

WITNESS SIMULATION SOFTWARE A FLEXIBLE SUITE OF SIMULATION TOOLS

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ABSTRACT

Over time, simulation tools have found use in most manufacturing enterprises. Due to the increased flexibility and openness of the tools available today, simulation can now begin to permeate all facets of the organization beyond the industrial engineering and manufacturing niche. The suite of decision support tools presented in this paper will provide the reader with a clearer understanding of this evolution.

1 INTRODUCTION

The premise of this paper is to introduce the practicality of an integrated suite of simulation tools for use within a manufacturing facility. Applications range from the initial design process for a "green" site to re-engineering of a fully-functioning manufacturing facility. By using this suite of tools, you allow a team of people to take a look at a process from many different viewpoints, and to solicit the input of various people within an organization, before arriving at one solution everyone can live with. The process comes to completion as presentation-quality simulation tools are used to communicate ideas to those who make the final decision, i.e., upper management, investors, CEO's and CFO's.

The products that comprise this suite of tools include MATFLOW (a material-flow planning system), WITNESS simulation software, WITNESS OPTIMIZER, and WITNESS^{VR} (virtual reality software). These products are available from Lanner Group, Inc., a leading international manufacturer of decision-support software

2 MATFLOW: DETERMINING THE OPTIMAL LAYOUT BASED ON MATERIAL FLOW

Whether an enterprise is embarking on the design of a new facility or redesigning an existing site, a critical first

step is the analysis of material flow. MATFLOW is a material flow optimization system for new or existing layouts. Because MATFLOW is fully integrated with AutoCAD, it can save time and money by importing plant layout drawings that may already exist in an organization. CAD drawings used by MATFLOW can range from a simple layout of the factory floor to a more detailed drawing, which contains representations of machines and other equipment.

MATFLOW optimizes the configuration of components by calculating the total flow of parts across an entire facility. By interchanging different combinations of pairs of machines, MATFLOW attempts to reduce the total flow of material. Flows are normally calculated as a number of parts multiplied by the distance traveled; however, other attributes of the materials can be considered, such as volume, weight or cost. Optimization could also be based on some combination of factors, with specific weighting applied to each of the factors.

Once a layout has been established, MATFLOW can generate a WITNESS simulation model, complete with the AutoCAD facility outline and machines accurately located. This WITNESS model can then be used to simulate the actual production process and provide further information on the operation of the system, such as location of possible bottlenecks and buffer size requirements. After bottlenecks have been identified and/or eliminated, buffer sizes can be passed back to MATFLOW where actual floor space requirements can be calculated and represented on the layout.

2.1 Working Data File

In addition to a CAD layout, MATFLOW requires a working data file. This file can easily be created using any spreadsheet. The file has a standard format which is easy to construct and understand. The data consists of:

- a description of parts and their routings through the factory,
- production times, setup times and batch sizes for each machine in the operation,
- product data, including number of units to be produced per day and any other attributes to be considered, and
- machine buffer sizes.

Once the working data file is created, it can be loaded into MATFLOW and the model building process can begin.

2.2 Creating the Layout

A schematic layout is created from the data in the working data file. Machines are placed strictly according to their order in the spreadsheet, with no consideration given to technical or economical restrictions. Fixed locations can be assigned to those machines and buffers which are required to be located in specific positions. Additional locations can be added to the layout as “empty” locations, which can be used later in the optimization process. If the material flow is reduced by moving a machine to one of the “empty” locations, that element will be switched from its current location.

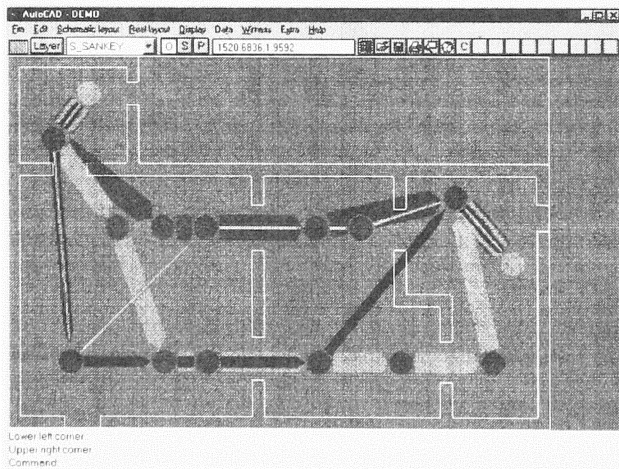


Figure 1: MATFLOW Schematic Layout

Material flow is graphically represented as arrows. These arrows can represent the flow of individual products or a summation of all product flows. Arrow thickness and color are varied to graphically show the flow volume. A control number represents the sum of all the areas of the summation arrows. This control number is used to compare different scenarios and show whether a change in position for a machine will result in an improvement or a worsening of material flow. The

objective of material flow optimization is to reduce the control number as far as possible.

