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PROGRAMMING-FREE GRAPHIC FACTORY SIMULATION WITH GEFMS/PC* (GRAPHICALLY ENHANCED FLEXIBLE MODELING SYSTEM)

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ABSTRACT

This paper describes the capabilities and operation of a simulation tool designed for manufacturing applications[1] that does not require programming. The input of the simulation is based on a graphic layout of the model and the user's responses to a series of questions and answers. This implementation on IBM Personal Computers makes it possible for a larger group of manufacturing planners, engineers, and others to use simulation than was possible with an earlier implementation on the DEC† VAX[2].

1. INTRODUCTION

1.1 GEFMS Simulation Approach

Although many discrete system simulation packages are available today[3,4,5] that can help solve almost any conceivable problem formulated as a discrete system model, most require the user to be familiar with the syntax of the selected package. This requirement is often an obstacle to the users of these packages who have primary responsibilities in other areas but are faced with problems that could be solved by simulation. The GEFMS simulation software is designed to help non-simulation professionals run simulations in a very short time, eliminating the need for programming in any form and making the input process completely self-explanatory.

The GEFMS approach to discrete simulation makes use of the technique of drawing sketches of a problem situation to explain it to others. This technique is normally done on a blackboard or a piece of paper, but in GEFMS it is done on the screen of a graphics terminal. For example, in a factory situation, the user might sketch the location of machines, other workstations, or storage areas to produce a layout of a factory floor. This sketch provides the main features of the simulation to the GEFMS software, while the details are entered by the user during a question-and-answer session. Because the layout of the problem is known to the software, distances are also known and transportation delays can be computed automatically.

Since English language prompts are used throughout, there is no need to learn a computer language and (perhaps best of all) no program debugging is required. The simulation is entirely transparent and output is generated automatically. There are opportunities for the user to change his inputs before the simulation is started in addition to making changes between runs. The input information provided by the user during the layout and the question and answer sessions is preserved in files that can be recalled and used for later simulation runs.

1.2 System Requirements

1.2.1 Hardware

GEFMS is written to run on IBM personal computers (e.g., IBM PC** with two drives, PC-XT and PC-AT) or IBM PC compatibles such as the COMPAQ††. The collection of programs called GEFMS requires at least 320K of memory to run. All the programs will run with or without the Intel 8087 co-processor, although the simulation program will run several times faster with the 8087 chip. An IBM color graphics adapter card and graphics monitor are required. The input graphics use cursor input, which can be controlled using either the PC keyboard or a mouse. Controlling the cursor with a mouse was found to be more natural than with the keyboard.

1.2.2 Software

GEFMS consists of the following four programs: LAYOUT, SIMULATE, MODIFY, and QGRAPH. LAYOUT is used during the input process to define the locations of the model elements and paths, and to collect the necessary data to define their details during the question and answer session. SIMULATE performs the discrete event simulation for the period of time requested by the user, and it writes several files containing the results of this simulation. MODIFY can be used to change a number of model definitions to make reruns of earlier defined and saved problems; QGRAPH is called when the queue content time history is to be graphed.

1.3 Simulation Capabilities

The features incorporated in GEFMS and their characteristics are:

- Workcenters (machine cells, stations...) — identical servers
- Servers (lathes, drills...) — workcenter contents
- Storage areas (queue, buffer stock...) — associated with workcenter
- Resources (tools, people...) — other than servers
- Materials handling device (truck...) — transport delay
- Set-up delay (tool change...) — prior to operation
- Maintenance (scheduled outage) — per workcenter
- Breakdowns (unscheduled outage) — per workcenter

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† DEC is a trademark of Digital Equipment Corporation.

** IBM PC, XT, and AT are trademarks of International Business Machines Corporation.

†† COMPAQ is a trademark of the Compaq Computer Corporation.

- Initial loading (work in process) — per server and queue
- Arrival scheduling (work input) — time-job profile, random, constant WIP
- Transport (truck, gantry...) — travel delay
- Blocking (busy next workcenter) — preceeding workcenter
- Distributions — constant, uniform, normal, and exponential

The use of these features in a simulation will be explained in the next section and in the example application.

