Using Modeling Software for Operations Improvement

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Given the advances made in information technology, both hardware and software, it has become possible to create software for operations improvement for use in the academic and small business environment that is technically on-par with the most sophisticated product available. In this paper we describe one such software, HOM: Operations Management Software for Windows and comment on its managerial orientation. We give examples of its use for case analysis. We briefly describe and compare HOM with similar software available on the market and share some of our teaching experiences.

1. Introduction

We believe that for large and small organization's their operating system is a key source of competitive advantage. While large organizations can rely on internal staffs, well known consulting organizations (Anderson Consulting, A.T. Kearney, etc.) and complex and expensive software systems (SAP, BAAN, etc.) smaller independent organizations or operations within these firms require a different solution approach. However, given the advances made in information technology, both hardware and software, the solution approach need not be technically inferior to the most sophisticated product that is available on the market. Thus, we should be able to bring state-of-the art approaches for problem solving and improvement of operations into the small and medium business environment.

This can be achieved through creating software that illustrates the power of algorithmic, simulation, and model building approaches to solving large and complex problems faced by operations managers the world over; and provides a tool that is not simply academic in content but one that can provide answers to practicing managers. It would also be useful for business school students, both undergraduate and graduate, who are trying to analyze cases and solve every-day problems faced by operations managers. An overriding concern in the design and development of such a system is that both individual students and practicing managers should be able to come up to speed and be able to use the software within a short period of time and with minimal learning effort.

These systems should be also based on two somewhat overlapping concepts. First, we must recognize that managers understand the problem environment and the availability of data in a language that is different from that required to develop and implement technical solutions to their problems. Second, the trade off between problem precision and rapid scenario evaluations should always come down on the side that facilitates the latter. Thus, the software system should stress managerially oriented data inputs and problem formulation philosophy. Therefore, the "real" technology or the engines for optimization and simulation are hidden from the decision maker. What are visible to the user are the screens and dialog boxes for stating the problem in managerial language. Alternative scenario analysis should be facilitated by having it built in whenever possible or with simple, user initiated parameter selection windows. Every attempt should be made to keep the problem formulation, analysis, and report generation format consistent across different problem environments. These design features underscore the decision analytical framework and the need for software to have minimal learning cost.

At a minimum, the problem solving environments should address the following five key competitive advantage drivers:

1. Process and customer service improvements by process analysis and waiting line management
2. Response time improvement by time management and process analysis.
3. Quality management using statistical process control and acceptance sampling.
4. Supply chain management by inventory modeling and material requirement planning
5. Capacity management by forecasting and aggregate planning.

In the next section, we give an overview of the software system (HOM) we developed for use in the small business and academic environments keeping the design considerations discussed in view. We highlight the features of HOM that have been specially crafted to better explain the managerial implications of the Operations Management techniques; and also briefly comment upon the design challenges in developing such a software. In Section 3, we describe how to use HOM. In Section 4, we give two examples of the use of HOM to analyze case studies. In Section 5, we compare HOM to two other substantial but inexpensive software systems available for students and businesses, Win QSB created by [1] and POM for Windows developed by [10]. We conclude in Section 6, with some of our teaching experience with HOM.

2. Software Overview

An overview of the capabilities of the HOM software system is given below in Table 1. The special features of the individual modules are then described.

2.1 Process Analysis

At the present, other than HOM, no low-cost-process-analysis software exists. This is indeed a limitation for solving process design or process improvement problems. Process analysis is at the heart of Operations Management. It provides insights into product cost and flow time. Service guarantees can not be crafted without recourse to such analysis. It addresses capacity management, which is often the starting point for any analysis of operations. The Process Analysis module of HOM can be used to model up to 15 products or services. Each product has a unique task sequence, and can be assigned a unique priority, and lot size. The module is capable of modeling

Table 1
Competitive Advantage from Operations Using HOM

Competitive Advantage Driver	HOM Software Module
• Process Improvements	• Process Analysis • Waiting Line Analysis
• Supply Chain Management	• Independent Demand Inventory Systems • Material Requirements Planning (MRP) • Facility Location & Transportation (Forthcoming)
• Time to Market	• CPM-PERT-Crashing • Process Analysis
• Capacity Management	• Forecasting • Aggregate Planning
• Quality Management	• Statistical Process Control • Acceptance Sampling

several types of labor and resources for performing specific tasks. Each task can be modeled as processing jobs one at a time, batch by batch, or as a continuous flow. A task can require a setup in addition to run time. Randomness can be modeled in demand arrival and task processing time. The scheduling discipline can be first come first served (FCFS) or one that saves setups. Results available on successful execution include: Production of each product, capacity utilization for each resource, labor utilization, delays due to labor and/or material unavailability, as well as the flow time distribution for each product. The unique feature of the process analysis module is that the users not only obtain capacity and labor utilization statistics (with identification of the bottleneck resources) but also the entire flow time distribution. Often, the latter is extremely hard to obtain but essential in developing a service guarantee, and can not be obtained using back of the envelope calculations when there is randomness in job arrival or task processing time.

2.2 Waiting Line Management

The typical waiting line package available for educational or small business use forces the user to make distributional assumptions about the inter-arrival time and service times. Moreover, these packages rarely if ever provide the standard deviation of the queue length or waiting time. These two variables are of critical importance in designing a service system or call center. In HOM, the inter-arrival pattern can be any one of Exponential, Erlang (of any degree), General (where only the first two moments of the distribution are specified), or Empirical. When the distribution is empirical, the user can input observed frequencies. The service time distribution can similarly be - Exponential, Erlang, General, or Empirical. HOM has the ability of simulating a waiting line environment so that queue-joining disciplines can include Random, Shortest Line, Jockey, and Cyclic, and the job selection criteria can be the popular FCFS or the Shortest Processing Time rule. The standard waiting line outputs are produced, namely, the average time in the system, the average time in the queue, the average number of customers in the system, and the average number of customers in the queue. In addition, HOM graphically depicts the wait time distribution, and in a unique manner provides the standard deviation of the above four statistics.

2.3 Project Management

PERT and CPM are two of the most frequently used techniques in Operations Management. Text books on Operations Management invariably cover: Critical Path Analysis, and PERT. HOM's project management module includes CPM and PERT analysis. HOM has virtually no limitation in the size of projects that can be analyzed. In addition, when it comes to crashing, HOM uses linear programming to determine the activities to crash. The PERT module has a built-in simulator to determine the completion time distribution as well as the criticality indices of activities. These features are novel to HOM. The standard outputs include: Early and Late Start information, Slack, and Gantt Chart. In addition graphic and text outputs are produced depicting the completion time distribution (for PERT) and the criticality index. Thus, HOM has features that extend the capabilities of these traditional techniques. For example, the completion time distribution can be used to understand what is the nature of variability: Is it a low probability of a very long delay or a symmetric distribution around the mean completion time? It can also be used to prioritize activities for uncertainty reduction by performing rapid what if analysis.

2.4 Forecasting

The forecasting module, due to the variety of techniques and user options, was the hardest module to design. There are several trade-offs that need to be made with respect to which aspects of the forecast to offer as a default option and how to allow (in what sequence) changes in the options. These changes have to be made so that the decisions take a tree like structure. If the user examines the dialog box where the options for the forecast are selected very carefully, s/he will notice that by choosing a particular option such as simple exponential smoothing will close out other options such as regression. In the parameters dialog box of HOM, options that are either fixed by a choice or disallowed due to a choice appear gray in color. This automatic closing out of options is probably the hardest part of designing the interface, both from the user's perspective as well as from the algorithmic perspective. The programmer has also to check whether the options are permissible. For example, if the smoothing constant for exponential is entered as -0.1 or 2.0, HOM should immediately warn the user that the value is not allowed.

