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MANUFACTURING PROCESS ANALYSIS -- TOOLS AND APPLICATIONS

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ABSTRACT

The use of Simulation for evaluating manufacturing lines has become an accepted means of gathering information and understanding of the lines. One of the primary reasons for this acceptance is the fact that the analysis is now being performed by the people who are experts in the process; those who understand the real world interactions inherent to their system. However, simulation is only one of many tools that can be used to evaluate and understand an existing or proposed manufacturing line. In this paper, the authors discuss how these various tools can be brought together in a tool suite to help both simulation experts and non-experts gain insight into the manufacturing process under consideration.

1. THE EMERGENCE OF SIMULATION

In the past simulation has been a tool used by simulation experts, mathematicians, and Industrial Engineers for the purpose of evaluating manufacturing processes. The use of these tools by non-experts was limited because the tools more closely resemble high level programming languages than manufacturing processes. This changed with the introduction of simulation packages such as MAP/1 (Pritsker and Associates, West Lafayette, Indiana). The simulation language is hidden within a package that uses terms that more closely resemble the manufacturing process. Tools like MAP/1 are specifically tailored to the evaluation of batch manufacturing systems. Simulation software vendors began to provide process experts with a symbol set and terminology that closely resemble the concepts and language that process engineers use on a daily basis. However, in providing a package to disguise the language many assumptions have to be made. Parts arrive at a station's input queue, are processed by the station, are placed in the station's output queue, and await transportation to the next station. Not only is this type of model constrained by the implicit assumptions of the package, but it is also constrained by the use of a generic model. These tools are extremely useful provided that the system under evaluation resembles the typical batch manufacturing process flow and does not violate the implicit assumptions of the package. Simulation packages provide a "natural" language for the non-expert while answering most of the questions posed.

When the system did not resemble the generic model within the package, the user had to revert back to a simulation language. Process engineers were required to learn a new language in order to use the tool. Those non-experts who had used a simulation package had the advantage of being able to translate statements from the package into building blocks used by the language. Even with this advantage, the non-expert ran into syntactical problems. Pre-run time processors like those provided by SIMAN (Systems Modeling Corp., State College, Pennsylvania) provide a syntactic check. However, the routing logic of the process was often lost in a long model print out. The advent of user utilities such as BLOCKS (Systems Modeling Corp.) for SIMAN and TESS for SLAM II (Pritsker and Associates) made the simulation languages easier to use by providing syntactical debug during the model input phase. Users no longer have to be concerned with entering the correct number of commas or omitting commas in order to use the default value associated with a field for a particular statement. Not only is syntactical debug time eliminated from the model building process, but a graphical representation of the model is being created. This graphical model resembles a flow chart and is more easily understood by the model builder and more easily explained to the modeling team and others concerned with the validity of the model. The advent of error checking at input time and graphically built models greatly decreased the development and debug time.

2. THE EMERGENCE OF ANALYTICAL TOOLS

With the increased use and acceptance of simulation for evaluating manufacturing processes, the number of people and organizations requesting simulation studies has increased exponentially. The number of alternatives requiring evaluation has likewise increased while results are expected within a shortening time frame. Evaluating alternatives is a time consuming activity. The amount of time required to evaluate an alternative is largely dependent upon the complexity of the model and the desired level of detail. However, the alternatives evaluated are often no better or worse than the base line model, and differ mainly at a very fine level of detail. Analytical tools give the user the opportunity to quickly abandon base line alternatives that will not meet specifications. At the same time, it is necessary to prove that only major changes in the nature of the system could be considered viable alternatives.

MANUPLAN (Network Dynamics, Cambridge, Massachusetts) provides the ability to quickly evaluate alternatives and spend valuable simulation modeling time on the more viable system configurations. MANUPLAN combines a network of queues with reliability modeling. The data used to perform an analysis include routing information, equipment groups, operations, reliability measures, mean time to failure, and mean time to repair. MANUPLAN, like MAP/1, uses manufacturing terms, and the input is organized to facilitate easy model development. In addition, the user may easily change some of the parameters, without losing the base line inputs, by specifying a speed-up factor. The output from this type of tool is usually less accurate than a detailed simulation model, but is certainly sufficient when performing high level first pass analysis, when there is not sufficient information for a detailed simulation model, or when ball park results are required in a short time. The short development time and the quick execution time allow the user to exercise a large number alternatives with a minimum time investment. If a base line model and its associated alternatives are abandoned, the time spent on that path is far less than would be spent on a simulation model. Minimizing time spent in evaluating bad alternatives leaves the user more time to study viable options. Analytical tools like MANUPLAN resolve the time pressure problem and direct attention to the more viable options.