2.3 Layout Optimization

Optimization of the layout can be done manually or automatically. The manual method involves exchanging the positions of one or more pairs of machines or buffers, and evaluating the resulting control number to see if any improvement is realized. Because this can be time consuming and complex, MATFLOW includes an automatic optimization function which will test different scenarios for layout, while trying to minimize the control number. MATFLOW allows the user to select the criteria to be considered in optimization. For instance, the decisive factor will not always be the quantity transported, but might be a product value or profit/sales ratio.

One optimization method is the Maximum method, where maximum flows between elements are considered first. These elements are exchanged and the resulting control number value is evaluated to see if an improvement was achieved. The process continues until all flows are evaluated, from largest to smallest.

Another method is the Exchange method, where elements are evaluated in the order they are listed in the work plan, places are exchanged, and the resulting control number is evaluated for improvement. The user has some control over the optimization process, by indicating how large an increase in the control number is acceptable when comparing two locations, and how many trials will be executed.

2.4 Data Transfer to WITNESS

The optimized schematic layout can be transferred to WITNESS for continued analysis. Machine cycle and setup times, as well as buffer sizes, will be transferred from the working data file. WITNESS will determine if buffer capacity and machine capacities are sufficient to meet objectives. WITNESS model results can be returned to MATFLOW to determine if sufficient floor space is available for machines and buffers. This iterative process continues until an optimum working layout is determined.

Additional features of MATFLOW allow the user to:

- define groups of machines, or cells, which represent cost areas, production units or departments,
- represent different input and output locations for large machines, and

- indicate transportation nodes to identify the path of flow from one location to another (i.e. material cannot flow through walls or other machines.)

3 WITNESS: CONTINUING THE STUDY VIA SIMULATION

Once meaningful results are available from the MATFLOW layout optimization, the process can be further studied using WITNESS, a true process simulation and modeling tool. The MATFLOW module assumes there is capacity for all optimized material flow. The next step is to evaluate the interaction among different product lines that may share a facility's resources.

With WITNESS, the optimization of the manufacturing floor layout, with respect to material flow, provided by MATFLOW can be further refined. WITNESS is used to simulate full production runs, over an arbitrary time period. This allows people designing a facility to get a glimpse of how the production lines might operate in reality. This is a good way to predict and solve any problems and inefficiencies that may present themselves if the production lines were built in the current configuration. WITNESS makes obvious any production bottlenecks, overly-idle resources, storage areas that are too small or large and any potential issues with respect to labor attending to the processing of parts.

3.1 WITNESS Modeling Elements

The WITNESS simulation package is capable of modeling a variety of discrete (e.g., part-based) and continuous (e.g., fluids and high-volume fast-moving goods) elements, as described below. Depending on the type of element, each can be in any of a number of "states". These states can be idle (waiting), busy (processing), blocked, in-setup, broken down, and waiting labor (cycle/setup/repair).

3.1.1 Basic Discrete Elements

The most basic discrete modeling elements are Parts, Buffers, Machines, and Conveyors.

Parts are simply objects that travel from one location to another. They may be pulled passively into the model by the simulation, pushed into the system by an active part arrival schedule, arrive from a part file, be created via a "production" machine, or any combination of the above.

Buffers are simply passive storage areas of finite capacity. Buffers can be configured as "delay" buffers, where parts must stay in for a minimum amount of time. They can be configured as "dwell" buffers, where they

cannot stay in the buffer any longer than a specified time. A part can be optionally ejected from a buffer if it violates any of these conditions. Combinations of First-In-First-Out / Last-In-First-Out sequencing are possible, as well as the ability to have parts pushed to and pulled from locations in the buffer other than the front and rear.