The techniques encapsulated in HOM are: Exponential Smoothing, Trend Regression followed by Exponential Smoothing, FIT Smoothing, Moving Average, Simple Average, Best of these Techniques, Weighted Moving Average, and Winter's Method. Multiple Regression is also included as an option. HOM allows for user determination or program optimization of smoothing parameters, allows for de-seasonalization and de-trending of data prior to constructing a forecast (in other words permits divide and conquer), automatic plotting of data, results, and deviations from actual. HOM also provides a robust set of statistical measures to evaluate the quality of the forecast. The measures are available for both the time series and multiple regression models, thereby facilitating their comparison.

2.5 Inventory

The inventory management module of HOM can be broadly classified into models for independent demand inventory management and models for dependent demand inventory management. The nine models that are available under independent demand inventory management are shown in Figure 1. Under continuous review models HOM allows, Finite or Infinite Replenishment Rate, Quantity Discounts, Back Ordering, Safety Stock Calculations, and also performs (in a unique manner) the Joint Optimization of Order Quantity and Safety Stock. Under Periodic Review Models, HOM allows the user to compute the Safety Stock for achieving a given level of lead-time or fill rate service level. The data for the nine models are entered in the same format! The novel feature of the design is that upon selecting the model, only certain parts of the data entry spreadsheet can be changed (and are shown in blue).

The dependent demand part of HOM contains a full scale MRP solver. The MRP takes as input the Bill of Materials and automatically generates the Low Level Code. The design of the data spreadsheet is unique in the sense it allows the user to toggle using the right mouse button between the MRP records for parts and the Bill of Materials information. HOM allows different batching rules (such as Fixed Order Quantity, Fixed Period Quantity, Lot for Lot, Least Unit Cost, Least Total Cost, and the Silver Meal heuristic). It allows the user to override the schedule generated by HOM (thus permits rescheduling) and allows the user to specify whether parts can be expedited or not. In addition, HOM computes the set up and holding cost for each part and assembly. This permits the user to optimize the production schedule by rescheduling the parts requirements. These features have been designed so that the user can carry out what if analysis and later on hook into a capacity management module (possibly implemented in a spreadsheet). The MRP module has been used in an industrial setting with over a 100 distinct parts and 14 sub-assemblies.

2.6 Aggregate Planning

One of the classic applications of optimization techniques in Operations Management is concerned with developing production plans over the medium term horizon. HOM's aggregate planning module enables this application with certain realistic features such as incorporation of set up time and set up cost. The user can model up to three products, develop plans up to 24 time periods and incorporate hire/fire costs, shift employment minimums and maximums, etc. Costs due to lost sales, subcontracting, or backorders can be specified, along with cost of over time, different amounts of available hours in different periods, safety stocks, as well as, starting and ending inventories. HOM's engine develops mixed integer optimal solution. It also emulates chase and level production and workforce strategies, thus enables the user to compare alternate policies. This much computing power is usually available only in uniquely tailored and developed production planning systems.

2.7 Quality Management

HOM's quality management module implements both statistical process control as well as acceptance sampling. Standard charts include $\overline{X}$, *R*, *s* charts; and *p*, *np*, *c*, and *u* charts. Several statistical tests are provided. These enable the user to judge whether the process is in control or not. The acceptance-sampling module can be used to plot the Operating Characteristic (OC) Curve and also to determine a sampling plan.

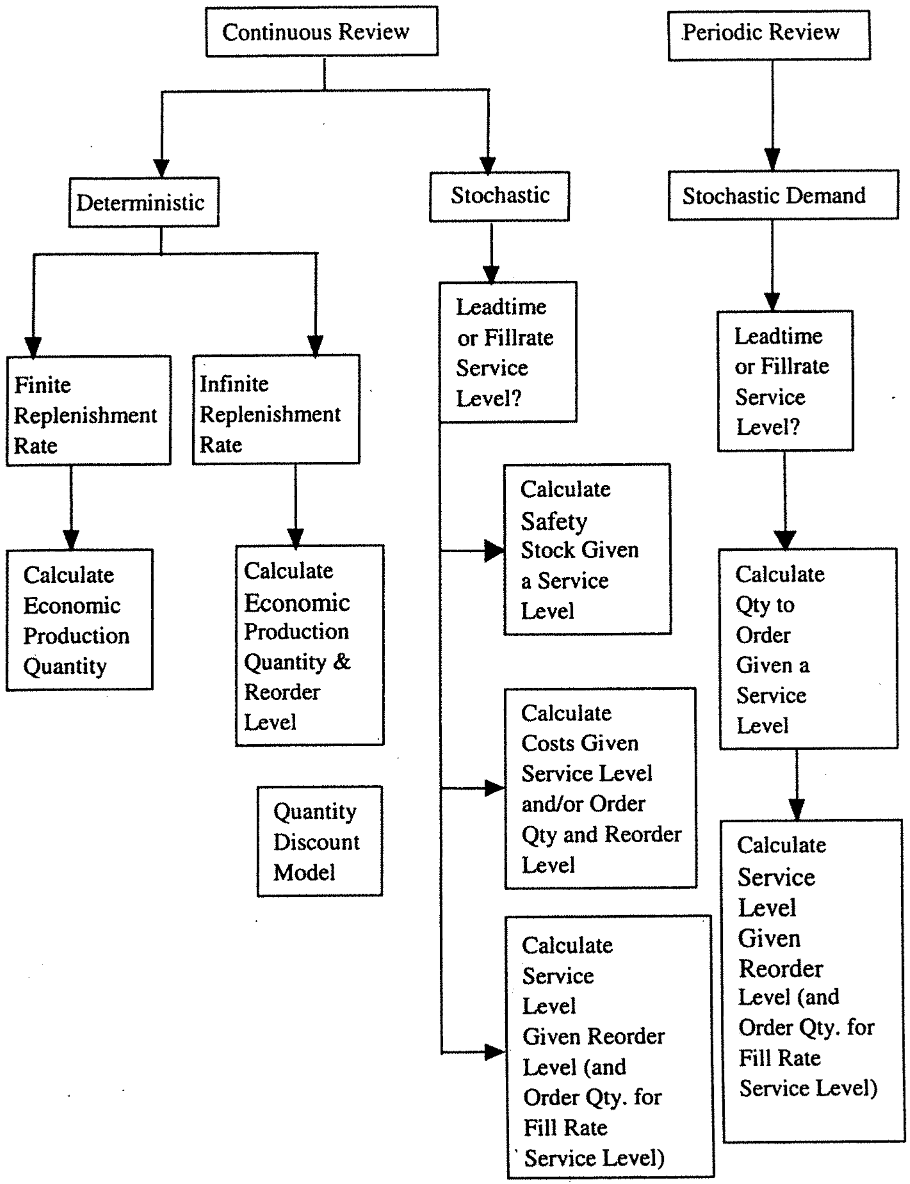


Figure 1 *Independent Demand Inventory Models in HOM*

3. Using HOM

The operating philosophy behind HOM is to have the user specify (1) broad problem-related input date (i.e., dependent and independent variables for forecasting demand) in a familiar *spreadsheet* format and (ii) data needed for model specification (i.e., the number of periods to forecast in the forecasting model) called *parameters*, in a single dialog box (the Parameters Dialog box). For ease of use and report generation, data can be exported from and imported to HOM from commercial Windows based spreadsheet packages. Results can be exported to word processing software, commercial spreadsheet programs or saved for future reference. Each HOM module has a unique How to Solve help file, found by using the command line HELP option and then the Index. These help files sequentially move the user through all the steps that are required to solve a particular operations problem. In addition to module-specific functions (which are explained in each of the How to Solve help files), there is a set of general capabilities that apply to all modules and are discussed in the How to Get Started help file.

