USING SIMULATION FOR PROCESS PLANNING

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SIMULATION MODELS FOR PROCESS ANALYSES

Simulation models speed process analysis

Simulation modeling is an important evaluative tool that mathematically measures the efficiency of each component of a system or process. As such, it is ideally suited for process planning. Automated simulation methods can be used to assess and perfect processes quickly without modifying existing processes or systems. Also, simulation modeling allows the engineer to assess alternative processes by performing what-if analyses for predictive or explanatory purposes in a fraction of the time needed to analyze one process manually.

This article discusses and illustrates the use of simulation in process planning

This article discusses the use of simulation modeling in process planning, which is only one of its many applications. Methods of employing simulation models to select and perfect processes are explored, and an example of a successful application is studied.

THE SIMULATION APPROACH

Simulations can evaluate a wide range of alternative designs

Careful analysis of process alternatives for cost-effectiveness and productivity has long been considered a major undertaking, since the process engineer must consider a wide range of operating rules and design alternatives for the analysis to be worthwhile. In addition, desirable design modifications may be difficult to identify in complex processes and quantifying their impact is often troublesome. Simulation allows the process engineer to evaluate, with minimal time and effort, alternatives. A variety of functions can be assessed quickly for their impact on a process. Some of the most important functions that simulation modeling can perform in process planning are:

- Evaluation of line configurations.
- Determination of equipment needs and requirements.
- Identification of potential backlogs or bottlenecks.
- Determination of expected throughput.
- Investigation of impact of failures and downtimes.
- Estimation of labor requirements.
- Determination of desirable operating rules.

EMPLOYING THE SIMULATION MODEL

Steps in using a simulation model

Before undertaking a simulation approach to process planning, forming a project team is often useful. The scale of the project will determine the membership of a team; for smaller projects, a single trained engineer may suffice. Ideally, the team should include simulation modelers and process design engineers who are familiar with the process. Together they must determine the features to be included, the model assumptions and logic, and the appropriate level of detail to be evaluated. Whether the project is performed by a team or individual, the methodology is similar. The following are typical steps in employing a simulation model for process planning:

- Problem definition and formulation.
- Model specifications.
- Data collection.
- Model development.
- Result validation.
- Analysis of results.
- Documentation of model and process.

Process engineer role

The process engineer must understand thoroughly the process and the objectives of the analysis to be performed and must work with the simulation modeler to determine the model logic. The process engineer also coordinates the gathering and validation of data required for the model. After the model is developed, it is tested and the results are validated. Once the model is validated, it can be run on the computer and the process engineer performs the sensitivity analyses.

Simulation modeler role

The role of the simulation modeler is to design, build, and help validate the model after working closely with the process engineer to understand the process and the objectives of the analysis to be performed. After evaluating the problem, the modeler presents the advantages and disadvantages of several model approaches, recommends one that will best achieve the objectives of the process analysis, and defines the data required to build and execute the model. Once the model is complete, the simulation modeler serves as a consultant.

Data Requirements for Model Building

Data collection is vital

Data collection is obviously the most vital step in process planning. The process engineer must ensure data validity and completeness because the simulation model bases its results on process flow data and operating rules. If the process information is uncertain, the simulation model should be set up to perform what-if analysis on different combinations of data.

The typical process information required when building a simulation model is:

- A description of the process flow.
- Operating rules
  —Number of shifts
  —Start-up times
  —Changeover rules.
- Process flow data. (If actual data cannot be obtained, random sampling from empirical distributions are often used.)
  —Process and assembly times
  —Downtime (intervals between breakdowns)
  —Travel and flow times
  —Labor requirements
  —Equipment requirements and capacities
  —Other necessary resources.

Model Output

Output must be easily interpreted

The simulation model uses the collected data to generate the results of the process analysis. This output must include the information relevant to the analysis in a form that the process engineer can easily access and interpret. The project team should determine the type of information that the model will generate and design reports, graphs, or charts for effective display of the model results accordingly.