With emphasis being placed on quality, managers are more concerned than ever with knowing how processes affect quality, how poor quality may impact processes, how correcting poor quality processes will affect yield, and so forth. A process step yield which considers the percent of product which will pass final test and the percent requiring rework is one way to view quality. Varying the yields would, for the sake of analysis, correspond to a change in product quality. The effect of quality on the throughput or equipment requirements can be easily seen within a simulation or rough cut model. To gain a better understanding of the yields, the cause of the yields must be understood. The yield is related to the defects, and by understanding the defects, where they are introduced, where they are detected and repaired, or not detected, one can understand what tolerances are acceptable and will have a better understanding of the overall manufacturing process. Through the use of statistics, expected yields and quality can be predicted. This provides process engineers with information that could change the course of a new process development or aid in correcting an existing process. A tool that provides this type of statistical analysis for a whole process line determines what resources are required. It places emphasis on realizable yields and defect detection. It also removes a complex level of detail from a simulation model by placing that detail in a more appropriate tool.

With supporting analysis concerning the feasibility of an alternative and quality related issues settled, a spreadsheet should be used to measure the cost of success. When recommending a process the ultimate owner of the process needs to know where the costs of the process are generated, at what point a part should be scrapped rather than repaired, and how much material must be put into the process to achieve the required finished goods production. Process engineers need to know if the process is economically feasible, how much it costs to build a better quality product, and where money is better spent to increase quality. Regardless of our ability to envision processes and find the equipment necessary to build the product, profit and loss can not be treated as a matter of interest only to the financial community.

Above we have mentioned some of the tools that are available for evaluating manufacturing processes. This suite of tools ranges from rough cut analytical tools for quick evaluation of alternatives, to defect analysis tools for assessing quality issues, to spreadsheet and/or financial modeling for costing alternatives, to simulation packages and languages for detailed analysis. Each tool excels in a particular area and each should be used to support the others. The process of designing and evaluating a manufacturing process is greatly improved when the correct tool is used at the proper level of detail and point in time for the analysis required. No one tool will answer all of the questions as well as a suite of tools used in combination to support each other.

3. APPLICATIONS

The application discussed here is a module board manufacturing process. The objective in doing the analysis was to determine whether a board could be built at or below a specified cost, and what conditions in the assembly process were necessary to achieve this goal. Our analysis began with the development, using the graphical network builder within TESS, of a high level SLAM II simulation model to which detail could be added. The flow began as a series of assembly and test steps (see FIG. 1). The results from the model indicated that, based on the input data concerning process flow, process time, and yields, the line was capable of building the required number in the required time for a price that was close to the expected price. But as in most model developments, there were changes in the base line assumptions of the model. Although the models were built with variables that allowed for quick and easy updating,

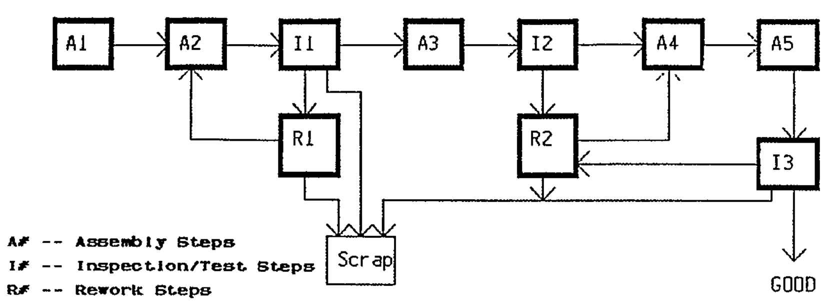


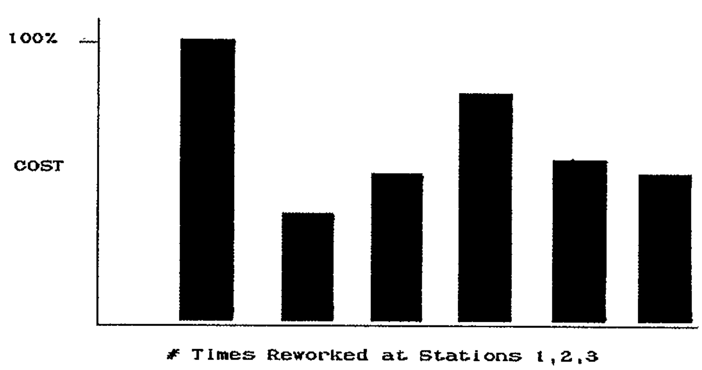
FIGURE 1. The manufacturing process flow. This flow was arrived at through several iterations of analysis using simulation.

often the old model was scrapped. A new model would be built rather than maintaining and updating the old model with new information. This was especially true when the process flow changed drastically. The flow represented in Figure 1 was actually arrived at through several iterations of analysis via the TESS/SLAM model which prompted the product and process engineers to suggest process modifications.