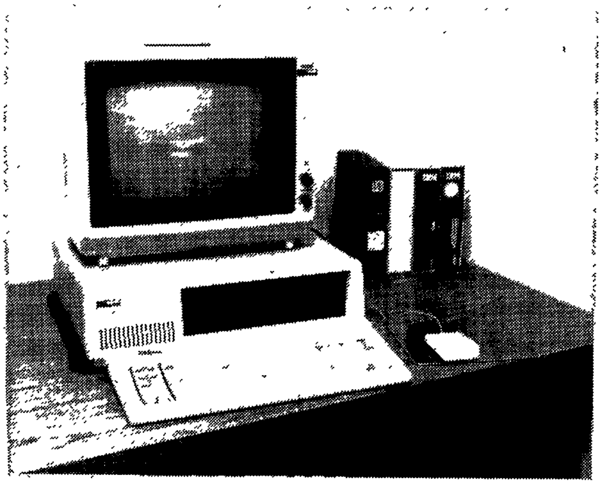

Figure 1.1: Typical PC System

1.3.1 Simulation Parameters

A number of parameters are imbedded in the software that limit the size of the problem that can be simulated with GEFMS:

Maximum number of active transactions = 500
Maximum number of machine cells = 20
Average number of machines per cell = 10
Maximum number of jobs = 15
Maximum number of operations per job = 25
Maximum number of resources = 15
Maximum number of transporters = 20
Maximum number of corners in a path segment = 10

These parameters can be changed in the source code and require recompilation of the SIMULATE program.

2. OPERATION (SIMULATION)

2.1 Running GEFMS

The first program called is LAYOUT. LAYOUT prompts the user to input the features of the problem: the location of the machining cells; the number of machines within them; and the location of the queues as well as the entry and exit areas of the factory or shop. It also asks the user for the different job types and the sequences of operations at the cells. Finally, the different paths taken by the job types are defined by the user with the help of this program.

2.2 Input Graphics

The graphics layout software displays a grid of points on the screen, and the menu of options appears. The user may employ one of several mouse devices or the keyboard to lay out the factory situation for the software. Messages in the lower part of the screen prompt the user to select his action from the menu and to position the elements of the factory on the screen.

2.2.1 Menu

The menu consists of the following options:

SYSTEM ENTRY
MACHINE CELL
SYSTEM EXIT
JOB SEQUENCE
OUTLINE
LABEL
DELETE CELL
DELETE OUTLINE
DELETE LABEL
DELETE PATH
QUIT

As a minimum, the user must select SYSTEM ENTRY, one or more MACHINE CELLs, SYSTEM EXIT, and JOB SEQUENCE. The locations of the SYSTEM ENTRY and the SYSTEM EXIT are somewhat arbitrary, serving as the starting and ending points for materials handling devices, although they may represent incoming and outgoing storages respectively.

2.2.2 Layout

To represent the equipment layout, the most often used menu item is MACHINE CELL. This item allows the user to position machine cells, specify the number of machines within the cells, position the cells' storage area (queue), and attach names to the cells. The software will prompt the user throughout this graphic input process at the bottom of the screen. By positioning and moving the cursor, the user draws rectangles representing MACHINE CELLs, individual machines, and queue locations.

2.2.3 Job Sequence

Once all the machine cells have been positioned and the locations of the SYSTEM ENTRY and EXIT have been specified, the user must define the jobs that will flow from the entry, through some or all of the defined cells, and to the EXIT. This sequence is done for each type of job by moving the cursor to each of the cells a job will visit in its proper sequence. Once this sequence is defined, the prompt asks the user to define the path that this job will take.

2.2.4 Path Definition

Each path between any two cells may consist of a number of straight line segments, starting at the SYSTEM ENTRY and ending at the SYSTEM EXIT. When the cursor is moved to define each segment of the path, a line is stretched from the starting point to the moving cursor (like a rubber band). By pressing appropriate keys, the path is fixed and extended to the next cell as needed. This process is repeated between all cells until the EXIT is reached.

After the job sequences and paths have been defined for all job types, the user moves the cursor next to QUIT on the menu provided that no changes have to be made. The graphic input process is complete and the question-and-answer session can begin.