The manual contains the technical assumptions, examples and details that are the analytical underpinnings of each HOM module. The manual is a WORD document and is resident on the CD.

The HOM package was developed as a low cost alternative. One of the goals continues to be: Make the HOM software accessible to students, business, and researchers the world over and at a low cost. Thus, the software along with manuals, solutions, and updates are available from the Internet at http://www.stern.nyu.edu. Another goal is to keep the software current both technically and technological. To this end, we plan to add modules related to supply chain management and logistics (such as facility location and transportation/warehousing network design). To keep HOM updated technologically, we plan to convert it so that it can run on any platform (currently Windows 3.1, 95, NT, and 98 are supported). A full 32-bit version of the software will be released in early 2001.

The initial window in all modules has the same visual topography: a command line; a tool bar; and an initial spreadsheet window for entering the broad problem input data. As with any Windows-based product, HOM has a tool bar that gives direct access to the most-often-used functions. Again, we use a combination of Windows-specific and HOM-specific icons. The first eight icons are familiar to Windows users and invoke the functions of New, Open and Save files, Print and Preview print files, and information manipulation functions of Cut, Copy and Paste. The next five icons are unique to HOM. These icons are shown below.

The first icon is in the format of a HOM Parameters Dialog box and allows the immediate jump to this dialog box from any stage in the problem-solving activity. The second icon unique to HOM is in the form of a graph, and using it automatically produces a plot of the data, if feasible, for the last specified variable. The third icon is in the form of a jogger and automatically Runs the last problem that was specified within the Parameters window. The fourth icon is in the form of a graph and text document and clicking upon it displays the Results of the last run. A previously saved result, can also be viewed using the Open option to retrieve any previously saved results. The fifth icon is in the form of a "hand writing" and is used to create a Log file for a data file or a result file. The log file is time stamped and useful for storing notes about what-if scenario analysis.

The last two icons in the HOM icon line allow the user to (1) get more general information about the current model, and (2) use a Bubble help for particular items. A comprehensive tutorial case (Mastercraftsmen of Newport) with data files and sample outputs is included as part of the distribution.

In addition to the software and the Tutorial Case, this package contains two integrated cases, Ice Queen Snow Blowers and United Bank Branches, that allow the user to apply many of the above models within a single organizational setting. Ice Queen presents a set of problems faced by a manufacturer of snow blowers, United Bank Branches presents a set of problems faced by a money center bank trying to gain efficiency by merging two branch locations. Cases involving only one task area (for example, Toy City Audit for Project and Time Management), as well as information-only databases for some classic Harvard Cases (for example, forecasting input data for the *Blanchard* case) are also included. Data files for all sample problems mentioned in the technical manuals are included in each module directory. HOM is available to instructors, after registration, from the World Wide Web: http://www.stern.nyu.edu/HOM.

4. Examples

In this section, we describe two examples: One from Process Analysis and the other from Project Management.

4.1 Process Analysis - Cookie Making Example[1]

We model a *deterministic* process for making custom baked cookies. We assume that only one type of cookie is made and that is sold a dozen at a time. We expect forty-four orders of one dozen each day. Thus:

Number of Products:	1
Order Size:	1 dozen
Demand per day:	44

The process to make cookies is as follows: Ingredients are first mixed in a bowl that has a capacity to mix dough for three dozen cookies at a time. (In the example modeled, each order for a dozen cookies is different, thus has to be mixed individually.) The dough is then spooned on to a cookie sheet one at a time. The sheet is then placed in an oven that can hold a batch of one dozen cookies. The cookies come out of the oven 10 minutes later and then can be placed anywhere to cool for five minutes. They are then packed one dozen to a box. Finally payment is required which takes the same amount of time for a batch up to 100 dozen. Worker requirements and other details are given below. There are five workcenters in this process as listed below.

Name	Type	No. of Machines	Max dozen cookies that can processed w/o additional set up
MIXSPOON	One at a time	1	3
OVEN	Batch	1	1
COOL	One at a time	100	1
PACK	One at a time	1	1
PAY	Batch	1	100

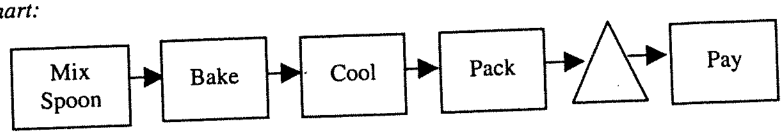
Labor:

Name	Number of Workers
Baker	1
Helper	1
Dummy	100

Process Recipe:

Process Step	Name of Work center	Wrkcntr Avg. Set Time/ Lot (MIN)	Wrkcntr Avg. Run Time/ Unt (MIN)	Type of Labor	Labor Avg. Setup Time (MIN)	Labor Avg. Run Time (MIN)
MIX&SPOON	MIXSPOON	6	2	Baker	6	2
BAKE	OVEN	10	0	Baker	1	0
COOL	COOL	0	5	Dummy	0	0
PACK	PACK	0	2	Helper	0	2
PAY	PAY	1	0	Helper	1	0

Process Chart:

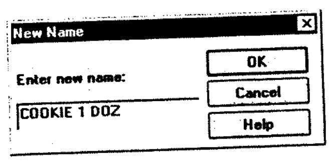


	Mix Spoon	Bake	Cool	Pack	Pay
Set up Time:	6	0	0	0	1
Run Time:	2	10	5	2	0
Labor Used:	Baker	Baker	Dummy	Helper	Helper
Labor Time:					
Set up Time:	6	0	0	0	1
Run Time:	2	1	0	2	0

Some of the data entry screens are shown below during the data entry stage.

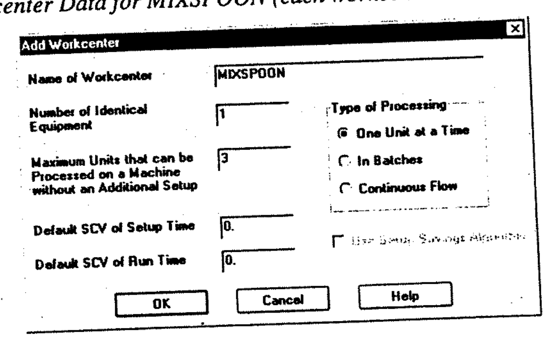
Screen 1

Add Product Dialog box (each product has to be first added).



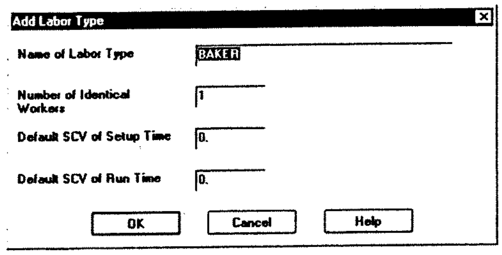
Screen 2

Entry of Workcenter Data for MIXSPOON (each workcenter data has to be specified).



