration, since faulty data leads to unexplainable results which do not match historical facts. The calibration process is usually interactive with the client, as questions are answered and experts consulted about the meaning of the data and possible causes for observed model results.

Once capacity and pricing are calibrated, other outputs, such as market share, can be compared to historically observed phenomena. This is frequently difficult to do in detail due to incomplete data. However, being able to generate output that makes sense in the context of the industry is an adequate calibration test.

3.3 Base Case

The base case forecast serves two very important functions. It is the standard scenario against which all alternate scenarios and what-if analyses are compared, and it is another major test of model validity. The length of the forecast interval is longer than that of many other types of business models, so that the input assumptions are tested more rigorously.

The base forecast is usually based on fairly simple, conventional forecasts for the macroeconomic environment. Feedstock and other input prices are often assumed to follow a simple upward path, even if historically they showed much more volatility. This simple environment highlights the importance of the effects of industry structure on behavior. Using multiple versions of a base forecast, with different exchange rates, interest rates, inflation rates, or demand is also possible, but has rarely been requested by clients.

The base forecast may bring out modes of behavior that have not been observed historically, but which do, upon reflection, make sense. This is a very important test of model validity. If unexplainable occurrences are observed, the availability of structural and physical detail in the model makes it possible to track their causes. It is then possible to determine whether the result is due to faulty behavioral assumptions or incomplete or incorrect data, or whether the result is, in fact, a logical consequence of the structure and behavior of the industry's participants. In this way the business understanding of those working with the model is improved.

3.4 Alternate Cases

There are two major classes of scenarios: "events" and "strategies". Events are changes in the business environment such as recessions and other exogenous demand changes, or unanticipatable happenings such as a hurricane shutting down the Gulf Coast. Strategies are short or long term actions taken by a producer (or group of producers) that may change the structure or behavior of competitors in the industry. Some strategy examples include: mergers and acquisitions, forward and backward integration, pricing changes, and R&D investment changes.

For analytical clarity, scenarios are usually run one at a time, and each scenario is compared to the base case results. Scenarios can be combined to study synergistic or opposing effects. Sensitivity analysis using a set of similar scenarios can show how important a given factor is in determining industry behavior. Scenario analysis also further proves the structural soundness of the model, since the causes for changes in results are explicit and analyzable.

3.5 Model Use Over Time

During the above four stages, client interaction with the model builder and the model is informal. Except for the interviews, only one or two representatives of the client company are closely involved. To consider the model to be truly successful, however, it must be used by the client company. This can be accomplished in several ways.

In addition to providing a consistent database, the model can help generate consensus within the client company, both by offering a forum for airing disparate views and by providing a way for viewing the effects of locally rational decisions on the company as a whole. One or more formal meetings, which include all of those interviewed and any others deemed appropriate by the client, serve to sign people on, inform them of the model's existence, and to disseminate results. Discussions of scenario results at these meetings also improve the model's usefulness as a framework for strategic planning and decision making.

The model is designed to be updated and expanded. Its modular structure makes it easy to add detail (e.g. additional regions or producers), as well as to expand it to include feedstocks, end markets, or additional competing products. The model is updated once per year, using the previous year's actual results. In this way the model becomes more accurate over time, as a longer calibration period with consistent input data becomes available. The model is also updated to reflect changes in industry structure: mergers, acquisitions, and other exogenous factors. The model generates capacity expansions and shutdowns on its own, usually with no need to change the calibration parameters.

Some clients like to use the model themselves to generate scenarios and business forecasts, but most will opt to have this done by the model builder on a quarterly or annual basis. Clients are provided with full documentation of their model, with all assumptions, inputs, and feedback relationships clearly explained.

4. Fun and Profit

Each model for every industry has unique aspects, and shows some (initially) surprising results. Every industry is complex, but the complexity can be modeled in a structural way based on physical, observable phenomena. Some examples of real models and results follow. The general process for building these models was as described in Section 3 above. Most clients have confidentiality agreements with Federal Group, and must therefore remain anonymous.

4.1 Calibration Surprises

In a chemical intermediate model, the economics of each plant had been given as inputs. However, it proved impossible to force the model to shut down a plant known to have been decommissioned in 1983. Upon questioning, the senior manager noted that this plant had very poor economics and high environmental cleanup costs, which had forced the shutdown. The junior people, who had provided the data, had been unaware of this history.

In a world wide polymer model calibration indicated that price sensitivity to the supply-demand balance varied greatly by region. To match observed prices, the European producers had to be much quicker to cut prices to maintain share than the US producers. This behavior was later confirmed by the client.

In another model it became clear that feedstock pricing and product pricing had to be linked in a "netbacking" situation. Upon questioning, the management said that this was so in Europe and Asia, but not in North America. They noted that in Europe about 30% of the value added margin (between feedstock and product operating costs and final product price) went to feedstock producers, while 70% was kept by the product producers. Calibration of the Far East region showed that there the netback margin had to be about 50%. The client subsequently confirmed the model calibration.

4.2 Strategy Options

For a specialty polymer used in certain industrial applications, a physical, structural model showed that issues of composition are key. Overall demand for the product was flat, but regional demand in Asia was growing rapidly. The Asian market consists of many small buyers, widely separated geographically, rather than a few large, concentrated buyers as in the U.S. Competing in this market would require a redesign of the salesforce and incentives because of changes in dollar productivity per salesperson.

A model of a group of semi-interchangeable specialty polymers was used by the client company in negotiations with a potential joint venture partner. The joint venture was formed, and the model continued to be used for comparison with internally generated forecasts. For the next two years the model results were far more optimistic than the internal strategic forecasts had been. In fact, the company did even better in this business than the model predicted.

A model of a high volume polymer showed several counter-intuitive results. A feared merger between two competitors would in fact have no significant effect on the market, as one of the competitors' plants would be shut down in either case. This model also showed that a recession would force quicker shutdowns of excess capacity, leading to improved profitability over the remainder of the simulation period. In addition, the model suggested that several potential client joint ventures in Europe and Asia would cannibalize some of the client's current sales, and lower his average prices due to the extra supply. These results also led to a re-examination of the client's own assumptions about the future environment.

5. Conclusion

Large, structural dynamic models are extremely useful in helping clients improve their understanding of their business and explore strategic alternatives in a thorough, quantitative way. Modeling the industry as a closed system yields sensible, understandable results, and ensures that a company's business environment is fully and correctly taken into account.

Asking a definable question, setting reasonable boundaries, using appropriate hardware and software tools, and obtaining hard and soft data from a client are the key elements necessary for building a good model. Building a model is an interactive process requiring an understanding of both business and dynamic modeling issues. The input data is subject to a more exhaustive test of validity than in other types of modeling exercises, since both the historical and forecast periods are ten years or more in length. The resulting model can be used to analyze short, medium and long term issues, and provides an ongoing tool for a company's strategic and business planning activities.

Building a business model is fun. It is also very profitable for the client who can understand his business better than the competition does, and can act now to ameliorate the adverse effects of a changing economic climate or decision making by competitors.

Reference

Richardson, G., and J. Pugh, **Introduction to System Dynamics Modeling with DYNAMO**. Cambridge, MA. The MIT Press, 1981, p. 379.