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NEELY SALES REGION

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TO:

SUBJECT: Outline of Proposed Presentation for HP3000 International Users Group Meeting in Lyon, France

I. Topic: Interfacing Quantitative Modeling Techniques to MFG3000

II. Background

A. MFG3000

1. What does it do
2. What doesn't it do

B. Some useful mathematical programming models

1. Exponential Smoothing

a) What is it

2. Net Present Value

a) What is it

3. Linear Programming

a) Single period

1) What is it
2) What are its limitations

b) Multi period

1) What is it
2) What are the advantages over single period

III. Application of Models and MFG3000

A. Exponential Smoothing

1. Forecast Demand

a) Establishes a master schedule of end items

B. Multi Period Linear Programming/Net Present Value

1. Determines if forecasted demand will maximize net present value of return on investment to firm

a) Adjust master schedule to maximize net present value

1) Realize that some opportunities cannot be carried over to subsequent periods

a.) Implies a sub-optimum solution may be necessary

C. MRP3000

1. Determines lower level requirements to build master scheduled items

D. Multi Period Linear Programming

1. Utilize to optimize mix of detail parts to be fabricated

a) Capacity constraints

IV. Example

A. Happy Peddler Bicycle Company

Interfacing Quantitative Modeling Techniques to MFG 3000

MFG 3000 is set of 3000 based application software available from Hewlett-Packard to aid in the planning for and control of raw materials. MFG/3000 consists of four modules which can be purchased separately or as an integrated package. The modules included in the current release of the software are Engineering Data Control (EDC), Inventory and Order Status (IOS), Materials Requirements Planning (MRP) and Standard Product Costing (SPC). Basically, EDC is used to structure a Bill of Materials (i.e., outline what and how many parts go into the fabrication of a final assembly item). IOS keeps track of which of these detail parts are on order (whether purchased or fabricated in-house) and how many of each detail part is available in inventory for issue. MRP looks at a company's master schedule (the schedule of end items that the company is planning to build); looks at EDC to determine all of the component parts and how many of each are required to build the end item; looks at IOS to determine if there are adequate detail parts in inventory or on order to fill the requirements generated by MRP; and finally, displays a list of suggested new orders (net of inventory) for these component parts.

Purchase orders are released for those parts that are purchased from outside vendors and production control releases orders for those detail parts that are fabricated in-house. At the appropriate time, the completed detail parts are released to the shop and the finished product is assembled. Sounds great! What else could a company possibly require to make this process work?

First, we assumed the Master Schedule existed and will always exists. Not a valid assumption! Someone has to create the Master Schedule. This is not a problem if items are put into the schedule <u>only</u> when an actual sales order is received. But what if we wanted to smooth out our production and try to predict over some planning horizon what the demand will be for our products? What tools does Hewlett-Packard offer in the area of forecasting?

Currently, nothing. Quantitative methods however, provides a model for forecasting demand based on past experience, but weighted to reflect any additional information which we might have. (i.e., sudden increase in sales due to some technological edge that we have over our competitors,or there are seasonal variations in our sales, etc). This technique is called Exponential Smoothing.

Once we have done a reasonable job of forecasting demand, the next question to ask is "is it profitable to make these products?" Again, Hewlett-Packard currently does not address this area with a purchasable software product, but there are models available which will aid us in making a decision. One such tool is a Multi-period Linear Programming model which utilizes discounted cash flows as inputs. Multi-period is used because we are assuming a planning horizon of more than one year and discounted cash flows are used because we are assuming that the firm wishes to maximize the net present value of its investments over time. (Building a finished good is an investment in labor, material and overhead).

Finally, we must consider the capacities of the firm in being able to actually produce the goods that we have determined will maximize the net profit of the company. Here, as before, we can utilize Multi-period Linear Programming with capacities as inputs to the model.

In summary, there are several modeling techniques available from Quantitative methods which will aid a company in better controlling its day to day operations and thereby increase its profitability. Even though Hewlett-Packard intends to address all areas of manufacturing from materials management to financial accounting, there is no need to wait for the one vendor solution. Utilize what has been available for years...Quantitative methods!

