PROJECT ANALYSIS AND INTEGRATION AREA

R. W. Aster and G. Fox of the Project Analysis and Integration Area (PA&I) presented a simulation program that investigates the relationship between manpower requirements and equipment availability in the presence of scheduled and unscheduled maintenance. The program is called the Personnel Simulation Program (PSP).

PSP runs on a microcomputer, and was used to check the accuracy of the cost projections made by Kayex Corp. for Czochralski ingot growth. The methodology can be used for any type of equipment or for several types of equipment sharing common operators or maintenance personnel. PSP can be an important tool for optimizing capital-investment and labor-cost tradeoffs.

R. E. Daniel of PA&I presented a method for optimization of metallization patterns at a Cell and Module Formation Research Area technological session (see p. 363 and p. 378).

MACHINE/OPERATOR REQUIREMENT SIMULATIONS (Using the Personnel Simulation Program)

JET PROPULSION LABORATORY

R.W. Aster
G. Fox

The Problem

The Personnel Simulation Program (PSP) Was Developed to Investigate the Relationship Between Manpower Requirements and Equipment Uptime (i.e., Duty Rate) in the Presence of Scheduled and Random Downtime.

In the Absence of Long-Term Experience With Pilot Plants, MEPSDUs, and ESGUs, This Analysis Approach Can Assist in the Validation or Correction of Assumptions Made by Process and Equipment Researchers.

Essentially, PSP Can Be Used to Determine the Degree to Which an Industrial Process Has Been Successfully Automated

The Classical Operations Research Model
The Case of Identical Work Stations

- **Steady-State, Birth-Death Model**
- **Failure and Restoral Rates (Events/Minute) are Independent of Event Histories**
- **Work Stations All Have Identical Failure and Restoral Rates, and Required Personnel**
- **Personnel Availability Can Be Stochastic**

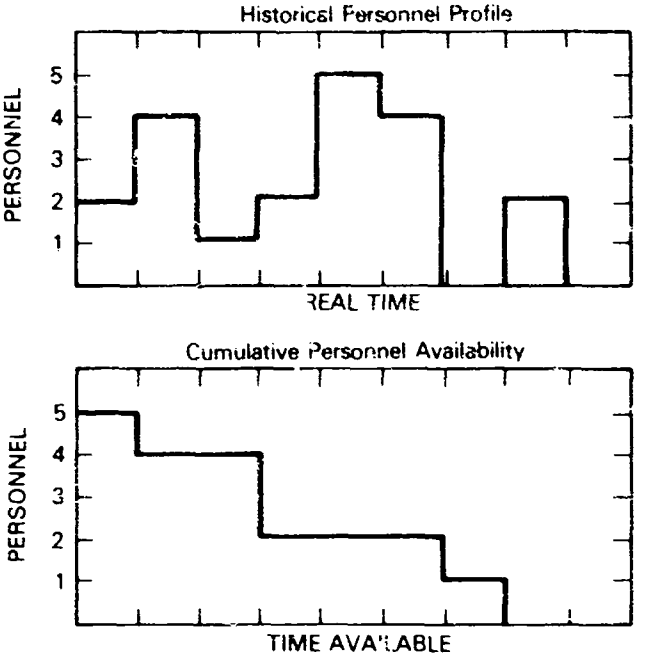
The General Iterative Model
An Extension of the Classical Model

- Steady-State, Birth-Death Model
- Arbitrary Failure and Restoral Distributions Without Loss of Memory
- Service Discipline is by Assigned Priorities, With Preemptive Rejection
- Personnel Availability Can Be Stochastic
- Work Stations Need Not Be Identical
- Multiple Personnel Requirements per Work Station Can Be Analyzed

Input/Output Data

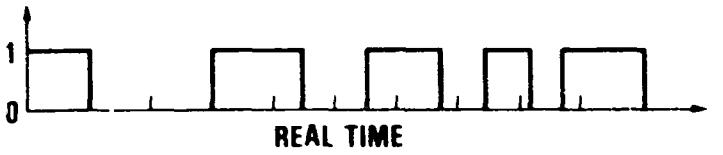
- Input Maximum Number of Operations
  - Percentage of the Time Each Operator is Available
- Input Number of Work Stations
  - For Each Work Station Input
    - Average Time to Failure
    - Average Time to Restoral
    - Minimum Number of Operators Required to Service/Set up
  - Work Stations Are Input in Priority Order
- Output Data for Each Work Station
  - Percentage of Time in Operation
  - Percentage of Time Being Serviced
  - Percentage of Time Waiting for Service
- Output Data Final Operator Availability Table