To build a model that is capable of being updated requires more time than to develop a model that only resembles the current alternative that is under consideration. Although the model may take longer to develop, it is the best approach. The disadvantage is that there is less time to perform additional analysis and the number of alternatives that can be evaluated is limited. Eventually a model that had few flow changes was developed. This allowed us more time for analysis. The other models that were developed and abandoned provided insight into the real world situation and helped develop the final version of the process.

During the model development it was found that the parameters that had the greatest impact on the line had to do with the impact of rework. The amount of rework was, of course, related to the yields. As the yields decreased the number of pieces of equipment required to handle the additional throughput increased. The lower yields necessitated higher input rates to maintain the same level of output. For each scenario, the output was tied to a spreadsheet to gain some understanding of the cost. In addition to each of the different yields, it was necessary to determine when it was best to stop rework and scrap the board. To arrive at these conclusions, an iterative process was followed. The first thing to do was to arrive at a steady state model, which required multiple simulation runs. Once that was achieved, the financial analysis was performed. Based on the outcome, the model was modified to reflect the new or eliminated equipment and the number of times that rework was permitted per board. The analysis continued iteratively until a cost effective and balanced line was achieved for each set of yields. High level models were used since many alternatives could be quickly executed and analyzed. The ability to perform analysis quickly and easily was critical due to time pressures. The simulation model was rerun with the new parameter sets once a few viable alternatives had been isolated.

Through the use of MANUPLAN we were able to perform these evaluations in a more timely manner, increase the number of evaluations, and add more detail as needed. Within the simulation model we put a limit on the total number of times a product could be reworked throughout the entire process. Using MANUPLAN we were able to go further in evaluating the number of times for each



Station 1	0	1	2	0	1	2
Station 2	0	0	0	1	1	1
Station 3	1	1	1	2	2	2

FIGURE 2. The cost of rework based on the number of times the product was permitted to pass through rework at each of the inspection stations before it was scrapped. The maximum number of times is noted below the cost columns for each of the stations. Through the use of MANUPLAN we could perform this analysis more quickly than with a simulation model.

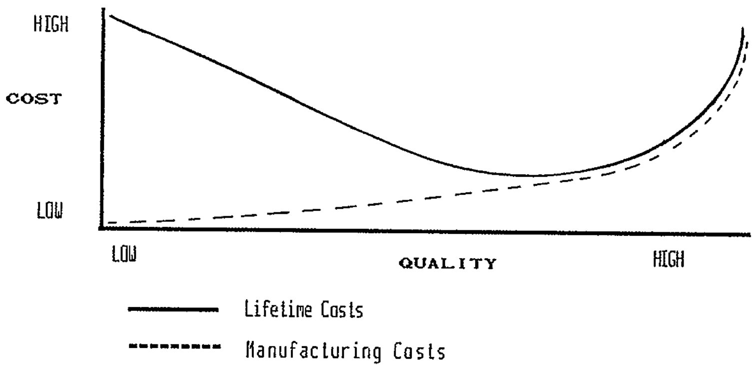


FIGURE 3. The cost of manufacturing a board and its lifetime costs are related to the quality of the product. The lifetime costs include manufacturing cost plus the field cost of the product once it is installed at a customer site. Obtaining an extremely high quality product may be too costly.

test/inspection step, due primarily to the short execution time of the models (see FIG. 2). The results from the MANUPLAN model were less accurate than the results from the TESS/SLAM model, but trends could be established, providing information for detailed simulation analysis.

Because the yields had an impact on the cost of the assembly, further analysis around the causes of the yields was requested. In this case, there were two major contributors to the yield; the incoming defects within the products and the defects introduced in the assembly area. The yield was based on the the coverage for each defect and on the number of occurrences of the defects. A package designed to perform defect evaluation provided the evaluation tool necessary to understand what yields were possible for the various process alternatives. The input data included defects added by the assembly process and the coverages at the test/inspection steps for each defect type. These combined with the incoming defects to determine the yield and the defects that escape detection. An understanding of the quality of the boards produced was also obtained, thus giving an indication of the product quality leaving the line and cost over the lifetime (see FIG. 3).