Machines are the workhorses of WITNESS. A variety of machine types are available:

- Single
- Batch
- Assembly
- Production
- Multiple-Cycle
- Multiple-Station

Machines can be defined with Setup and Breakdown parameters, useful for modeling real-life failures, retooling, preventive maintenance, etc.

Conveyors are defined by a length in parts and an index time which represents the time it takes a part to move from one position on the conveyor to the next. Parts can be pushed to and pulled from any position on the conveyor. The conveyor itself can actively pull parts from the rear and push parts from the front. Conveyors may be fixed or queued. A fixed conveyor maintains the space between parts if the part on the front of the conveyor is blocked. By contrast, a queuing conveyor allows parts to compact together even though the conveyor may be stopped. The only time a queuing conveyor stops is when there are no gaps left, it's completely full, and no parts are being removed from it.

Other discrete elements include:

- tracks and vehicles
- labor
- shifts
- variables
- part attributes

3.1.2 Continuous Elements

Continuous elements are used whenever the movement of parts is represented as a flow rate, rather than the movement of individual parts. Typical materials used in a continuous simulation model might be fluids, powders, gases, or any high-volume fast-moving part. A good example of high rate part production, more suitable for continuous simulation modeling, might be small individual candies, nails, screws, bottle caps, etc. Other scenarios appropriate for continuous modeling might

include the processing of large rolls of sheet metal, wire, adhesive tapes, paper, etc.

Fluids, Tanks, Processors, and Pipes comprise the WITNESS continuous flow modeling elements. Fluids, as already described, can be liquids, but they can also be powders, gases, grains, or a high production rate part. Fluids and their resulting flow rates are usually measured in volumes or weights, the exact units of which are chosen by the user. It is common to use gallons, liters, or even tons. In any case, it does not matter what units are used, as long as their usage is consistent throughout the simulation.

A Tank stores fluid and is analogous to the Buffer element in discrete processing. A user indicates tank capacity and input and output flow rates. The flow rate is expressed in user units over simulation time units (such as gallons per hour, liters per minute, cubic centimeters per second, etc.). Warning levels can be set on rising or falling, allowing user actions to be taken under certain conditions. Just as machines can be repaired and retooled, tanks can also be configured for a cleaning cycle when required.

The Pipe element moves fluid from one location to another, and is analogous to the conveyor element in discrete processing. Pipes have input and output flow rates, as defined in the input and output rules attached to them. They also have a maximum volume specification, which determines how long it takes a given fluid to go from one end of the pipe to the other, given the assigned flow rates. Pipes can have breakdowns associated with them, for modeling such events as bursts, leaks, clogs, or other periodic downtime. Pipes can also be scheduled for cleaning or purging, independent of the breakdowns. When a pipe breaks down, any fluid in the pipe can optionally be sent to a "waste" area (and recorded in the simulation's statistics). A pipe can also be configured to have fluid flow from it even though there may be no volume of fluid arriving at the other end. The ability for fluid to empty from a pipe even though there is no arriving fluid, allows for convenient modeling of gravity-fed material handling systems for fluids, powders, and small objects. The operation of valves (on, off, partially closed, etc.) is easily modeled simply by toggling the flow rates into and out of tanks, pipes, and processors, from a positive flow rate to zero.

The Processor element is analogous to the machine element in discrete processing. The processor first fills to capacity (or to a specified processing level), then processes the fluid for a given amount of time, then empties completely. Common uses of the processor are to simulate agitators and mixing machines, aerators, fluid separators, degassing equipment, gas injection

equipment, etc. Processors, as well as tanks, will show the proportional mix of two or more fluids. Processors can be configured for cleaning cycles, as well as breakdowns (e.g., a mixing drive motor may fail.) Like tanks, processors can also trigger warning level alarms.

Finally, it is possible to mix fluids with parts in the discrete machine element. This feature is commonly used when filling vessels with fluid (paint cans with paint, bottles with soft drinks, etc.) It is also commonly used when a fluid of some type is being consumed at a machine that is processing discrete parts. In such situations, there may be a coolant or lubricant being consumed during the machining of a part, or detergent or other cleaning agent being consumed in a part clean-up stage.

3.2 WITNESS Graphical User Interface

The WITNESS user interface is Windows compliant. The primary interface to the software is either pulldown menus or the button tool bar just below. The operation of the simulation model is controlled at the bottom of the screen, from a toolbar, which starts, stops, and resets the model.