2.3 Questions and Answers

The question-and-answer session collects all the remaining data needed to specify a simulation. It deals with resources, job processing, queues, breakdowns and maintenance, transportation, and job arrivals. The GEFMS software will ask the user all the appropriate questions and present the options. The user must be prepared to supply the answers.

Initially, the available probability functions are listed along with their abbreviation and the parameters needed to specify each distribution. To properly specify these parameters, the user must have selected a particular time unit (e.g., hours, minutes, seconds). It is important that the time units used throughout the modeling process are consistent.

2.3.1 Resources

The user is asked to define, one by one, all resources (tools, fixtures, people) that are needed by any of the machine cells. Resources are entered, giving their name and the maximum number available for each.

2.3.2 Jobs

For each job type defined during the layout process, the user will be asked the operations to be performed at each cell and the time required for them. There may be several operations including set-up at each cell. For each operation, the user enters the distribution and parameter values. The user is also asked for the quantity of resources that are needed. The series of prompts continue for all the cells that this job type visits. When all operations are defined, there is an opportunity to enter data for another job type that takes the same path but differs in the operation times and resources required.

2.3.3 Queues

The next series of questions determines the queue discipline and the capacities of all queues in the model. The current queue disciplines available are FIFO and Earliest Due Date. Prompts ask the queue capacity for each cell. If Earliest Due Date is chosen, the date is approximated as twice the sum of all operational delays experienced by each job type.

2.3.4 Job Arrivals

The options to specify the job arrival process are given next:

1) Inter-Arrival Times
2) Work In Process (no replacement)
3) Work In Process (replacement)
4) Scheduled Arrivals

If *Inter-Arrival Time* is chosen, a summary of the available distributions is given, and the user is asked to input the distribution and its parameters for each job type.

If *Work In Process* is selected, the user can input the work by cell or job type. If there is no replacement, the simulation will stop after the last job is complete. If there is replacement, and a job of a given type has reached the SYSTEM EXIT, a new job of the same type will start at the SYSTEM ENTRY.

If *Scheduled Arrivals* is chosen, a file containing the arrival sequences should exist. The file should contain the name of the job type, the lot size, the arrival time, and the due date.

2.3.5 Initial Conditions

The user has the opportunity to specify any initial queue content. If queue content is to be entered, it may be done by cell or by job type. After specifying the initial queue content for the queues desired, a summary of the data can be requested.

2.3.6 Downtimes

Machine downtimes can be specified for all machines in a cell. For each cell, the user enters the distribution and its parameters; first for the frequency of unscheduled outages, then for the duration of these outages. This is followed by the request to enter the same information for scheduled outages, first specifying the frequency and then the duration.

2.3.7 Changes

If desired, the user can review all data entered. If changes have to be made, questions are asked to determine the type of the changes: job data, queue capacity, queue loading, and arrival time data.

2.3.8 Transport

Individual jobs are assumed to be transported through the factory by materials handling devices. This transporting involves delay and the possibility of shortages of needed transporters. The transportation delay depends on the distances covered and the speed of the transporter. Because the relative distances have been defined during layout, only the distance represented by the grid spacing and the transporter speed are needed to determine any delay. This completes the specification of the problem.

2.4 Simulating

Before the start of the simulation, the program prompts for the problem name, in case the user re-entered the sequence of programs just for a simulation. The length of the simulation run is then requested. The user can also select a trace output and have data collected for queue graphs.

The simulation runs entirely transparent to the user. An event-driven simulation written in FORTRAN is executed using the facilities of SIMCORE*. During the simulation run, progress is reported from time to time so that the user knows that the simulation is still in progress.

After the simulation terminates normally, the user can access the output report file for the run statistics or request the queue content versus time graphs for each cell.

* SIMCORE is a GE proprietary discrete simulation package.

2.5 Output Statistics

Summary output statistics are automatically collected and tabulated. The following three tables are presented:

Time In System
Queue Statistics
Utilization Statistics

The tables display the following information:

Name
Average
Standard Deviation
Minimum Value
Maximum value
Number of Observation or Period of Observation

Time in System represents the time it takes each job type to move through the system (i.e., the cycle time).

