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Rapid modeling tools for manufacturing simulation and analysis

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ABSTRACT

We present a set of five compatible tools for rapid modeling and analysis of discrete manufacturing systems. **Lotus 1-2-3** spreadsheets form the database and most fundamental analysis tool for basic calculations. **Manuplan II** provides the user with a powerful tool to study the dynamics of manufacturing systems through analytical modeling: with this tool, models can be built in hours and each "what-if" is analyzed in minutes. **SimStarter** allows almost instantaneous conversion of the analytical model into simulation code. **Siman** provides detailed simulation modeling abilities in a package designed for the industrial user. Finally, **Cinema** gives manufacturing analysts the power of animation to present their results to co-workers and management in a convincing manner. All of these tools are designed to work together: **Manuplan II** has a **Lotus 1-2-3** interface, **SimStarter** connects **Manuplan II** and **Siman**, and **Cinema** works directly with **Siman** code. Using this integrated set of tools, analysts can rapidly investigate decisions in all stages of the design and operation of manufacturing systems. This leads to cost-effective and timely analysis of manufacturing decisions, and hence to greater productivity and competitive position of the manufacturing enterprise.

1. INTRODUCTION

1.1 Motivation: Software "Shelved"

Jill, a process engineer with a major electronics manufacturer, felt a sense of disappointment as she stared at the simulation/animation package lying on her shelf. Her company was constructing a "greenfield" facility to introduce a new product line. Jill was convinced that they could benefit from simulation analysis of the proposed manufacturing line. She had purchased the state-of-the-art simulation package some months ago, and been to a week-long training course. However she had been very busy working with the design team on finalizing the process parameters for one critical part of the line. Now, despite her best intentions, it seemed like she would not have the time to put together the detailed simulation analyses and animations for a thorough study of the line. Would her investment in the sophisticated simulation software end up being wasted?

While the name has been disguised, this incident is true. We shall see a resolution of the above question later in the paper. It is useful first, to provide some background on today's manufacturing environment.

1.2 Modeling Needs in Modern Manufacturing

Modern manufacturing lines can be very complex, embodying many of the latest technologies such as robotics and automated material handling, as well as the latest ideas such as just-in-time (JIT). Designing such facilities can involve a number of difficult decisions about which technologies to use, number of machines or robots, layout, achievable schedules, and so on. Modeling and simulation software packages are purchased by industry to assist in making complex decisions such as these. Quite often, however, they fall short of their expected performance and force the manufacturing decision-maker to make costly choices with little or no assistance. Why is it that

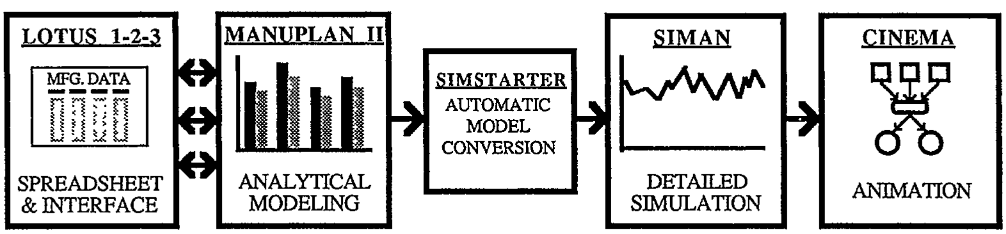

FIGURE 1: INTEGRATED TOOLKIT FOR RAPID MODELING

powerful, state of the art simulation software so frequently winds up just "taking up space" on a hard drive or bookshelf?

The key drawback of modeling and simulation packages available today is the time required to use them. Modeling time requirements, even with extensive training efforts, significantly reduce the value of the simulation tool. The reality of the manufacturing world is that engineers and managers are typically forced to make decisions about factory design or operation policy, under severe time pressure. But choices that have to be made in a couple of days may take weeks to model and analyze on the company's simulation package. While simpler tools may be available, they usually ignore important system characteristics.

What manufacturing decision-makers would like to have is a package capable of rapid analysis, but one that considers the important complexities of their manufacturing environment. Is there a single modeling package available that can do all of this? No, but there is a close "cousin" that promises significant increases in analysis productivity: rather than being a "universal" modeling tool, it is a toolbox.