INTERFACING QUANTITATIVE MODELING TECHNIQUES
TO MFG 3000

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Hewlett-Packard Company is well-known in the electronic's industry as a manufacturer of computers and computer peripherals, components, instruments, microwaves, as well as many other products. Singling out the computer product line, we find software products that enhance the capability of the hardware. On the 3000, we find MPE the powerful operating system that controls and schedules online and batch processes. Additionally, there are several compilers, data management techniques, and general purpose utilities to aid the user in designing and implementing applications unique to his environment. During the 1980's Hewlett-Packard will continue to enrich its computer with new and/or improved products keeping in mind the basic philosophy of the company of not being a "ME TOO!" vendor. IE, developing products that will make a technological contribution to the marketplace. Expanding on this philosophy, some great marketeer (not to be confused with mouseketeer) asked "Why not combine our knowledge of computers and our knowledge of manufacturing and offer products that will aid other manufacturers in better controlling their environment? Let's develop something that is general purpose and can be used by anyone from a fruit processor to an aircraft manufacturer; something that is friendly and easy to implement and use; and let's take advantage of our existing hardware and software tools."

Business Systems Division was born with these goals in mind. Specifically, the areas that needed to be addressed were: Materials Management; Production Management; Order Management; Financial Management; and Sales Management. Because Materials Management yielded the quickest return on investment (by aiding in inventory reduction, thus reducing inventory carrying costs and freeing up working capital) and is the basic input to production, it was the logical place to start.

MFG 3000 is set of 3000 based application software, available from Hewlett-Packard, to aid in the planning for and control of raw materials. MFG/3000 consists of four modules which can be purchased separately or as an integrated package. The modules included in the current release of the software are Engineering Data Control (EDC), Inventory and Order Status (IOS), Material Requirements Planning (MRP), and Standard Product Costing (SPC). Basically, EDC is used to structure a Bill of Materials (i.e., outline what and how many parts go into the fabrication of a final assembly item). IOS keeps track of which of these detail parts are on order (whether purchased or fabricated in-house) and how many of each detail part is available in inventory for issue. MRP looks at a company's master schedule (the schedule of end items that the company is planning to build); looks at EDC to determine all of the component parts, the lead times and how many of each are required to build the end item; looks at IOS to determine if there are adequate detail parts in inventory or on order to fill the requirements generated by MRP; and finally, displays several reports with recommendations for appropriate action to be taken on each component part based on its lead time, due date, and order policy. (eg. new orders, orders to cancel, orders to expedite, etc.)

Purchase orders are released for those parts that are purchased from outside vendors and production control releases orders for those detail parts that are fabricated in-house. At the appropriate time, the completed detail parts are released to the shop and the finished product is assembled. Finally, Standard Product Costing is the means by which we are able to value our Bills of Material based on user-input accounting standards.

In short, we are able to reduce our inventory levels of raw material because we only order what we need, when we need it, versus stockpiling and hoping that we'll need it.

Sounds great! What also could a company possibly require to make its manufacturing process run smoothly and efficiently? Just purchase MFG 3000, load in your parts structure information, do a physical inventory count and load IOS, then run MRP and you'll know exactly what, when, and how much to order. Right? WRONG! We made several invalid assumptions that MFG 3000 does not address but must be considered in the overall manufacturing process.

First, we assumed that the Master Schedule miraculously appeared and will continue to reappear with each new planning horizon. Not a valid assumption! Someone has to create the Master Schedule. This is not a problem if items are put into the schedule only when an actual sales order is received. But what if we wanted to smooth out our production and try to predict over some planning horizon what the demand will be for our products? What tools does Hewlett-Packard offer in the area of forecasting? Currently, nothing. Quantitative methods, however, provides us with several models for forecasting demand based on past experience. One such model is Linear Regression. With this model, we are stating that there is a correlation between two or more variables, (i.e., one variable is dependent on one or more variables) and this relationship can be expressed in a linear fashion in the form $Y = A + BX + e$ where Y is the dependent variable, X is the independent variable, A is the Y intercept, B is $\frac{\Delta Y}{\Delta X}$ (slope) and e is the error term (the portion of Y's variance unexplained by X's variance.) The objective is to plot the "best fit" line between several points and use this line to predict the future. Figure 1 is a plot of past sales history. The Y axis is quantity sold and the X axis is product availability.

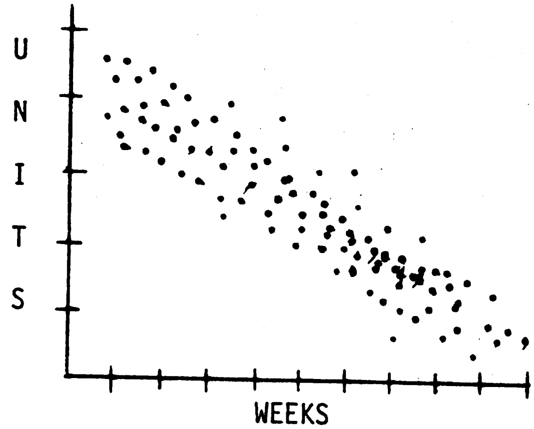

FIGURE 1

The method of determining the "best fit" is called Least Squares, which requires the simultaneous solving of two equations. These are:

$$\sum XY = A\left(\sum X\right) + B\sum X^2$$
$$\sum Y = nA + B\sum X$$

where $\sum$ = summation
X = observations on X coordinate
Y = observations on Y coordinate
n = total pairs of observations

In our example the best fit line is $Y = 24.51 - 1.63X$.