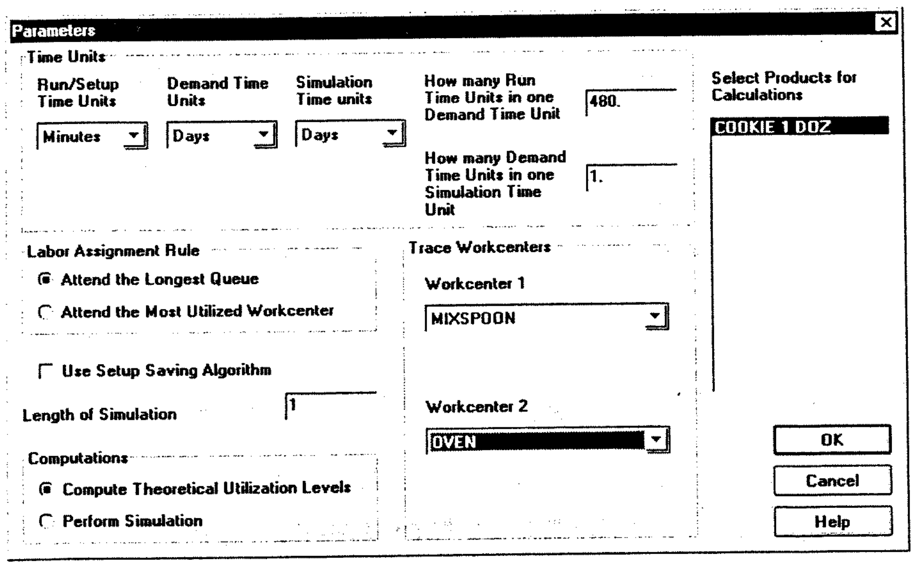
Screen 3

Entry of Labor Type Data for Baker (each labor type has to be specified).



Screen 4

Parameters Dialog box (the parameters of the simulation are entered in this box)



The time units as well as the conversion factors have been specified in the top three boxes. For example, each day has 480 minutes. We have asked HOM to trace the queues at two workcenters, MIXSPOON and OVEN. The simulation is for 1 day. HOM is asked to first compute the utilization levels. On running HOM with these choices, the following text output is produced.

Process Analysis Calculations

Theoretical Utilization (%)

Workcenter Name	Utilization
MIXSPOON	73.333
OVEN	91.667
COOL	0.45833
PACK	18.333
PAY	9.1667

Labor Type Name	Utilization
BAKER	82.5
DUMMY	0
HELPER	27.5

The utilization levels are less than 100%, thus we can go to the second step of running the simulation. The result of the simulation for 1 day is shown below.

Process Analysis Calculations

Utilization (%)

Workcenter Name	Theoretical Utilization	Simulated Utilization
MIXSPOON	73.333	71.667
OVEN	91.667	88.106
COOL	0.45833	0.43504
PACK	18.333	17.083
PAY	9.1667	8.5416

Labor Type Name	Theoretical Utilization	Simulated Utilization
BAKER	82.5	80.625
DUMMY	0	0
HELPER	27.5	25.625

Simulation Results

Workcenter Name	Average Jobs In Queue	Avg. Num. At Workcenter	Maximum Num. In Queue	Unavoidable Delay
MIXSPOON	0	0.71667	1	0
OVEN	0	0.87708	1	0
COOL	0	0.43106	1	0
PACK	0	0.17083	1	0
PAY	0	0.085417	1	0

** Unavoidable delay is due to waiting for labor or material.

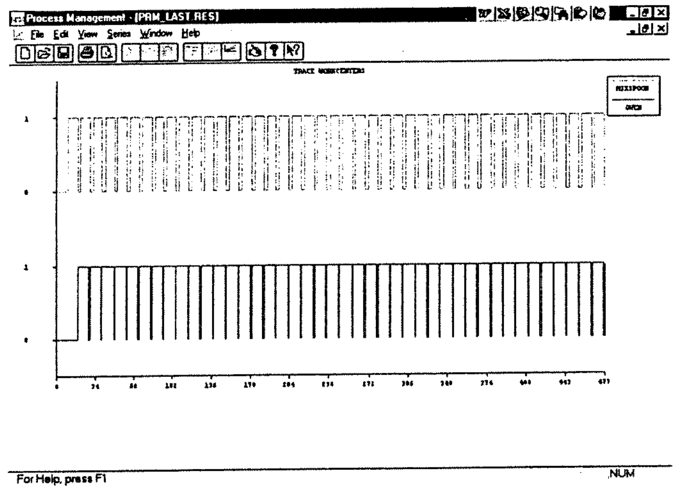
Product Name	Average Flow Time	Std. Dev. of Flow Time	Quantity Produced
COOKIE 1 DOZ	26	0	41

Product Flow Time Distribution

COOKIE 1 DOZ

Left End Point (T1)	Right End Point (T2)	Fraction of Jobs w/Flow Time <= T2
26	26	1

The trace of queues at the mix and spoon and oven workcenters are shown below (the queues are clearly stable):



Process Analysis Calculations

Utilization (%)

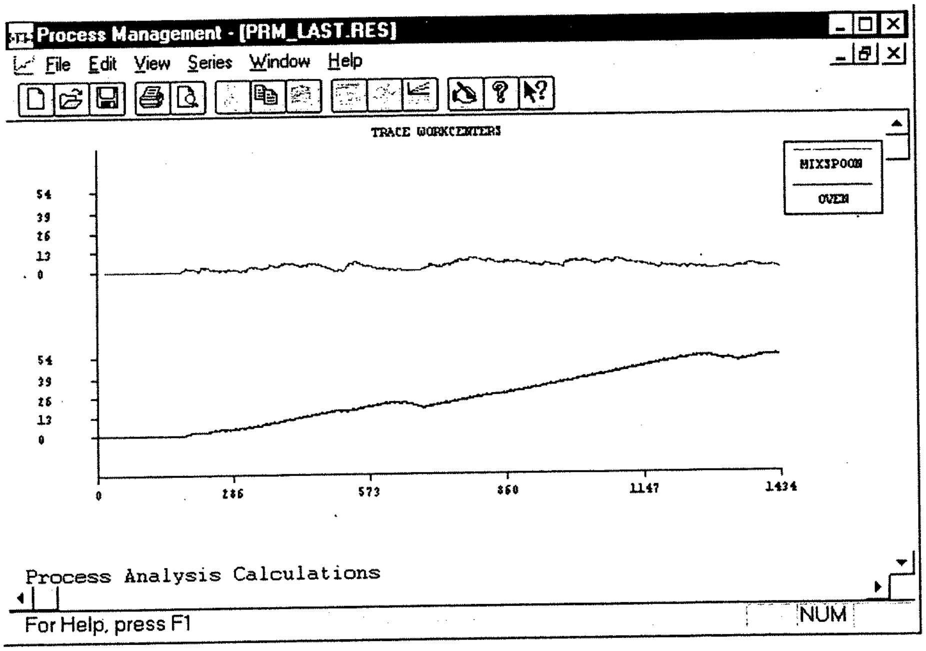
Workcenter Name	Theoretical Util. (%)	Simulated Util. (%)
=============	============	===========
MIXSPOON	73.333	60.511
OVEN	91.667	54.167
COOL	0.45833	0.27083
PACK	18.333	10.789
PAY	9.1667	5.3472

Labor Type Name	Theoretical Util. (%)	Simulated Util. (%)
=============	============	============
BAKER	82.5	65.928
DUMMY	0	0
HELPER	27.5	16.136

4.2 Cookie Making Example -- Variations

The following variations of this example can be created: Instead of the orders arriving in a deterministic manner, the squared coefficient of variation of the inter-arrival time between successive customers demand is changed to 1. You see below that the queue at the oven will build up and that the system is unstable!