1.3 The Need for a "Toolbox"

All metal-cutting is not done with a 3/4" milling cutter. Depending on the job to be done, there is a variety of tools that an experienced process planner must choose from. The same is true of modeling. One should not expect all decisions to be analyzed by one universal modeling tool. An experienced analyst will choose the appropriate modeling tool based on the type of decision to be made, the available data, and most of all the amount of time available before the decision must be made [Thesen and Travis (1988)]. Thus, the analyst should be equipped with a "toolbox" of modeling software.

However, just having a toolbox is not enough. Consider another typical example. A firm wishes to investigate whether it makes sense to put a family of five products in a dedicated group technology (GT) cell. A manager may only want a quick study to indicate whether or not it is worth pursuing the idea. If this "feasibility" study shows that there may be substantial benefits, the manager could then allocate more resources to a detailed study and possibly even design of a cell. In this case, the tool used for the feasibility study may not be the appropriate tool for the detailed study. In general, decisions tend to proceed from "rough" to "detailed", from "preliminary" to "final", from "general" to "specific". In such instances it may become necessary to switch tools when going from one stage of analysis to the next. This is where an integrated set of tools shows its potential: as we shall see below, one can move from the simpler analysis to the more complex, with minimal duplication of modeling effort. Such rapid modeling can have considerable effect in modern manufacturing situations.

1.4 The Benefits of Rapid Modeling

In the competitive manufacturing environment of today, the benefits of rapid modeling and analysis can be very significant [Suri (1988)]. In the planning of new systems, early feedback to the designers and managers can result in important changes in direction, often with a very large payoff. Nymon (1987), and Brown (1988) give examples where rapid modeling had significant impact on the design of "greenfield" plants for Alcoa and IBM. With product life cycles becoming shorter and shorter, the ability to complete a plant and bring a product to market six months earlier can help to "shut out" the competition. In existing facilities too, rapid modeling has its place. Suri (1988) states an example where quick modeling enabled Pratt & Whitney to be competitive in a bid. As mentioned in that article, the same company also uses rapid modeling on a frequent basis to look at the impact of varying lot sizes, set-ups, schedules and so on. Thus, both in system planning, as well as in system operation, rapid modeling offers considerable benefits (Figure 2).

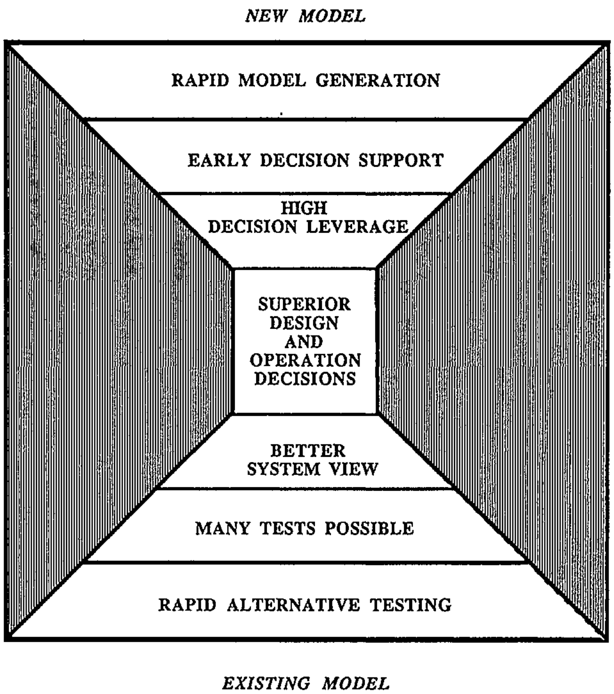

FIGURE 2: BENEFITS OF RAPID MODELING

1.5 Satisfying Rapid Modeling Needs: An Integrated Set of Tools

To answer our earlier question, there *is* an effective way for manufacturing engineers and managers to perform complex analysis rapidly and in a broad range of situations. However, no single program has been designed to incorporate all of these abilities in one package. It is necessary to employ an array of different modeling and analysis tools in order to take best advantage of the strengths of a variety of different methods. A set of Rapid Modeling tools has recently been introduced which enables manufacturing decision-makers to do just that (Figure 1). These tools provide rapid analysis capabilities both, for situations where decisions must be made over night, and for design projects that allow for months of planning. Furthermore, these tools are integrated to smooth the transition from one tool to the next.

This set of tools has already seen some initial success in the manufacturing world [Anderson et al. (1988), Shimizu and Van Zoest (1988)]. The purpose of this paper is to provide, for the manufacturing analyst, an overview of these tools and the methodology behind them.