Standard and custom-made reports

The project team can prescribe either the standard reports generated by the simulation package, if one is being used, or customized reports when standard reports are not possible or do not provide adequate information. Standard reports usually summarize throughput, resource use (equipment and labor), waiting times, buffer (queue) sizes, and downtime. The simulation package can be directed to report additional process statistics as well. For example, standard reports typically give the mean, minimum, and maximum inventory levels and their standard deviation, but most simulation packages can also plot the process information values over a fixed period of time. In spite of these flexible reporting and plotting features, the project team may need to develop customized reports when important information is not included or standard reports are too cumbersome to allow easy extraction of needed data.

Results Validation

Model performance must be verified

After the simulation model has been defined, developed, and employed, its performance must be validated by the process engineer and the simulation modeler. The validation process involves both model code verification and results validation. Validation enhances the credibility of the analytical tool and demonstrates that a proper correlation exists between the simulation model and the actual process.

Validation can be done with historical or comparable data

The modeler typically performs the validation by executing the model with historical process data and comparing simulated results with actual performance. In design applications in which the process does not yet exist, the model results can be compared to the performance of a similar process or reviewed with the process design engineer for reasonable accuracy. One potential pitfall is that the simulation model may accurately represent the actual process only under certain conditions. Therefore, the model must be tested under numerous scenarios and be validated within the scope of its design. Another potential problem is the use of a model to analyze a situation in which the model may not be valid.

Model Flexibility

Interfaces may be useful

The simulation model can be made flexible so that analyses can be performed by changing data input rather than the simulation code. If they are economically advantageous, interfaces can be used that allow a process engineer to execute what-if analyses on the computer without the direct participation of the simulation modeler. Such flexibility may be important when multiple analyses must be run quickly. Full-screen interfaces for entering and updating data on a CRT allow the process engineer to update data quickly, and the process engineer can use the screens to scan and validate the model data. The full-screen interface alleviates the need for the simulation modeler to assist model execution and for the process engineer to understand data file manipulation.

Simulation software is available

To facilitate such ease of use, the simulation modeler should use a simulation language with a network modeling capability. Although a language like FORTRAN can sometimes achieve desired results, a high-powered simulation language allows process flow diagrams that use standard symbols to be converted into model code. Also, substantially less programming effort is needed, since the simulation language has built-in routines that drive the model, collect statistics, and report results. Two examples of simulation packages with network modeling capabilities are SLAM II from Pritsker and Associates Inc and NETWORK II.5, from CACI Inc.

A SIMULATION MODELING CASE STUDY

Part assembly

An application of simulation modeling was used to evaluate the proposed design of a flexible automated manufacturing line (FAML). The proposed layout of the FAML, which is used to assemble products in three stages, is shown in Exhibit 1. The FAML consists of a part assembly area with three robotic assembly stations and a final assembly area with two robotic stations. Both areas include other stations where manual assembly and testing take place. The first stage of the process flow occurs in the part assembly area where parts are assembled at one of three robotic stations and transferred to subsequent stations for screw insertion, seal application, curing, and testing. When the assembly is complete, the part is transferred to a storage area.

Subunit and final assembly

The second and third stages of production take place in the final assembly area. In the second stage, two parts are assembled into a subunit. The first part from the storage area is installed in the subunit base by the Final Assembly Robot Number 1 (FA1), then transferred to the Final Assembly Robot Number 2 (FA2) for the screw application. This procedure is repeated for the installation of the second part. The subunit is then transferred to the holding area.

The process flow of the third stage, the final product assembly, is summarized in Exhibit 2. The unit casting requires two assembly processes performed by the FA1 robot. The FA2 robot turns the casting before the second assembly process. The FA2 robot removes the casting to a holding area after the second assembly is completed. When two subunits are available, they are installed into the unit casting by the FA2 robot. The unit is then transferred to the holding area, where a manual operation is performed. The assembly of the unit is complete after inspection in the final test area.

Parts, subunits, and units are transferred between stations on a pallet by an electric cart. If a station is full, the cart leaves the pallet at the storage area until the station is available. All robotic assembly stations can process only one pallet at a time, but other stations have the capability of processing or storing several pallets at once.