The trace of queues at the mix and spoon and oven work centers:



Simulation Results

Workcenter Name	Type of Processing	Average Jobs in Queue	Avg. Num. At Workcenter	Max. Num. At Workcenter	Avoidable Delay (%)
MIXSPOON	One at Time	1.3687	1.9709	7	2.9732
OVEN	In Batches	8.12	8.6334	31	26.889
COOL	One at Time	0	0.27083	1	0
PACK	One at Time	0	0.10694	1	0
PAY	In Batches	0	0.053472	1	0
** Avoidable Delay is Due to Waiting for Labor or Material.					

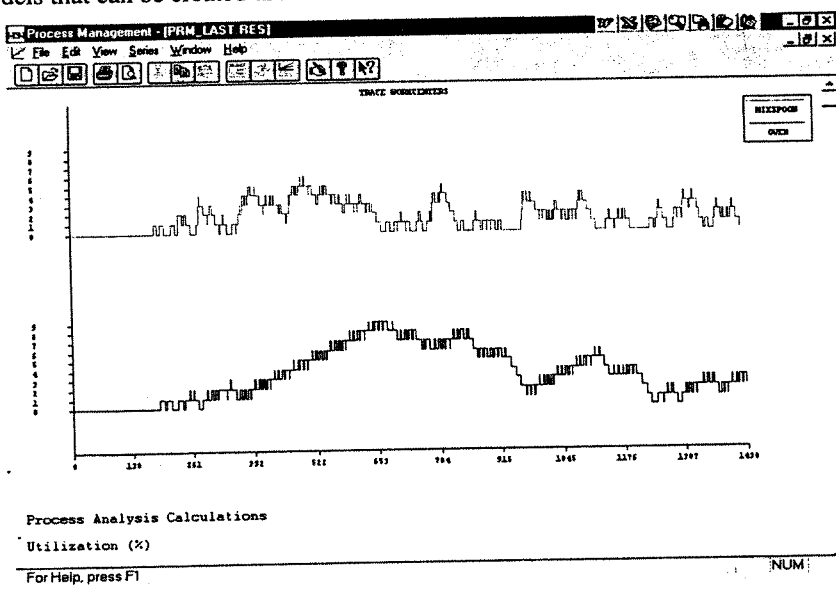
Product Name	Average Flow Time	Std. Dev. of Flow Time	Quantity Produced/DAY
COOKIE 1 DOZ	134.52	57.694	25.6667

Product Flow Time Distribution

COOKIE 1 DOZ		
Left End Point (T1)	Right End Point (T2)	Fraction of Jobs w/Flow Time <= T2
34	59.025	0.12987
59.025	84.05	0.19481
84.05	109.07	0.31169
109.07	134.1	0.53247
134.1	159.12	0.68831
159.12	184.15	0.85714
184.15	209.17	0.8961
209.17	234.2	0.92208
234.2	259.22	0.97403
259.22	284.25	1

The queue build up at the oven is due to a phenomenon called machine interference. Notice that the avoidable delay at the OVEN is in excess of 25%. The average flowtime also increases to five times its previous value. The service time guarantee for 90% of the customers exceeds 230 minutes (from 26 minutes!). The problem arises because the Baker is heavily utilized, and therefore can not be in two places (the MIXSPOON and the OVEN) at the same time. A simple solution is to assign the Baker's work to the Helper so far as the loading of the oven is concerned. With this change the system becomes stable. The traces are given below. The average and standard deviation of flow time are 37.98 and 16.93 minutes. The service guarantee for 90% of customers comes down to 67 minutes.

Other modeling variations are described in the manual. In general, the types of models that can be created are unlimited.



4.3 Project Management - Table Manufacturing Example

We illustrate the capabilities of the Project Management Module using a short case study: Christopher Townsend, the co-founder of the Newport Cabinetmaking School, was thinking about his furniture making business in the summer of 1750. He had just returned from the Quaker summer meeting held in Salem, MA that year and had seen some of the latest production techniques used by the larger Quaker furniture making shops of that city. His son, John was almost finished with his seven-year apprenticeship and was demonstrating skill equal to his own in every facet of the furniture making craft.

Christopher currently built tables by completing every task himself (serial processing). He would select and trim the wood for the legs and top, which would take a total of one day, then cut and carve the legs (4 days), then cut and carve the top (3 days), then assemble the parts (2 days) then stain and finish (1 ½ days) and pack the table for delivery (½ day). Christopher usually worked 24 days a month.

In Salem, he learned that some tasks could be allocated to other workers and could be done at the same time as other tasks (parallel processing). Since John's skills were so advanced, Christopher was wondering by how much he could shorten the delivery time for a table (flow time). At a minimum, he wanted to know what the effect would be if John would cut and carve the legs at the same time as he was making the top? (It also takes John four days to cut and carve a set of legs).

Christopher also knew that his brother, Job's sons were also gaining skill as cabinetmakers and that he could hire them to help with the work. At a cost of 2 pounds per day he could cut up to 2 days off the time to make legs. At 3 pounds per day he could cut 1 day off the time to make the top, at 4 pounds per day he could reduce the assembly time by 1 day and at 1.5 pounds per half day he could reduce the stain and finish time by ½ day. Christopher is wondering if he employed Job's sons how much it would cost for each day's reduction in the time it would take John and himself to produce a table.

Christopher knows that adding extra workers might add some uncertainty to certain of his completion time estimates. The new range of possibilities are given below:

Christopher would like to be 90% confident in any completion time estimate he gives his customers. What should his completion time quote be (service guarantee)? Christopher is very confident in his own abilities and knows he can always complete tasks in the expected time. Which tasks would you recommend he work on, and why?

The HOM module project management can be used to solve these questions. The required input file is given below.

Times

Task	Pessimistic	Expected	Optimistic
Buywood	2	1	1
Makeleg	5	4	3
Maketop	4	3	2
Assemble	5	2	1
Stain	3	1.5	1
Pack	0.5	0.5	0.5

HOM Data

Activity	Duration	Min. Durn	Cost/ Time	Opt. Time	Likely *T*	Pess. Tim	Pred. 1	Pred. 2
Buywood	1	1		1	1	2		
Makeleg	4	2	2	3	4	5	Buywood	
Maketop	3	2	3	2	3	4	Buywood	
Assemble	2	1	4	1	2	5	Makeleg	Maketop
Stain	1.5	1	3	1	1.5	3	Assemble	
Pack	0.5	0.5		0.5	0.5	0.5	Stain	

RESULTS

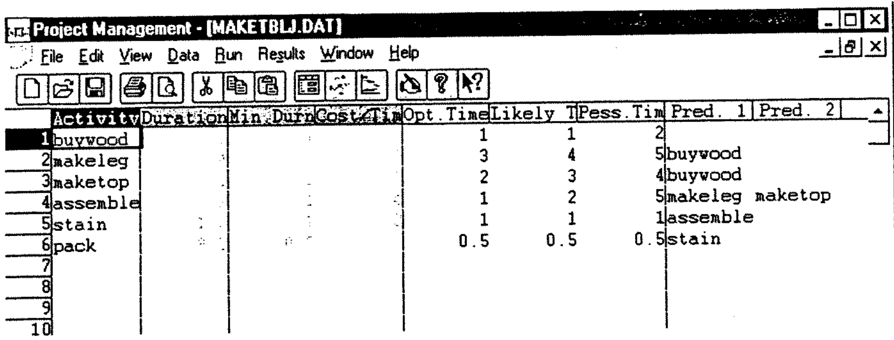
The data spreadsheet is the first input screen of the project management module. The project activities, their predecessors, and their duration times can be entered directly into this spreadsheet in their indicated rows. Data entry for project crashing and PERT can also be entered at this time or postponed until they are needed. To solve the first questions requires the use of CPM. This is specified by clicking on the parameters icon, and then on the CPM button in the drop down parameters window and then setting the ACTIVITY range from 1-6. The results report produces a Gantt chart, a list of the activities on the critical path (Buy, Makeleg, Assemble, Stain, Pack) and its time (9 days). This is a 3 days improvement over Christopher's doing everything on his own. (Buy, Makeleg, Maketop, Assemble, Stain, Pack = 12 days)