Through the use of the defect evaluation package, the MANUPLAN models, the TESS/SLAM simulation models and the spreadsheet, the overall cost was determined for each

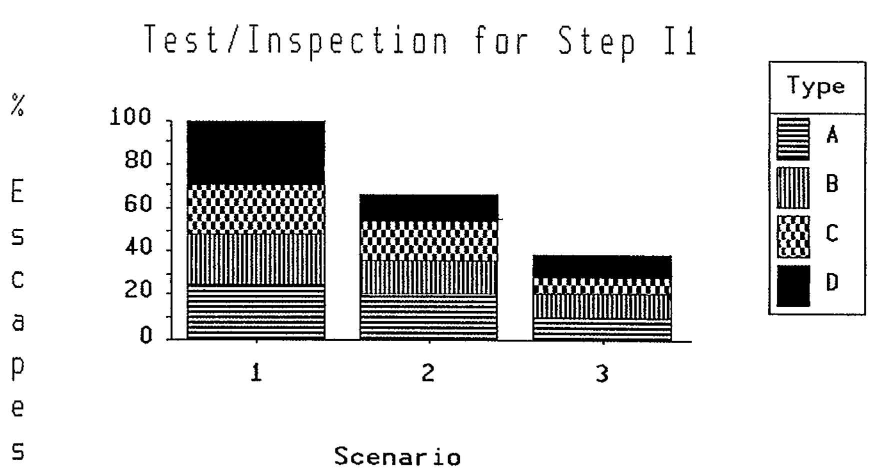


FIGURE 4. A relative comparison of the defects escaping from an inspection step demonstrates the advantages or disadvantages of different inspection scenarios.

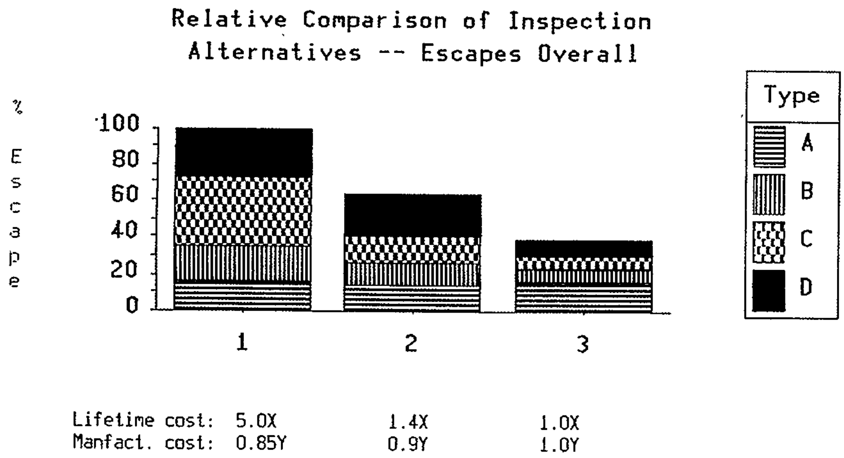


FIGURE 5. A relative comparison of inspection scenarios. Scenario 1 was the worst case; Scenario 3 the best. case. The cost X represents the relative lifetime cost and Y represents the relative manufacturing costs. Although the best case scenario is the most expensive to manufacture, the lifetime costs for the product are the lowest.

alternative view of defect introduction and capture. An additional area of investigation was to determine the best location for the test/inspection stations, as well as what type of testing should be performed, without significantly impacting cost.

In the analysis there were several scenarios, each representing a different understanding of the test/ inspection process and the use of different technologies to perform the inspection. Each scenario was analyzed to show the defects that escaped and the overall cost per unit produced (see Figures 4,5).

4. CONCLUSION

When this analysis began, the only tool available was the TESS/SLAM simulation software. The work that was done, including the cost and defect analysis, could have been done using only TESS/SLAM. However, as the other tools became available, we used the tool that best fit a particular analysis need. If we were to undertake a project with the same scope and needs as described above, the modeling process would proceed as follows: one, begin with an analytical modeling tool like MANUPLAN for evaluating many alternatives quickly; two, tie it together with a spreadsheet or other financial analysis package; three, evaluate yield alternatives with a defect analysis tool; and finally, use a detailed simulation model to understand the dynamic interaction of the process flow.

The use of a tool should be based on what the user needs to know and how well the tool can answer the questions that are being asked. No one tool will supply the breadth and range of analysis techniques required when undertaking a complex project. That is why a tool suite is needed.

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