2. A BRIEF LOOK AT THE RAPID MODELING TOOLS

2.1 Components of the Integrated Tool

The set of rapid modeling tools described here provides analysis capabilities for a broad range of situations. Lotus 1-2-3 provides data handling abilities and is the most fundamental analysis tool in the group. It enables simple engineering and financial calculations to be performed quickly and easily. Next, rough cut manufacturing system models can be built and analysis performed in as little as a couple of hours using Manuplan II. This analytical modeling package considers the dynamics of the system and provides accurate information regarding plant capacity, flowtime, work in process, and many other important manufacturing concerns. SimStarter allows almost instant conversion of Manuplan II models into Siman simulation code. Siman simulation can provide for advanced operation research of the rough-cut model, (e.g. scheduling studies), or allow the addition of more complex features to the basic model (e.g. material handling). Finally, the Cinema animation package gives the analyst a greater ability to observe and communicate the results of the modeling effort. Using the Rapid Modeling tools, simple models can be built in under a day, and more complex systems can be modeled in a few days.

2.2 Compatibility is the Key

At this point, the reader may be concerned about time requirements for using five different modeling and analysis programs on one project. While there is a clear advantage in having several different tools available, time requirements for creating a number of different, non-integrated models would make such an approach infeasible. This set of Rapid Modeling tools is compatible, allowing the user to build, in effect, only one model. That model can be successively refined at each stage of analysis without duplicate data entry or coding. Lotus 1-2-3 acts as the interface for Manuplan II, which can be directly converted to Siman code using SimStarter. Cinema animation can be laid out using a CAD-like interface, and then driven directly from Siman. This integration allows for the broad range of abilities already described, while providing flexibility of choice to the analyst. After reviewing the nature of the decision to be analyzed, manufacturing decision-makers can choose the method (and complexity) with which they wish to conduct their analysis.

3. A CLOSER LOOK AT THE TOOLS

Having discussed the general role of the Rapid Modeling Tools and shown some of the key benefits of using an array of analysis methods, we go on to discuss each of the tools specifically. We will present the basic methodology behind each tool, its key strengths, appropriate situations for use, and the constraints associated with each package.

3.1 Lotus 1-2-3

An electronic spreadsheet is the first tool employed when using the rapid modeling approach. Complete information regarding the manufacturing system to be modeled can be entered into the spreadsheet. Information on equipment, manufacturing resource requirements, and product demand are examples of data commonly included. Lotus 1-2-3 is a widely used electronic spreadsheet, and is chosen as the first package in our toolbox. Using 1-2-3, data is available in standard form to the rest of the tools in the system.

The key advantage to using 1-2-3 as the database is its ability to both hold, *and* manipulate, large amounts of data efficiently. Using the spreadsheet provides a database that is flexible, accessible, and easily amenable to engineering and financial calculations. Data can be added, modified, or moved as quickly as it can be gathered. In addition, the popularity of this package provides an added bonus. Since almost all manufacturing decision-makers have had a basic exposure to 1-2-3 it is likely that the user will already be familiar with the Rapid

Modeling interface. On a similar note, since many companies already employ spreadsheets to handle manufacturing information, data needed for the analysis project may already be directly accessible through 1-2-3.

As mentioned, the spreadsheet has analysis abilities above and beyond its strength as a data handler. 1-2-3 has considerable economic analysis capabilities that can be used to assign dollar values to design alternatives (discussed more in the Manuplan II section). Rough assessment of machine time requirements can also be performed, giving a "ball park" prediction of equipment needs. These static calculations of system capacity can be a useful starting point for further analysis. Shimizu (1988) gives a good example of the use of 1-2-3 for initial analysis of a manufacturing line.

Spreadsheets are not an appropriate tool for analysis when complex dynamics of the manufacturing system need to be included. Interactions between work stations, machine downtime, raw material delivery delays and other such issues involve computations that are beyond the normal use of 1-2-3. Since these characteristics are crucial in operating manufacturing systems, a more powerful analysis tool is needed.

3.2 Manuplan II

Based on industrial experience with using the toolbox, we find that Manuplan II tends to be the tool of choice for most situations. This is because the ratio of time spent to benefits obtained is usually very high [see examples in Suri (1988)]. Manuplan II provides very fast "rough-cut" dynamic analysis of discrete manufacturing systems by using an advanced analytical model. All necessary data is entered in five basic screens using the 1-2-3 interface. These screens (Figure 3) include information on system operation time, equipment, product types and demand, part routings, and operation setup and run times. This data can either be entered manually or pulled directly from existing 1-2-3 databases that can be accessed in the Manuplan II input model via 1-2-3 cell references (Shimizu (1988) shows a detailed example of this). The program delivers results based on this data in a matter of seconds. The results include information on equipment utilization levels, queues, average flowtime for each part produced and work in-process levels (Figure 3). Using this data the analyst can assess not only the capacity of the system, but also its ability to meet lead times, and the general efficiency and flexibility with which it will operate.