To reduce the time it takes to make a table to less than nine days requires the enabling of the crashing option in the parameters window. Changing the value in the completion time box forces the computer to try and reach that time in the most efficient manner. In our example, it costs $2 to reach a completion time of 8 days, a total of $5.5 to reach 7 days ($3.5 extra) and a total of $10 to reach 6 days ($4.5 extra). For each of these scenarios a new Gantt chart, critical path activities and time are developed. The computer tells you that the project cannot be reduced to 5 days. The summary showing the activities crashed and the new critical path(s) for crashing to 8 and 7 days is attached.

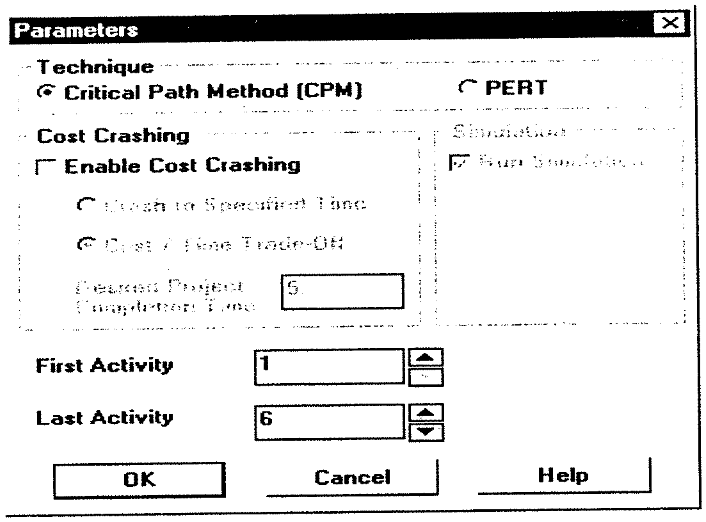
To determine a service guarantee for Christopher requires the enabling of the PERT analysis option in the parameters dialogue box. The analytical result for these problems are developed by enabling PERT. The results of the run depict a completion time histogram and its digital analog. They indicate that a 10-day guarantee would have about a 90 percent likelihood of being correct. The simulation alternative, enabled by clicking on its indicator box, lists the percentage of the time that each activity was on the critical path in 1000 simulations of the problem (criticality index). Clearly, those with a percentage on or near 100 would be where Christopher should do the work since he knows his ability with certainty. The output shows that the maketop task is on the critical path only 1.8 percent of the time. Christopher should, thus, do any task other than this one since all the others are almost always on the critical path.

HOM Sample Inputs and Outputs

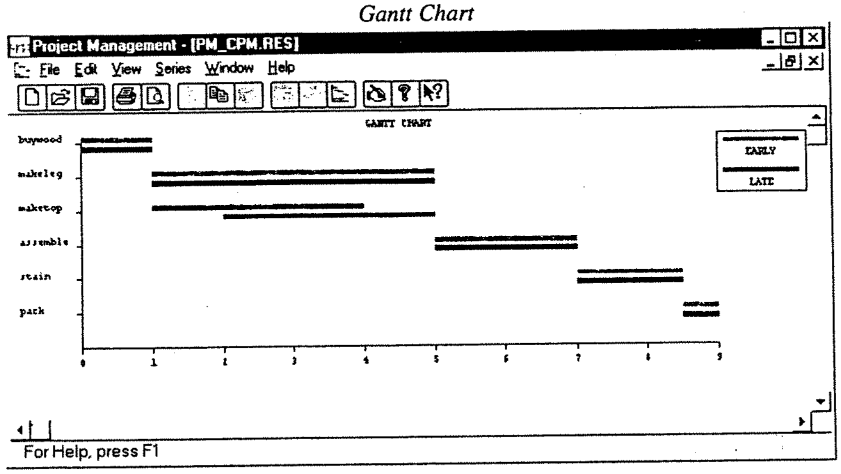
Input Data Spreadsheet



Parameters Window



Gantt Chart



Output Table of Critical Path Calculations

Critical Path Method Calculations Results

Activity Name	Early Start	Early Finish	Late Start	Late Finish	Slack
buywood	0	1	0	1	0
makeleg	1	5	1	5	0
maketop	1	4	2	5	1
assemble	5	7	5	7	0
stain	7	8.5	7	8.5	0
pack	8.5	9	8.5	9	0

Expected Completion Time: 9
Critical Path: buywood makeleg assemble stain pack

Output of Crashing to 8 Days

Critical Path Method with Cost Crashing Calculations Results.

Activity Name	Crashed by	Cost of Crashing	Present Duration	Early Start	Early Finish	Late Start	Late Finish	Slack
buywood	0	0	1	0	1	0	1	0
makeleg	1	2	3	1	4	1	4	0
maketop	0	0	3	1	4	1	4	0
assemble	0	0	2	4	6	4	6	0
stain	0	0	1.5	6	7.5	6	7.5	0
pack	0	0	0.5	7.5	8	7.5	8	0

Expected Completion Time: 8
Total Crashing Cost: 2

Critical Paths:
buywood makeleg assemble stain pack
buywood maketop assemble stain pack

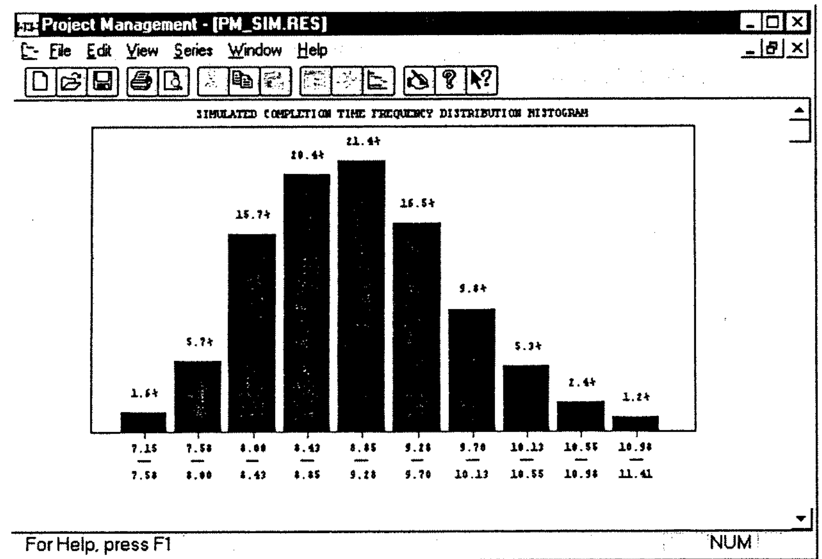
Results of Crashing to 7 days

Critical Path Method with Cost Crashing Calculations Results.