Figure 2 is a graphic representation of this line. We can now readily predict the sales of our product simply by supplying an availability in weeks and solving the equation. For example, if we expect our product availability to be 13 weeks on the average over our planning horizon, then our demand will be 3.31 units.

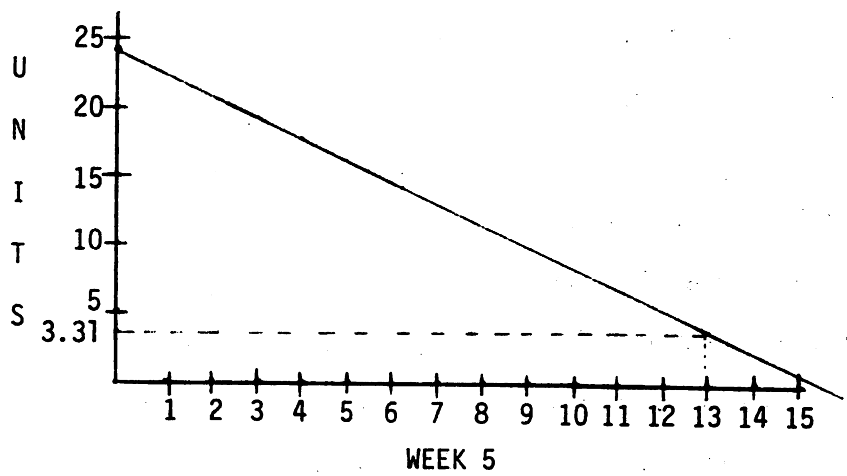

FIGURE 2

We have now established a master schedule for product #1 of our product line and continue in a similar fashion for the remainder of our goods.

This logic can even be applied to situations where demand is seasonal as can be seen in figure 3. In this situation, a line is fitted to a curve depicting cyclic demand for a product.

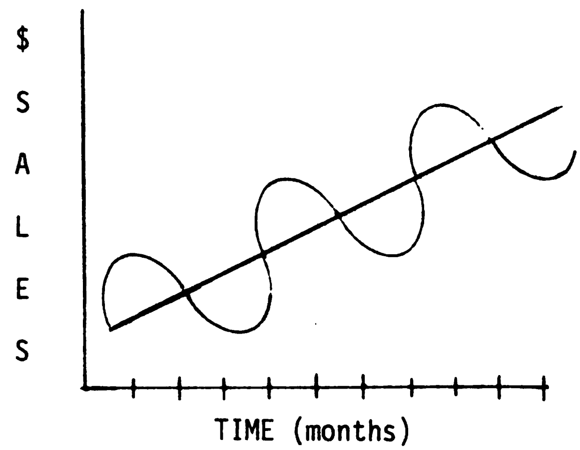

FIGURE 3

However, in many companies there isn't a correlation between a product and some variable (at least no quantifiable relationship). Stating that there is a linear relationship between sales and time in figure 4 would be nonsense. In this situation, a better technique to utilize would be

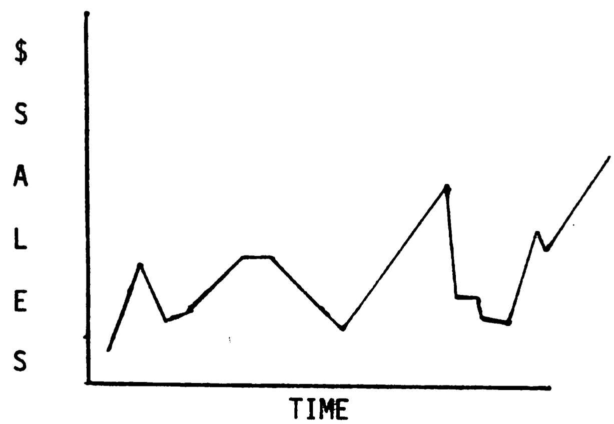

FIGURE 4

an exponential smoothing model. With this model we are able to forecast demand based on past experience but weighted using one or more smoothing constants to reflect any additional information that we might have. (i.e. sudden increase in sales due to some technological edge that we have over our competitors) and can be used for a steady increase or decrease in events.