The majority of the activity however, takes place in the Simulation Window. It is here that items are placed in drag-and-drop fashion. The Designer Elements are commonly used to quickly drag-and-drop pre-defined items onto the simulation screen. After the required elements are on the screen, visual Push and Pull rules are added, via the mouse.

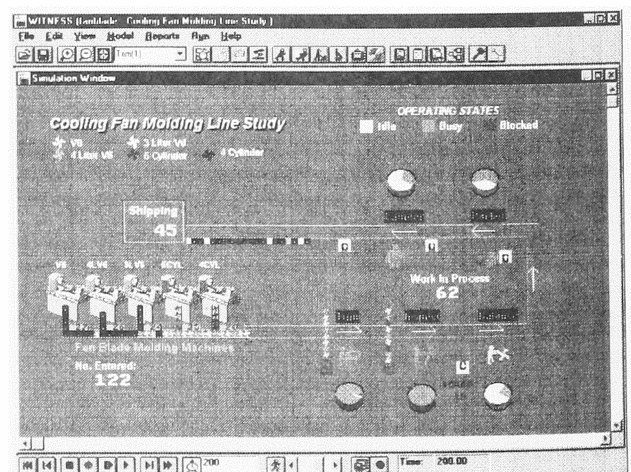


Figure 2: WITNESS Simulation Screen

Once a basic model has been assembled on the screen, the next step is to add more detail to elements in the model. These details are communicated to WITNESS via a detail dialog box. It is from this detail dialog that all of the logic for an element is entered. The detail dialog can be invoked by double clicking with a mouse on any element on the screen.

While the Detail dialog controls the logic of the model element, the Display dialog controls how it looks. From it, one can control any visual aspect of the modeling element, such as the icon to be used, text font, color, and an assortment of other items which can be attached to the display of each modeling element. The display dialog can be invoked by double right clicking on any element on the screen.

Standard WITNESS reports can be viewed on the screen either in tabular or graphic format. In addition, several graphical elements are available for summarizing statistics from a model. Pie charts, timeseries and histograms provide a meaningful, easily-read format for data from a simulation model run. In addition, data can be read from and written to external files.

A WITNESS model has associated with it up to 500 icons, which can be used to represent elements on the screen. In addition, a screen editor allows a user to add text and other graphics to a display. Any bitmap files can be imported into a WITNESS model as an icon, and AutoCAD dxf files can be imported to provide a shop floor layout to be used as a backdrop for a model. Audio and video clips can also be activated from within a WITNESS model.

4 WITNESS OPTIMIZER: FINDING THE OPTIMUM SOLUTION

Simulation is not, in and of itself, an optimization procedure, but a means to model different scenarios and compare the results. Because the number of variable factors in a model can be very large, Lanner Group provides a plug-in module which can intelligently test different combinations of changes within a model, and indicate the “best” model based on an objective function provided by the model builder. This objective function quantifies the objective of the optimization.

In addition, a user provides information on any constraints within the system, i.e. factors within the model which can vary, and what their range of variation is. Model run-length, as well as number of replications, is also indicated by the user. More sophisticated users can choose from several different search methods to be used in arriving quickly at the optimum.

4.1 Preparing a Model for Optimization

An objective function is defined as a normal WITNESS function. It takes no parameters and returns a numeric result, either integer or real. Generally, it is some function of current values of the optimization variables and results of the simulation. An example objective function might be:

value of throughput – cost of machines – cost of staff.

During the optimization process, different aspects of the model are varied, and the resulting value for the objective function will be compared to previous values to see if any improvement has taken place.

4.2 Running the Optimizer

A model optimization dialogue provides a means for users to select from several different objective functions they may have specified, and to indicate whether the function should be maximized or minimized. Optimization variables can be added or removed from a list of those available. Each variable has a range of possible values or a discrete set of possible values. Any number of variables can be considered during optimization. In addition, a user can manage constraints within a model to reduce the total number of possible combinations of values. Constraints are expressed as linear functions of two or more of the optimization variables. For example:

$$\text{staff1} + \text{staff2} \leq 10.$$

Any number of constraints can be included in an optimization scenario.