The major advantage of the analytical modeling approach is its ability to perform rapid dynamic analysis without the extensive model development effort required by simulation packages. With Manuplan II, a

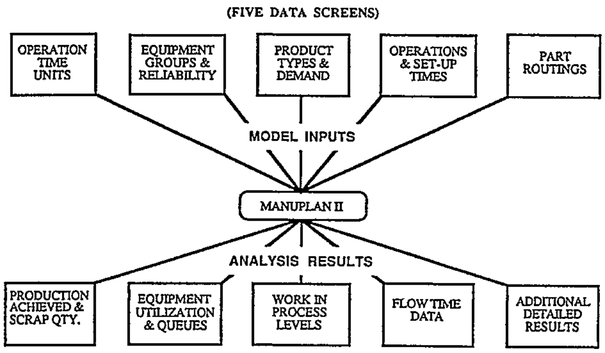

FIGURE 3: MANUPLAN INPUTS AND OUTPUTS

modeling and analysis study can be taken from its starting point through final recommendations in a matter of days, compared with weeks or months for simulation [Anderson (1987)]. Each "run" of an input model takes about a minute on an AT computer, compared with nearly an hour or more a comparable for simulation run. The package is also "user friendly", allowing users with manufacturing background to learn the package without special classes or extensive training.

The 1-2-3 interface upon which Manuplan II is based provides an important analysis atmosphere. Basic manufacturing data, the input model, and the results file are stored in spreadsheet form, allowing the analyst to perform economic calculations that can be used to compare design or operation alternatives in monetary terms. In this way, the analytical model is specifically suited for manufacturing decision-making.

The strengths listed above make Manuplan II an ideal tool for situations where decisions need to be made "overnight". Rough models can be built in a matter of hours and changes to existing models can be executed in minutes. Manuplan II gives the manufacturing decision-maker support in time constrained situations where simulation modeling and analysis could never be completed in time. In less "urgent" situations, rapid modeling still affords significant benefits. Using rough cut analytical modeling from the early stages of a project provides the analyst with better insight into the system as a whole [Brown (1988), Nymon (1987), Haider et al. (1986)]. The short analysis run time allows the decision-maker powerful "what if" capabilities, allowing the analyst to evaluate many alternatives in the time it would take to perform one simulation run. In this way, Manuplan II can be used to focus more extensive investigation on only the most promising design or operation alternatives. At this point more detailed modeling can be performed using Manuplan II or simulation.

While Manuplan II is a very powerful analysis tool, it does have limitations. Since analytical models deliver results based on the steady state performance of discrete manufacturing systems, they cannot be used to research issues related to detailed scheduling or very short-term conditions (such as start-up procedures). They also do not consider the impact of buffer size constraints. Likewise, it is not possible to animate the analytical model directly. While Manuplan II cannot perform these tasks by itself, the following tools effectively compensate for these deficiencies.

3.3 SimStarter

SimStarter is a unique program that allows Manuplan II model files to be directly converted into Siman simulation code. This link enhances the abilities of analytical modeling and simulation, completely eliminating the need for duplicate model building.

The key benefit of the SimStarter package is the drastic reduction in time required to develop and debug an initial simulation model. As noted above, Manuplan II is far more effective than simulation for rapid modeling and for initial decisions or decisions under time pressure, but it is unable to perform some more detailed analysis tasks. In cases where simulation is clearly needed, one might think the analytical modeling is unnecessary, duplicating the results given by simulation. However, using Manuplan II, some fundamental insights regarding the system can be gained earlier than with simulation. Then using SimStarter, the analytical model can be directly converted to Siman code. At this point, one has both: a good idea of which alternatives to explore with the simulation, and an initial simulation model; and all this in much less time than it would traditionally take just to build the simulation model alone! At this point one can easily incorporate the detailed features of the manufacturing system into the Siman code.

In addition to the reduction in model development time, SimStarter minimizes debugging time by constructing an error-free initial system configuration in the Siman Model file, and error-free placement of a large amount of initial data and parameters in the Siman Experiment file. Experienced simulation users will appreciate the importance of such a starting point from which they can enhance the model with other details.