The formula for an exponential smoothing model using one constant is:

$$\overline{F}_n = F_{n-1} + \alpha(D_n - F_{n-1}), \text{ or}$$

$$\overline{F}_n = D_n + (1 - \alpha)\, F_{n-1}$$

where: $\overline{F}_n$ = Forecasted Demand in next period
α = Smoothing constant $(0 < \alpha < 1)$
D_n = Actual Demand in current period
F_{n-1} = Forecasted Demand previous period

Essentially, what we are doing is predicting demand in the next period (n) based on what we predicted would happen in the current period (n-1), what actually happened and weighted by some constant .

For example, if we had experienced the following sales:

Period	Demand (Actual)	Forecast
1975	12	
1976	13	
1977	12	
1978	20	13
1979	?	15.8

and implemented this model at the end of 1977 (forecasting 13 units in 1978 assuming a smoothing constant of .4), then our forecast for 1979 would be

$$F_{1979} = F_{1978} + \alpha(D_{1978} - F_{1978})$$

$$F_{1979} = 13 + .4\,(20 - 13)$$

$$F_{1979} = \underline{15.8}$$

Using a larger value for α , say .8, demand for 1979 is 18.6 which says that we are putting an 80% weight on actual demand and a 20% weight on what we forecasted the demand to be in the previous period. The choice of α is normally guided by judgment though you could predict economically best or near best values through studies. This model can similarly be used for other products in our line and can be refined using triple smoothing constants of alpha, beta, and gamma.

Once we have done a reasonable job of forecasting demand, the next questions to ask are "do we have sufficient capacities to satisfy this demand? and is it profitable to make these products?", or - restated, given unit costs and selling price of my products and a finite factory capacity, "what optional mix of products should I build to maximize my profit subject to my demand constraints?".

Again, Hewlett-Packard currently does not address this area with a purchasable software product, but there are models available which will aid us in answering the questions posed.

One method that is commonly used is the "Business as Usual" approach. Others find sanctuary in the "S.W.A.G." model. Perhaps a better approach would be to utilize another technique from Quantitative Methods called Linear Programming. The object of this model is to maximize (eg. profit) or minimize (eg. costs) some function subject to a set of constraints. Consider the example of a firm that produces three products and has a planning horizon of one year. Table 1 is a summary of the firm's operating environment. To make one unit of product A it takes five machine hours and four assembly hours with each unit contributing $1.00 to profit.
($ PROFIT = $ SELLING PRICE - $ PRODUCTION COSTS)

Product	MH/Unit	LH/Unit	Demand	SP ($)	PC ($)	PM ($)
A	5	10	4	11	10	1
B	2	1	1	3	1	2
C	3	2	2	5	2	3

Total Machine Hour Capacity = 100 hours
Total Labor Hour Capacity = 80 hours
Total We Can Sell = 60 units

TABLE 1

Product A is the top end of the product line. It's a great product and unlike some of our other products, it works. We expect to sell at least four units. Product B is the low end of our line and is subject to frequent failures, but we expect to sell at least one unit during this planning horizon. Product C is the middle of our line and contributes the most to our profitability, so we'd like to sell a bunch. We have a bottleneck in our sales force in that they can only sell sixty units total of all products. There is one additional constraint imposed by the president of our company who states that "as long as I'm running the show, we'll never, I repeat NEVER, produce more than a total of five product B's! and/or product C's. I wanted to drop those darn things from the product line, but mom wouldn't let me."

The next step is to reduce table 1 to a set of equations which will be solved simultaneously. These are:

$5A + 2B + 3C \leq 100$	Machine Capacity Constraint
$4A + B + 2C \leq 60$	Sales Constraint
$B + C \leq 5$	President Constraint
$10A + B + 2C \leq 60$	Labor Capacity Constraint
$A, B, C \geq 0$	Nonnegativity Conditions
MAXIMIZE $A + 2B + 3C$	Objective Function

These equations can be solved manually using the SIMPLEX METHOD or very easily using your HP 3000 Computer. The final iteration (optional solution) is displayed in table 2. Note that some new variables, S_1 through S_4, were added. These are called Slack variables and are required to change the equations from inequalities to equalities. One Slack variable is required for each equation.

	A	B	C	S_1	S_2	S_3	S_4	Solution
S_1	0	- .5	0	1	0	-2	- .5	50
S_2	0	- .6	0	0	1	-1.2	- .4	22
C	0	1	1	0	0	1	0	5
A	1	- .1	0	0	0	- .2	.1	7
f	0	- .9	0	0	0	-2.8	- .1	

TABLE 2

Looking at the right most column we will find the optimal solution which says:

> Produce 7 units of A, 0 units of B, and 5 units of C for a total profit of $22.00 (7*$1 + 5*$3). Note that the firm has 50 hours of surplus machine time and 22 units of surplus sales capacity. The resource that was totally exhausted was the available labor hours.