Modifiable data

One of the key goals of a design simulation model is flexibility. Input data must be added or modified to allow what-if analysis of the following variable data:

- Number of electric carts
- Capacity of process stations
- Assembly and process times

Exhibit 1. *Proposed Layout of the Flexible Automated Manufacturing Line*

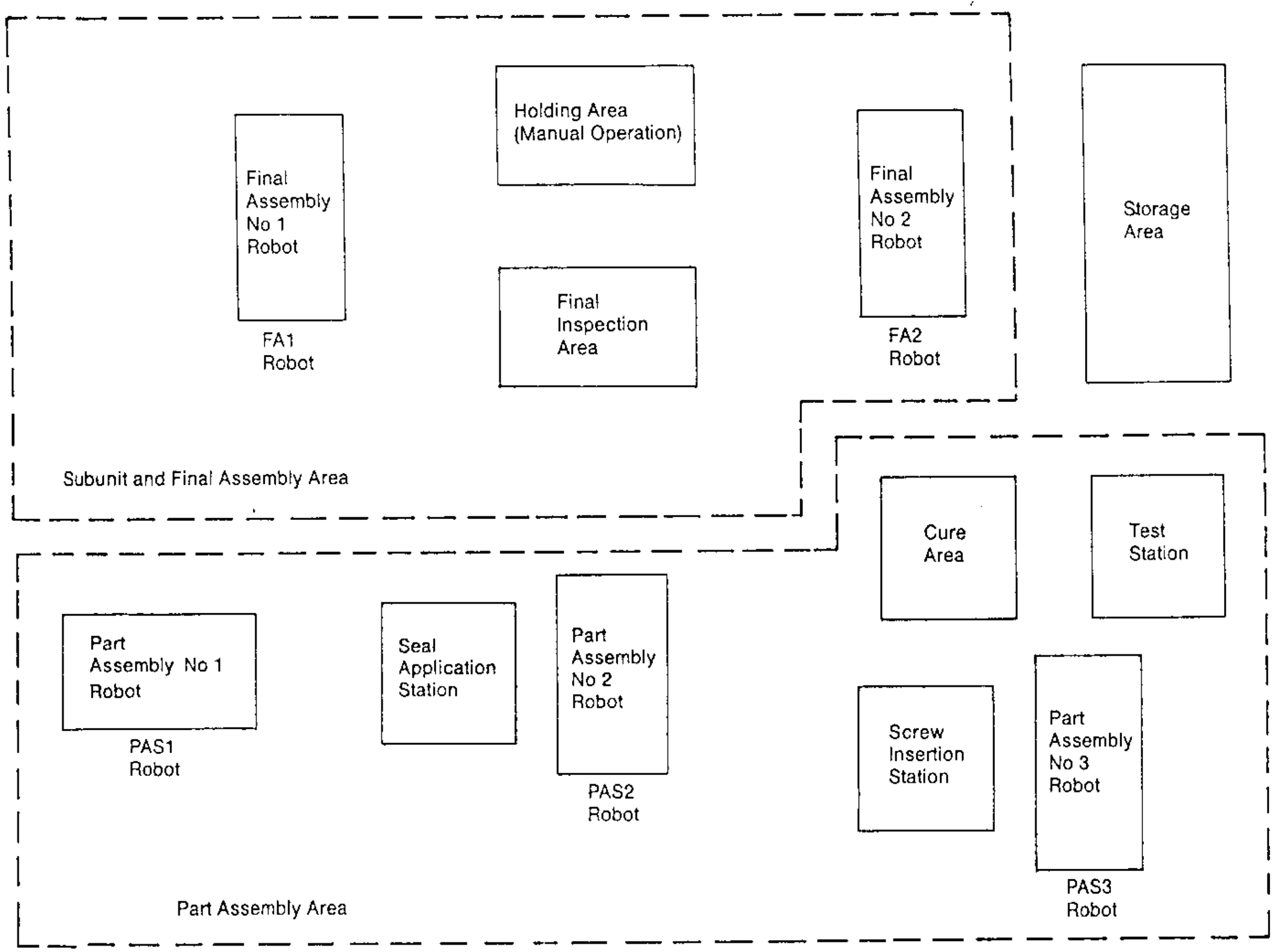
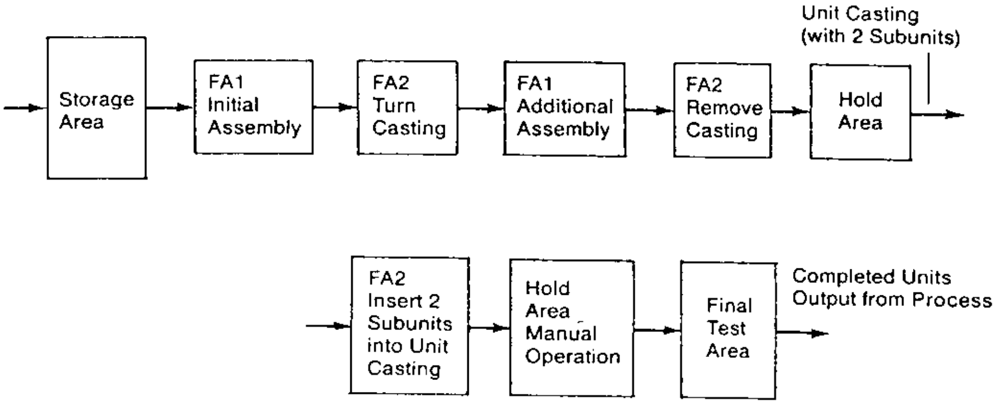