SimStarter users have noted additional benefits that accrue to organizations from using such a package [Anderson et al. (1988), Shimizu (1988)]. These include the standardization of the program file structures and portability of code between programmers. Also, there is less resistance to exploring radically different alternatives, as the analyst knows it will be relatively easy to generate the simulation code for the new alternative.

Finally, such a conversion package allows the analyst to make a smooth and efficient transition from high level analysis to detailed analysis. Analytical modeling (Manuplan II) and simulation (Siman) become complementary rather than competing tools.

The main constraint of SimStarter is that it works best for manufacturing systems that follow the type of discrete manufacturing modeled in Manuplan. The greater the deviation from the general structure of the Manuplan model, the more work it will be to enhance the Siman code generated by SimStarter. The examples in Anderson (1987), Brown (1988) and Shimizu (1988) however, indicate that for many electronic assembly and metal-cutting applications, this is not a problem.

3.4 From Spreadsheets to Animation - With No Programming

At this point we note that the SimStarter conversion package also enables a new level of modeling if desired. The analyst can go directly from the analytical model to animation if simulation studies are not called for at the current stage of the project, but animated representations are needed. The 1-2-3 interface and Manuplan II can be used by any manufacturing or industrial engineer with very little training, and require no programming. SimStarter converts the Manuplan II model to simulation code with one command. This code defines a completely functional simulation program. A Cinema layout can be designed using a CAD-like drafting system interface. Thus, all the ingredients for an animation can be generated without any programming! In this way, production analysis can go from initial modeling in a spreadsheet to animation in only a few hours! Of course, the animation will be of a "high level" model, omitting the details that would be appropriate at a further stage of study. But even such a "rough animation" can be important, as our original case study about Jill now shows.

Fortunately, Jill had already used Manuplan in the early stages of the project, to look at overall system capacity and ability to meet general project goals. She had the Manuplan models available on her disk. Hearing of the SimStarter package, she decided to try it, and within a day of receiving the package, had a working Cinema animation showing the general layout of the facility and the flow of products, without many of the details that were currently being considered. Jill showed this animation to her manager as well as the manager in charge of the layout project. They now clearly perceived the tremendous benefit it would be to include such studies in their analysis. The two managers agreed that she should devote more time to such work. The simulation package had finally moved off the shelf into regular usage!

3.5 Siman

Siman and Cinema are sophisticated and powerful packages. Introductory tutorials on them can be found in the articles by Pegden and Davis (1988) and Miles and Sadowski (1988) included in these proceedings. The following sections only give an overview of these packages and deal mainly with how they fit into the set of rapid modeling tools.

Siman is a complete simulation language which is well-suited to detailed modeling of discrete or continuous manufacturing systems. Within the integrated tool concept, Siman code is generated from the Manuplan II model by the SimStarter package. The simulation model file can then be run in its basic form or detail can be added, as mentioned above.

Detail is a specialty of this simulation program. With the Siman package, all of the details and intricacies of a manufacturing system may be included in the model, enabling very accurate results to be compiled. The structure of the Siman language is such that manufacturing features are easily modeled. For example, various types of material handling are easy to incorporate in the simulation code. The Siman program produced by SimStarter is at the "Manuplan level" of modeling. Usually, the analyst will enhance this model by adding code on such features as: specific scheduling and priority policies; labor allocation policies; buffer size constraints; material handling paths and routing policies.

The traditional disadvantages of using simulation analysis, namely, extensive model development and run time requirements [Thesen and Travis (1988)], are diminished by the integrated tool concept. When used in conjunction with the other tools discussed, simulation is applied "down the line" in the analysis process. Early decision-making and guidance will already have been assisted by Manuplan II, affording more time for models to be built and data gathered to support final analysis and eventual decisions.

Modeling complexity is also a problematic issue in standard simulation analysis. Since the simulation approach considers so many details, it is often easy to "lose sight" of system wide objectives [Suri and Diehl (1987)]. Such problems are alleviated through the "back to basics" insight gained by the manufacturing decision-maker in the rough cut analysis performed before simulation begins. Several manufacturers have already demonstrated benefits of this concept in real world applications, for example, Digital Equipment Corp. [Harper and O'Loughlin (1987)], Siemens Corp. [Anderson (1987)], and a Wisconsin manufacturer of electrical equipment [Shimizu and Van Zoest (1988)].