Additionally, the solution tells us that for one more unit of labor we can expect a -10¢ increase in total profitability (see column S_4 Row F) and that we are not willing to pay for any additional machine time or sales capacity since we have excess. Also, note that if we decided to produce one unit of product B anyway, we would have to decrease production of product C by one unit resulting in an increase in machine hour surplus of .5 hours; an increase of available sales capacity of .6 units; an increase of product A production of .1 units and decrease in profitability of 90 cents. The model can be rerun relaxing or increasing the constraints to give the effect of a "what if?" model.

However, many firms have planning horizons that extend beyond one time period. For these firms, a static model may not be useful or may yield sub-optimal results. Fortunately, Quantitative Methods does provide models covering multiple time periods called Multi-Period Linear Programming or Dynamic Programming Models. For simplicity, consider the case of a company that produces a single product and is faced with making decisions over the next three time periods. Unit production costs are \$5, \$6, and \$6 for time periods 1, 2, and 3 respectively and must be paid in the period incurred. Storage costs of \$1 per unit per period must be paid in advance in the period the product is produced. Production capacity in period 1 is 40 units; in period 2, 50 units; and in period 3, 60 units. Unit selling prices are \$7, \$6.50, and \$8 for periods 1, 2, and 3 respectively. Sales capacity (demand) is 50 units in periods 1 and 2 and 70 units in period 3. The firm operates on a cash basis and has an opening balance of \$225. Cash from sales is received one period after the period in which the sale was made.

The objective is to maximize the profits subject to the constraints and realizing that products produced in one period may be sold in another. Let X_{ij} denote the product where i = period produced and j = period sold. Therefore, we end up with six unique combinations X_{11} (built in period 1, sold in period 1); X_{12}; X_{13}; X_{22}; X_{23}; X_{33} (assuming all products are sold at the end of period 3). Our contribution to profit then, for each period, is Selling Price - (Production Costs + Storage Costs). For period 1 it is \$7 - \$5 - 0. Our objective function for all periods thus becomes:

$$\text{MAXIMIZE} \qquad 2X_{11} + .5X_{12} + X_{13} + .5X_{22} + X_{23} + 2X_{33}$$

For the constraints the equations are:

Production

Period 1 $X_{11} + X_{12} + X_{13} \leq 40$

Period 2 $X_{22} + X_{23} \leq 50$

Period 3 $X_{33} \leq 60$

Sales

Period 1 $X_{11} \leq 50$

Period 2 $X_{12} + X_{22} \leq 50$

Period 3 $X_{13} + X_{23} + X_{33} \leq 70$

Cash

Period 1 $5X_{11} + 6X_{12} + 6X_{13} \leq 225$

Period 2 $-2X_{11} + 6X_{12} + 7X_{13} + 6X_{22} + 7X_{23} \leq 225$

Period 3 $-2X_{11} - .5X_{12} + 7X_{13} - .5X_{22} + 7X_{23} + 6X_{33} \leq 225$

The means of solving these equations would be identical to that of the pervious example except that I would recommend doing it via computer versus manually (unless, of course, you are a masochist).

The output table would also be similar to the previous example and would indicate how many to produce during each time period.

If the time periods that we are referring to are a year in length, this methodology could be further refined by using discounted cash flows as inputs to the model.

The outputs from this model can now become the inputs to our master schedule, but time phased to achieve the greatest profitability (or net present value if discounted cash flows are used). And as was previously mentioned, MRP can explode these master-scheduled items into the component parts and produce, as its output, reports of what, how much, and when to order the detail parts, and thereby reduce investments in inventory levels and minimize production disruptions due to stockouts.

Establishing a master schedule is only one of many problems that a firm must face. As the orders are released to the shops, the company may experience bottlenecks or queuing of parts waiting to go through a given workcenter. Perhaps a given type of machine in the workcenter is creating the bottleneck. A method for determining how many machines that you will need to eliminate the problem area is available with Queuing Theory (Waiting Line Models).

A modified version of the transportation model may be utilized to place or schedule orders on different machines taking into consideration the efficiency of each machine. Program Evaluation and Review Techniques (PERT) has a use in scheduling long lead time items. And the list goes on and on.

In summary, there are several modeling techniques available from Quantitative methods which will aid a company in better controlling its day to day operations and thereby increase its profitability. Even though Hewlett-Packard intends to address all areas of manufacturing from Materials Management to Capacity Planning, there is no need to wait for the one vendor solution. Utilize what has been available for years...Quantitative methods!