Exhibit 2. *FAML Final Unit Assembly*



- Transfer times between stations
- Mean robot downtimes
- Mean interval between robot downtimes
- Changeover times
- Start-up times
- Number of 8-hour shifts to be run per day
- Total time duration to be simulated

Exhibits 3, 4, 5, and 6 show the original data input for resource capability and availability, assembly and process time, and operation rules. In the system used for this simulation, an override option can be used to change the original (default) data for subsequent simulations.

Exhibit 3. *Resource Capacity and Availability (Default Values)*

Resource	Number Available or Capacity
Electric Carts	1
Screw Insertion Stations	1
Seal Application Stations	1
Cure Area	25
Test Stations	1
Storage Area	500
Holding Area	10
Final Inspection Area	1

Exhibit 4. *Assembly and Process Times (Default Values)*

	Assembly and Process Times (sec)
Part Assembly	
Part Assembly on PAS	76.0
Screw Insertion	64.0
Epoxy	24.0
Cure	24.0
Testing	30.0
Subunit Assembly	
Part Installation	416.0
Part Screwing	396.0
Manual Operation	20.0
Final Product Assembly	
Initial Assembly	560.0
Turn Casting	20.0
Second Assembly	265.0
Remove Casting	20.0
Insert Subunits	50.0
Manual Operation	65.0
Final Test	30.0

Exhibit 5. *Transfer Times (Default Values)*

From	To	Transfer Times (sec)
PAS	Screw Insertion Station	20.0
Screw Insertion Station	Seal Application Station	11.0
Seal Application Station	Cure Area	5.0
Cure Area	Test Station	20.0
Test Station	Storage Area	20.0
Storage Area	FA1 Robot	10.0
FA1 Robot	FA2 Robot	7.5
FA1 Robot	Holding Area	10.0
FA2 Robot	Holding Area	10.0
Holding Area	Storage Area	20.0
Storage Area	Final Inspection Area	20.0
Storage Area	PAS	20.0
Storage Area	Screw Insertion Station	20.0
Storage Area	Seal Application Station	20.0
Storage Area	Cure Area	20.0
Storage Area	FA2 Robot	20.0

Exhibit 6. *Operating Rules (Default Values)*

	Default
Duration of Simulation (days)	7
Number of Shifts Per Day	2
Start-up Time (min)	20
Changeover Time (min):	
Product A	60
Product B	60
Product C	90
Product D	75
Product E	60
Mean Downtime (min):	
PAS1 Robot	11
PAS2 Robot	11
PAS3 Robot	11
FA1 Robot	15
FA2 Robot	15
Interval Between Breakdowns (min):	
PAS1 Robot	720
PAS2 Robot	720
PAS3 Robot	720
FA1 Robot	960
FA2 Robot	960

What-If Analysis with the Simulation Model

Simulation to find an idealized process design

The simulation model can be used to determine the equipment configuration that will maximize the weekly output of a product given that the number of existing robotic stations is fixed. The FAML operates two shifts per day, and all three part assembly stations (PASs) can be used. The simulation model can also be used to analyze the assembly of unique products or combinations of products. If the process engineer submits a production plan at execution time indicating the product type and the number of units to be produced, the model simulates the assembly of products in the same sequence as the production plan. Exhibit 7 shows a screen with which the process engineer has entered the desired production plan.