3.6 Cinema

The Cinema animation package gives the user the power to construct helpful, visual representations of the simulation model. Cinema has a CAD-like interface to allow easy construction of animation for users with little programming knowledge. As mentioned, this enables quick animations to be developed in a couple of hours from the converted Manuplan II file. More detailed animations can be developed with a couple of days of effort.

Animation is not actually an analysis tool, but it has become a very popular approach for presenting the results of modeling studies. We have already discussed how difficult it can be for the analyst to grasp the "big picture" when using simulation. Seeing the results or implications of such analyses can be even more difficult for parties that have not been involved in the modeling process. To this extent, animation is an extremely effective way of bringing a project "home". It provides a way of visually communicating complex system models to managers, other design engineers, and shop floor personnel. The first four Rapid Modeling tools provide the decision-maker with remarkable analysis capabilities, and Cinema can often play a key role in convincing top management to put the analyst's recommendations into action.

Compared with a few very sophisticated animation systems, Cinema lacks the "3-D" capability of some systems, and its CAD-like interface is not quite as sophisticated as complete drafting systems (which allow multiple "layers" and groups of entities to be defined, moved, erased, etc.). On the other hand, it is very well suited to manufacturing animation, with concepts such as material handling and part routing definable in simple, intuitive ways.

4. EFFECTIVE USE OF THE TOOLBOX

In the manufacturing world, effective use of modeling to support decision-making is still the exception rather than the rule. To some extent, this is because of a reputation of "paralysis by analysis" created by some modeling experiences, where consultants have taken many months and tens of thousands of dollars to study time-critical decisions. The set of integrated tools described here can do much to convince the manufacturing decision-maker that analysis can be cost-effective, timely, and beneficial.

Brown (1988), Nymon (1987), and Suri (1988) describe instances where upper management obtained significant insight, and large savings in cost, by rapid, early modeling studies using Manuplan. The speed with which alternatives can be evaluated, and overall insight obtained, lays the foundation that convinces manufacturing management and other engineers in the team that modeling can be applied effectively to their project.

There are two paths along which analysis can proceed at this stage (Figure 4). The first is that, if needed to complement these initial studies, high level animation (as discussed in section 3.4) can be used to communicate the analysis to the other members of the project team and to management. We have already described the case where Jill's effective use of such high level animation made her modeling expertise an integral part of the facility layout project. The SimStarter- Siman- Cinema combination allows such an animation to be created quickly and with no programming.

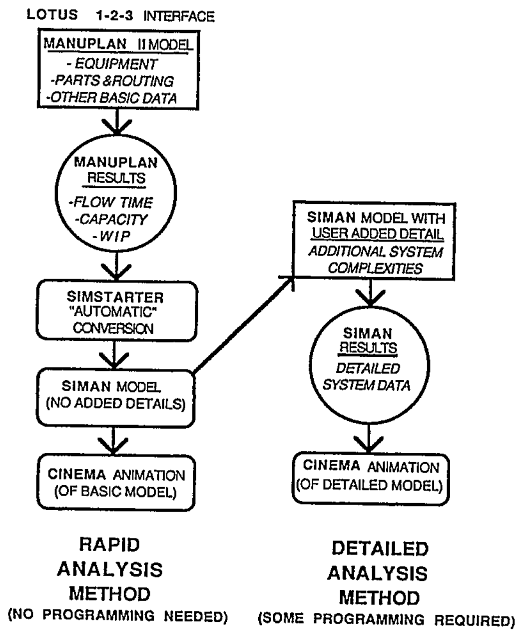

FIGURE 4: TWO WAYS OF USING RAPID MODELING TOOLS

The second path (Figure 4) is in the case where, based on the rapid modeling studies conducted with Manuplan, management decides to invest more time and resources to a detailed study. In such a case, it is easy to add the details to the Siman code generated by SimStarter. Shimizu and Van Zoest (1988) show how detailed scheduling issues were investigated for a modern electrical equipment factory, with just a few simple additions to the SimStarter- generated code. (They also mention some of the benefits of the early analysis with Manuplan II, which was instrumental in convincing factory management to proceed with more modeling studies.) Shimizu (1988) shows the investigation of buffer sizing and material handling container issues, again with minor additions to the rapidly generated simulation code.

In the new era of competitive manufacturing, a firm's ability to design and deliver high quality products to the market in short lead times, will be critical to the survival of the firm. Rapid modeling will be an important component of the firm's survival strategy in this marketplace. For the design and operation of truly streamlined production facilities, we must ensure that we also use streamlined analysis procedures. The integrated set of tools presented here strives to accomplish this goal.

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BIOGRAPHIES

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