Deriving Input Data



Construction of Failure and Restoral Distributions

- **Sample Duty Profile of Work Station**



- **Average Time to Failure is the Average of the Lengths of Time Between a Failure and the Previous Restoral to Operation**

- **Average Time to Restoral is the Average of the Lengths of Time Between Restorals to Operation and Their Previous Failure Events**

Example Calculations

Based on Kayex Projections of 6-inch Cz Ingot Pullers

5 Ingots per Crucible
6-Inch Diameter
4 Operations:

1. **Preparation (Load Si, Melt)**
2. **Growth (1st Cycle)**
3. **Recharge and Growth (4 Times)**
4. **Clean Up and Set Up for Next Crucible**

Total Run Time 4680 min
Total Growth Time (Kayex Estimate) 2350 min
Total Operator Time (Estimated) 890 min
Furnaces/Operator/Shift (Kayex Estimate) 6
15% Idle Time in Addition to Run Time (Kayex Estimate)

Duration of Activities

	Operator Minutes	Machine Minutes	Full Time
Preparation	60	200	
Growth	60	680	470
Recharge/Growth (4 Times)	170	915	470
Clean and Set Up	90	140	

Sensitivity Analysis I

Ingots Per Run	Perfect Schedule* Furnaces Per Oper.	Perfect Schedule* Pull Ratio***	Perfect Schedule* Inches Per Shift	Stochastic Schedule** Pull Ratio	Stochastic Schedule** Inches Per Shift
1	4.1	0.461	45	0.378	36.3
2	4.3	0.486	50	0.408	39.2
3	4.4	0.495	52	0.419	40.2
4	4.4	0.499	53	0.424	40.7
5	4.5	0.502	54	0.428	41.1

*Non-Integer Machines per Operator, 85% Operator Availability, Operators and Furnaces Never Idle

**4 Furnaces per Operator, Long-Term Average Idle Time for Equipment and Operators, but No Breakdowns

***Time Spent Pulling Usable Ingot Divided by Total Time

Efficiencies of Scale

Operators	Furnaces	Pull Ratio	Inches/Shift/Operator
1	3	0.473	34.1
1	4	0.428	41.1
1	5	0.376	45.1
2	9	0.420	45.4
4	18	0.433	46.8
10	45	0.473	51.1
Perfect Schedule	4.5	0.502	54

Sensitivity Analysis II

There Are 3 Types of Failure Modes:

1. **Lose Ingot – Recover by Recharging and Restarting**
   Possible Reason: Ingot Turns Polycrystalline
   Time to Recover: 347 Machine Minutes, 70 Man-Minutes

2. **Lose Run – Recover by Completing Poly Ingot, Cleanup, Restart**
   Possible Reasons: Crucible, Ingot, Raw Si Problems
   Time to Recover: 375 Machine Minutes, 80 Man-Minutes

3. **Damage Equipment**
   Time to Recover: Not Available From Hayex at This Time
   (Accounted for by 15% Down Time)

At What Frequency of Failures Do You Pull Fewer Ingots?
Based On: 4 Furnaces per Operator, 5 Ingots per Run, Variable Frequency of Type 2 Failures in Last Ingot

Case	Frequency	Pull Ratio	Inches/Shift
A	0%	0.428	41.1
B	5%	0.425	40.8
C	7%	0.424	40.7
D	10%	0.422	40.5

Conclusion (Based on Incomplete Example Data): If the Growth of the 5th Ingot Fails 7% of the Time or More, Then You Are Better Off Growing Fewer Ingots

Future of This Methodology

Development Steps.

- **Incorporate a Submodel to Perform Capital/Labor Tradeoff Optimization for a Type of Work Station, Given an Output Requirement**
- **Expand Capability to Multiple Work-Station Types and Personnel Types and (Possibly) Buffer Inventories to Make Work-Station Interdependency Tradeoff Studies**
- **Document and Make PSP Widely Available for Applications**