Activity Name	Crashed By	Cost of Crashing	Present Duration	Early Start	Early Finish	Late Start	Late Finish	Slack
buywood	0	0	1	0	1	0	1	0
makeleg	1	2	3	1	4	1	4	0
maketop	0	0	3	1	4	1	4	0
assemble	0.5	2	1.5	4	5.5	4	5.5	0
stain	0.5	1.5	1	5.5	6.5	5.5	6.5	0
pack	0	0	0.5	6.5	7	6.5	7	0

Expected Completion Time: 7
Total Crashing Cost: 5.5
Critical Paths:
buywood makeleg assemble stain pack
buywood maketop assemble stain pack

Output of Simulation



PERT Simulation (Criticality) Calculations Results

Activity Name	Criticality Indices
========	========
buywood	1
makeleg	0.982
maketop	0.018
assemble	1
stain	1
pack	1

Project completion time

Minimum:	7.14945
Maximum:	11.4058
Mean:	9.02302
Standard Deviation:	0.766755

Completion frequency distribution (1000 runs performed):

Interval Start	Interval End	Frequency (%)	(Counts)
========	========	========	========
7.149	7.575	1.6	16
7.575	8.001	5.7	57
8.001	8.426	15.7	157
8.426	8.852	20.4	204
8.852	9.278	21.4	214
9.278	9.703	16.5	165
9.703	10.13	9.8	98
10.13	10.55	5.3	53
10.55	10.98	2.4	24
10.98	11.41	1.2	12

5. Comparison with Similar Software Packages

We briefly compare HOM with other Operations Management educational software in this section. The comparison is not meant to be an exhaustive survey of all such products. Our objective in making this comparison is to compare pedagogical approaches. There are two ways of classifying the software that is available for Operations Management: (1) Is the emphasis on Operations Research or on Operations Management? (2) Is the software a spreadsheet add-in or not? There are two reasons we make these distinctions at the outset: (1) There are several *specialized* software products that cover topics such as linear, non-linear, and combinatorial optimization, for example LINDO and LINGO (LINDO Systems), MATLAB (The MathWorks, Inc.), and ILOG's OPL Studio (ILOG Corporation). These belong to the realm of Operations Research. Such products are less oriented towards managerial problem solving and more convenient for teaching Operations Research solution techniques as well as to teach how to mathematically formulate an optimization problem. These products do not neatly fit into the lecture sequence followed in Operations Management, such as, process analysis, time to market, supply chain management, etc. Also, the specialized products do not cover all the techniques used in an Operations Management course. There are several *educational* software products in the Operations Research area that cover many of the techniques taught in an Operations Management course. In contrast to these, the software meant for teaching Operations Management cover as much or more material and usually are tailored to solve problems from one or more OM text books. (2) Spreadsheets are a viable approach for teaching students how to formulate and solve problems faced by Operations Managers and Operations Researchers. Now a days almost every textbook on Operations Research has a special section in each chapter on using a spreadsheet to implement the techniques covered in that chapter. With the optimization software now embedded in Microsoft's Excel, it has become easier to pose and solve challenging problems. Moreover, Visual Basic scripts can be created to allow the user to change not just the data, such as the task duration, but also the parameters of the problem, such as the number of tasks in a project. Examples of such an approach are found in [11], [8] and [2,3] The limitations of this approach are twofold, first, as the spreadsheet is upgraded the old macros and programs have to be upgraded, and second, the approach is not yet suitable for facilitating tasks such as: easy variation in the parameters, allowing or disallowing certain combination of options (such as can be achieved using a dialog box) or solving very large problems or saving and comparing outputs side by side or even for developing a consistent method of data entry and problem formulation for all modules.

In fact, HOM began as a spreadsheet add-in. However, due to rapid changes in the spreadsheet versions, we had to place much more emphasis on managing multiple versions rather on the development of the HOM software product. Therefore, we abandoned the approach of having HOM within a spreadsheet and instead took the present approach that uses a spreadsheet within HOM. On the other hand, spreadsheets remain the tool of choice for most managers and they are the tools that managers work with day-in-and-day-out. Thus, given the widespread usage of spreadsheets we expect that over time the differences between the software and the spreadsheet will reduce. For example, we plan to completely integrate the input and output windows so that they take on the look and feel of a spreadsheet. Thus, inputs and outputs will be represented as worksheets within the same spreadsheet and figures will be presented as embedded objects that can be imported into any spreadsheet or word-processing software. This will preserve the look and feel of a modern day spreadsheet but allow the software to be tailored to the problem formulation and solution without being tied into a particular version of a spreadsheet. Finally, C++ and Fortran are the standard languages for codifying algorithms. Until it becomes easy to use these languages within a spreadsheet, it will be difficult to create products that solve medium to large sized problems, such as those encountered in Aggregate Planning or Process Analysis.

We have spelt out many of the desirable features of software that is meant for managers and students in the field of Operations Management in the previous paragraph. We hasten to add that some of these features are favored due to our personal experience in software development and also because the features support our approach to teaching and solving operations problems. They are by no means universally accepted! Especially, there is a deep divide amongst professors whether techniques should be taught in-class, whether students should get their "hands dirty" by solving a problem by hand or step-by-step using a software or should students simply comprehend how to formulate a problem, understand the choices that are available, and carry out sensitivity analysis. We subscribe to a combination of the second and the last approach, namely, the student should be able to quickly solve a problem by hand and where necessary use a powerful tool to understand the finer aspects of the problem or solution.

The list of features that can be used to describe software for Operations Management is probably more easily created, and will comprise the items shown below: (1) Topics covered. (2) Problem Formulation: Parameters and Data. (3) Data Entry. (4) Problem Size/Modeling Flexibility. (5) Models Selection. (6) Solution Approach. (7) Output Screen. (8) Sensitivity Analysis. (9) Import and Export. (10) Help Features. (11) Supplements. (12) Downloadable from Internet. (13) Platforms supported. (14) Expository cases. (15) Other Features. WinQSB created by Chang (1998) and POM for Windows developed by Weiss (1997) are the two software products other than HOM that have many of these features. These products are briefly compared with HOM.

WinQSB is a versatile product that offers several modules for teaching "modeling oriented" Operations Research and Operations Management topics. (1) Topics covered: WinQSB offers several Operations Research related modules that are not covered under HOM, specifically, Dynamic Programming, Decision Analysis, Linear, Integer, Goal, Quadratic, and Nonlinear programming; Markov Process, Network Flow Models and Scheduling. WinQSB does not offer Process Analysis instead it allows the user to simulate multiple stage queueing systems. Otherwise, the coverage of Operations Management topics is the same as HOM. (2) Problem Formulation: Parameters and Data: WinQSB's approach is to first select the model and then enter the parameters and the data. Thus, it is model oriented and not problem focused. Thus, for example, in Aggregate Planning the choices are Simple Model, Transportation Model, and General LP Model. Similarly, the choices for Inventory are offered under EOQ Model, (s,Q) Model etc. (3) Data Entry: The data entry screen does not open up until the model is chosen, unlike HOM. The screen is not a spreadsheet, but has a grid like appearance. (4) Problem Size/Modeling Flexibility: In general the modules have similar capability as HOM's. However, in