Exhibit 7. *Production Plan*

Product	No of Units	Part Assembly Station
A	100	1
A	100	2
A	100	3
B	50	1
B	50	2
B	50	3

Steps for maximizing throughput

The number of units produced in the plan is deliberately set higher than the expected output for one week. The process engineer takes the following steps to determine an equipment configuration that maximizes throughput:

1. Execute the model, using current model default values.
2. Scan model results to determine the number of units produced and to identify backlogs.
3. Increase capacity of equipment where necessary to alleviate the backlogs.
4. Repeat steps 1 to 3 until the model results are acceptable.

Case study results

The model in this study was executed five times to achieve maximum throughput. Each case simulated the same production time. The results of the simulation and an explanation of the adjustments are shown in Exhibit 8.

Exhibit 8. *Case Study Simulation Results*

No	Stations	Capacity of Seal Area	Capacity of Cure Area	Capacity of Test Area	Total Units Produced	Change in Units Produced
1	1	1	25	1	39	—
2	2	1	25	1	72	+33
3	3	1	40	1	81	+9
4	3	1	40	2	90	+9
5	3	2	40	2	91	+1

Note:
—Original value

Execution Number One. The initial model execution used the default values for the model variables. The model results show a total of 39 units produced in the time period, and subsequent analysis reveals backlog awaiting the screw insertion operation in the part assembly area. The impact of the backlog is substantial because the average queue time for screw insertion is 193 minutes and 125 units are in queue. The results show that the output of the line can be significantly increased if the capacity of the screw insertion area is increased to alleviate the bottleneck.

Execution Number Two. The second execution of the model reflects a theoretical increase in the number of screw insertion stations from one to two. The results show that output increases from 39 to 72 units. However, a backlog still exists awaiting the screw insertion stations where the average queue time is 516 minutes and 32 units are currently in queue. A backlog has also developed in the cure area, with an average queue time of 203 minutes and 12 units in queue. The number of units produced should again increase if another screw insertion station is added and the cure area expanded.

Execution Number Three. The third execution of the model reflects the addition of another screw insertion station and an increase in cure area capacity from 25 to 40. Model results show that total output increases to 80 units. Backlogs at the screw insertion stations and the cure area have been alleviated as the model fully utilizes all three screw insertion stations and at maximum use, the cure area does not exceed its 33-unit capacity. However, a backlog is discovered at the test station of the part assembly area, where the average queue time is 321 minutes and 20 units are in queue.

Execution Number Four. The fourth execution of the model reflects an increase in the capacity of the test station from one to two. The results show that total output increases from 81 to 90 units. The backlog at the test station disappears, but a backlog develops at the seal application station, where the average queue time is 16 minutes and two units are in queue.

Execution Number Five. The fifth execution of the model reflects an increase in the capacity of the seal application from one to two. The model results show that the backlog at the seal station is eliminated but total output increases by only one unit (from 90 to 91). Any further inclusion of additional equipment or capacity is not expected to increase total output significantly.

Analyzing the Simulation Results

Results are subject to economic analysis

The simulation model has been used to validate the proposed design of an FAML. The series of what-if analyses were performed to determine what equipment configuration would maximize throughput of the product. The final configuration is expected to increase total weekly throughput from 39 to 91 units. The process design engineer must now assess the economic implications of the configuration. The most efficient configuration will be the most expensive to implement, so the engineer must determine whether the increased efficiency forecasted by the simulator will warrant the additional cost. If a lower output rate does not affect company profitability, one of the first four configurations can be selected.