For a given optimization run, the user can indicate a warm-up period (a period after which statistics are zeroed out, and a model run continued), the length of a run (in simulation time units), a number of replications, and information on how random numbers are to be varied for each replication. Information is provided on the variability of statistics for these replications, providing the user an indication of the statistical stability of the model.

Several optimization methods are provided, ranging from simply running all possible combinations to more complex algorithms. Available methods are:

- All combinations
- Min/Mid/Max – runs 3 evaluations based on minimum, midpoint and maximum values of all variables

- Hill Climb – generates random iterations which are accepted if of higher quality and rejected if not.
- Random solutions – generates random combinations of variable values
- Adaptive Thermostistical SA (simulated annealing) – less dependent than the Hill Climb method on the starting values chosen and less likely to get “stuck” at a local optimum. Sophisticated users may manually adjust the search parameters.

Output from an optimization scenario is in the form of tables and graphs of best results. Information is also provided on variance, confidence limits and “t” tests. In turn, the output from an optimization run can be used to set values in a model, and the entire optimization scenario can be saved for later analysis.

5 WITNESS^{VR}: VISUALIZING AND COMMUNICATING VIA VIRTUAL REALITY

Once a WITNESS model has been completed and meaningful results emerge, it may be desirable to create a 3D Virtual Reality version of the model. It is from this VR model that people not associated with WITNESS can begin to more easily understand the underlying logic of the simulation.

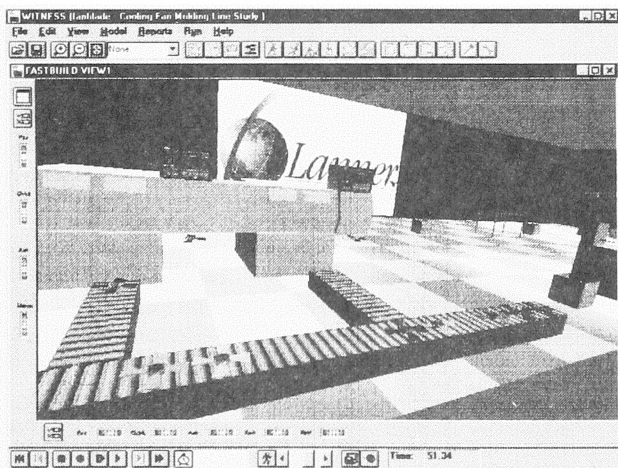


Figure 3: WITNESS^{VR} Screen Shot.

To create a 3D view from a 2D view, the WITNESS VR fast-build facility is used. The fast-build takes the 2D model icon locations and creates a 3D VR world by placing 3D objects into those locations, in a separate view. The 3D objects selected for each 2D icon are found in a reference file containing a number of default 3D objects.

The result of creating a VR world is that the user is free to fly around the created world and view it as it runs. By doing this, the viewer has a much better understanding of what is happening in the simulation. Many times, a WITNESS simulation is created rather schematically, and although very understandable to the people who wrote the model, may not be understandable to those not closely associated with the project (upper management, accountants, potential investors, etc.) Therefore it is of great benefit to have on-hand a version of the model which runs in a very realistic, Virtual Reality mode.

The VR module comes with the ability to create and edit objects and virtual worlds. It also has the ability to attach a camera to an object (a part for example), and follow that object through the VR world as the simulation runs. This has the visual impact of following a part through the simulation from beginning to end.

6 CONCLUSION

From MATFLOW, to WITNESS, to the Optimizer, to the Virtual Reality Module, we have demonstrated how a suite of simulation tools can be used to model a process within an organization. While this example pertains to manufacturing, the same principles can be applied to non-manufacturing applications. (A General Terminology version of WITNESS exists for use in Service industries (e.g., banks, hospitals, offices). In this version parts are entities, machines are activities, buffers are queues, and labor is a resource, for example. The functionality of these elements is identical to that of the corresponding manufacturing elements – the naming is simply different.)

7 SPECIFICATIONS

WITNESS requires the following minimum requirements:

- Intel 386 processor (Pentium recommended)
- Windows 3.1x, Windows for Workgroups, Windows 95, Windows NT 3.x or 4.0
- 8MB RAM (16 recommended for Windows 95 and NT)
- 15MB of free disk space
- Minimum 16 colors (65535 required for VR module)
- VGA (640x480) screen resolution, SVGA (800x600) recommended.

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