Aggregate Planning the modules do not allow for setup time or setup cost. Process analysis is restricted to straight-line flows unlike HOM. And, the managerial flexibility and choice under Waiting Line Management module of HOM is greater. (5) Model Selection: The model selection is done first, whereas in HOM parameters and models are selected in a single window and also made as far as possible to be independent of the data. The HOM approach facilitates repeat analysis with different parameters without having to re-enter the data. (6) Solution Approach: WinQSB allows the user to seek optimal solution wherever possible, similar to HOM. (7) Output Screen: The graphical outputs are better in WinQSB. The outputs are still not completely spreadsheet like. (8) Sensitivity Analysis: WinQSB does not have automatic sensitivity analysis that is provided in some of HOM's modules. (9) Import and Export: The spreadsheet supported by HOM appears to be easier to copy and paste information. (10) Help Features: WinQSB focuses on the technical aspects, such as formulae for forecasting. This is in contrast to HOM, where the user is given a step-by-step "How to Solve" tutorial on how to forecast. (11) Supplements: Sample problems. (12) Downloadable from Internet: No. (13) Platforms supported: Windows. (14) Expository cases: Not available. (15) Other Features: WinQSB is developed using Visual Basic as can be inferred from the dynamic link library objects installed. HOM is more compact and allows for seamless integration in the 32-bit Windows environment because it uses compatible Visual C++ and Visual Fortran compilers. All in all, WinQSB is an extremely impressive and professional product that is suited to model oriented teaching.

POM for Windows is a program that delivers elementary solutions to a wide range of operating problems. (1) Topics covered: POM offers several Operations Research related modules and a host of shop-floor manufacturing techniques that are not covered in HOM. These additional modules are Assignment, Lot Sizing, Linear Programming, Plant Layout, Scheduling, Simulation and Transportation. The major Operations Management techniques are not covered in the depth presented by HOM or WinQSB. Process Analysis and Stochastic Inventory models are not addressed at all. (2) Problem Formulation: Parameters and Data: POM's approach is to first have the user select the parameters to be used in the formulation, then enter the model type, and then the data. Thus, for Aggregate Planning the user first indicates the number of periods and whether backorders or lost sales are permitted; then specifies the model type, i.e., simple production, produce to demand, etc.; and then the relevant data, such as, the demand, capacity and cost. Similarly, the waiting line module is used by first selecting the model amongst M/M/1, M/G/1 or M/M/s; then whether or not to use costs and then the data on arrival and service rates. Thus, this approach is in-line with that of WinQSB with a model rather than a problem focus. (3) Data Entry: The data entry screen does not open up unless the model is chosen unlike HOM. The screen is not a spreadsheet but data can be copied to it from a clipboard. It is not easy to view multiple data sets or the data and the results screen using the tile or cascade windows function. (4) Problem Size/Modeling Flexibility: In general, the maximum size of problems that can solved using POM is substantially less than the corresponding size in HOM or WinQSB. For example, the Forecasting module in POM allows a maximum of six variables and 90 observations compared to 20 variables and 1000 observations in HOM. There is no method for dealing with seasonality, no provision for Winter's method or for finding the best fit, namely, for optimizing the model parameters. The Aggregate Planning module does not allow for optimization or for including setup time and setup cost or for specifying minimum personnel in a shift. Simulation is not allowed in Waiting Lines or Project Management. The Waiting Line module does not cover GI/G/S systems or systems with empirical distributions for the inter-arrival or service time. (5) Model Selection: Like WinQSB, model selection is done first. This is in contrast to HOM where the data is entered first and model as well as parameters are selected later. The HOM approach facilitates repeat analysis with different parameters without having to re-enter the data. (6) Solution Approach: Unlike HOM or WinQSB, optimum seeking or simulation methodology is often not used in POM. Aggregate Planning, Project Crashing, and "Best Fit" in Forecasting are a few examples. POM can not determine activity criticality indices or probabilistic project completion times, nor model "join the shortest queue" or "jockeying" in waiting lines. (7) Output Screen: Graphs are clear and sharp and more on level with WinQSB than HOM. There are some pre-programmed graphical alternatives such as in Waiting Line analysis, which is a nice feature similar to HOM. (8) Sensitivity Analysis: There is little hard-wired sensitivity analysis as in HOM where waiting line analysis yields results for +/- 5% change in service rates. (9) Import and Export: Straightforward using the clipboard. (10) Help Features: On-line help tells the user the data items that should be entered but the "How to Solve" feature of HOM is missing. (11) Supplements: None. (12) Downloadable from Internet: No. (13) Platforms supported: Windows. (14) Expository cases: No. (15) Other Features: POM also appears to be developed using Visual Basic.

6. Teaching Experience with HOM

Using HOM in the classroom requires that the instructor devote some time to familiarize students with the menu structure and data entry conventions. Some examples of how we go about doing this in our courses are given below.

Our Operations Management course places emphasis on process analysis. The process analysis module of HOM is thus invaluable when used to discuss set up time and lot size trade-offs, the effect of product mix on capacity and profitability, staffing issues, as well as, flow time management. On the other hand, due to the versatility of the HOM module, the time required to describe this module can be substantial. Nearly, half a class (40 minutes) is required to show how the data is entered, any unique definitions explained and how the options are selected. For example, in process analysis, each task can be "one at a time", "batch" or "continuous flow." The differences between these types of operations must be explained if they have not already been covered in class. On the whole, once the initial effort has been made, students rapidly appreciate the power of computers for analyzing processes. All the other modules are introduced with a "20 minute how to" lecture in the class before their use is required. This gives the student a basic feel for how the data should be entered, the scope for analysis and interpretation of results.

For large problems, such as a process with ten products and/or complex recipes or a project with 30 activities, HOM data files are provided for the student. These data files contain the initial set up of the problem. The student is then required to improve upon the current situation and is set definite targets to achieve. As another example, in an advanced class, the MRP module and a spreadsheet based capacity calculator are provided to the student. The objective is to develop a capacity constrained production plan that minimizes the work-in-progress and finished goods inventory carrying cost while simultaneously avoiding significant backlogs of products demanded.

We have used HOM in our core Operations Management classes since 1994. The most powerful motivator for using HOM in the classroom is its ability to solve realistic problems of moderate size with relative ease. In addition, we are able to demonstrate counter-intuitive results that are not available through performing back-of-the-envelope calculations; such as, situations in which: there is simultaneous excess capacity of labor and long waiting lines due to interference of work, deliberate under-staffing in the cheaper first shift due to minimum workforce size requirements in the costlier second shift, high probability of stockout co-existing with high fill rate service level, etc. Lastly, more complex analysis, such as the computation of optimal lotsize in stochastic networks, simultaneous optimization of the order quantity and safety stock level, and the evaluation of reduction in processing uncertainty, are also facilitated using HOM. Thus, we *are* not only able to bring state-of-the art approaches for problem solving into the classroom or the small business environment but also to sensitize students and managers to hidden and/or more complex trade-offs.

Based on user feedback, we have learnt that the software is powerful enough that it can be used to solve class problems or to find a first cut solution to problems that might be encountered on the job. Also the time and effort spent in learning how to model problems and interpret results in HOM can be carried forward into future use of this or other commercial process improvement software packages. The feedback from students and instructors that have used this software has generally been positive. The more intuitive modules, such as Project Management and Forecasting, have drawn greater praise. Process Analysis is the most complex module and draws criticism due to the amount of learning required. Students and instructors have commented that the output formats and graphics can be improved and that users should be able to cut and paste graphs from the output screen to other software.

Finally, to win the user over teaching note solutions to all cases must be made available. David Juran has created several such notes. Examples are found at djuran@stern.nyu.edu.

7. Acknowledgements

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Footnote:

1. Data for this example is taken from *Kristen's Cookie Co.* published by the Harvard Publishing Corp.

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