Queue Statistics represent the number of all jobs waiting for a particular service. The first rows in the tabulation correspond to the number of jobs waiting for service at cells. The next rows represent jobs waiting for transportation (if any), and the last rows show jobs waiting for resources (if any).

Utilization Statistics are reported for each machine, transporter, and resource. For each machine belonging to a cell, statistics are given for being busy, down, and blocked. For each transporter and each resource, only their busy fraction is given.

3. EXAMPLE

3.1 FMS - With Options

This example will illustrate the use of some of the available options that can make a simulation very realistic. The main feature of this model is a flexible machining cell with four machines that can perform a number of operations. Three operations are to be done on each workpiece, using three different fixtures.

The individual workpieces are transported by AGVs to the loading station from the Incoming Storage, a distance of 250 ft. At LOADING, the workpieces are fixtured and they wait to be assigned, on a FIFO basis, to one of the machines in the FMS as soon as one becomes available. The new workpiece will be transported to the FMS and loaded on a free machine, an average distance of 100 ft. Each of the three operations on the FMS has different operation times and when each operation is done, the job is transported to the WASH station (100 ft away). There, the fixture is removed, and the workpiece is deburred and cleaned. From the WASH station, the work is transported to GAGING for measurements and inspection (a distance of 150 ft).

The operation times (in min.) at each workstation are:

	Oper 10	Oper 20	Oper 30
Loading	Uniform(3,5)	Uniform(3,5)	Uniform(3,5)
Machining	Constant(15)	Constant(20)	Constant(25)
Wash	Constant(5)	Constant(5)	Constant(5)
Gaging	Uniform(8,12)	Uniform(8,12)	Uniform(8,12)

Once all three operations have been performed on each workpiece, the completed piece is removed by AGV to Outgoing Storage (100 ft away). If more operations have to be performed, the work is sent back to LOADING (which is 250 ft distant). Storage space is limited to the following number of workpieces: LOAD-25, FMS-0, WASH-100, and GAGE-10.

Each machine in the FMS is subject to occasional breakdowns occurring about once a shift and taking between 30 and 90 min to fix. When the machine is repaired, the operation continues where it was interrupted. There is one person at the fixturing and loading area, one to remove the fixture and cleaning, and two at the gaging station.

At the start, the FMS has four workpieces loaded in its machines — one beginning Operation 10, two Operation 20, and one Operation 30. Eight other workpieces are waiting to be loaded. Whenever a job is removed to Outgoing Storage, a new workpiece is moved from Incoming Storage to LOADING. There are three AGVs, which have an average speed of 100 ft/min. At the start of the simulation, they are at Incoming Storage, by convention. Also, there is a total of 15 fixtures — 5 each of types FIXT10, FIXT20, and FIXT30.

The object of this simulation is to estimate the capacity of this system and the various resource utilizations.

As a consequence of the transportation distances, it is required to draw the layout to scale. This takes some planning to position Entry, Exit, and the cells so that the connecting paths have the specified lengths. A printed screen image with only the grid displayed is helpful in planning the layout. For this problem, we assumed that the distance between two adjacent dots is 25 ft. In entering the job sequence, the cursor is positioned on the LOAD, FMS, WASH, and GAGE blocks three times in that order. Finally, the paths of the AGV's are drawn to produce Figure 3.1.

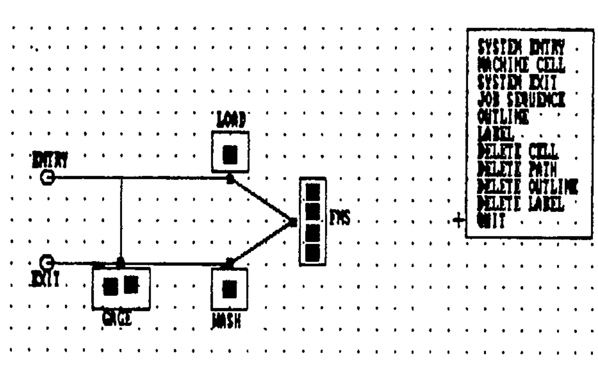

Figure 3.1: Complete Layout for FMS

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         JOB SUMMARY:

number job types = 1

Job type 1 - JOB1 - 12 operations
               setup          operation time                  resources
oper#   cell   status dist.name        param1   param2
  1     LOAD     n    uniform           3.00     5.00     *FIXT10*      * *
  2     FMS      n    constant         15.00     0.00     *FIXT10*      * *
  3     WASH     n    constant          5.00     0.00     *FIXT10*      * *
  4     GAGE     n    uniform           8.00    12.00     * *    * *
  5     LOAD     n    uniform           3.00     5.00     *FIXT20*      * *
  6     FMS      n    constant         20.00     0.00     *FIXT20*      * *
  7     WASH     n    constant          5.00     0.00     *FIXT20*      * *
  8     GAGE     n    uniform           8.00    12.00     * *    * *
  9     LOAD     n    uniform           3.00     5.00     *FIXT30*      * *
 10      FMS      n    constant         25.00     0.00     *FIXT30*      * *
 11      WASH     n    constant          5.00     0.00     *FIXT30*      * *
 12      GAGE     n    uniform           8.00    12.00     * *    * *

Hit carriage return to continue
      WIP SUMMARY:

Job  1 - JOB1 - 12 operations
cell    LOAD        FMS         WASH        GAGE        LOAD        FMS         WASH
    GAGE        LOAD        FMS         WASH        GAGE
WIP      8           1           0           0           0           2           0
     0           0           1           0           0
Hit carriage return to continue

cell  2 - FMS
   Unscheduled downtime:
     Frequency: uniform     240.00 720.00
     Duration:  uniform     30.00 90.00
Hit carriage return to continue
```

Figure 3.2: Input Summary for FMS Example

During the question-and-answer session, the three fixture types are first defined and the steps for Job1 are then entered. Each step has only one operation. We enter the operational delays as specified for LOAD, FMS, and WASH all of which require Fixt10. Gaging does not require fixtures. The next operations are LOAD, FMS, and WASH, which require Fixt20, and GAGE, which does not. The final set of operations is again LOAD, FMS, and WASH with Fixt30, and GAGE, without. Thus, there are a total of 12 operations.

After entering the queue capacities, arrival type 3 was chosen, which recycles each job as it finishes its last operation. The cells were then preloaded by job and operation number as follows: Oper.#1-8, Oper.#2-1, Oper.#6-2, and Oper.#10-1. To enter downtimes, the frequency of one breakdown per shift was interpreted as samples from a uniform distribution between 4 and 12 h, converted to minutes. Three transporters were entered, grid spacing was specified as 25 ft, and the speed of the AGVs was entered to be 100 ft/min. A summary of this input is shown in Figure 3.2. The results are represented by Figure 3.3, the graph of the LOAD queue versus time, and the statistics of the run are shown in Figure 3.4.

4. SUMMARY

A simulation tool for the IBM PC that can be used by non-simulation professionals to solve manufacturing problems has been described. The user does not get involved in any programming activity, nor does he have to debug any programs. Because of this, the time spent in entering a model into the computer for simulation is reduced significantly. The user can therefore produce results more quickly or increase his attention on model definition and results interpretation.

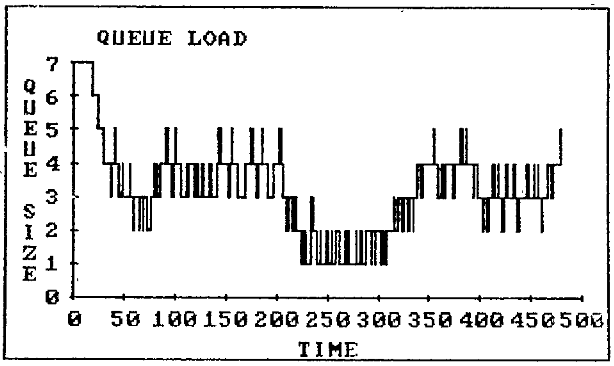

Figure 3.3: LOAD Queue Graph

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1

SIMULATION SUMMARY REPORT

RUN NUMBER 1 OF 1

RUN ENDED AT TIME : 480.000

NUMBER OF EVENTS : 1473

TIME IN SYSTEM

NAME	AVERAGE	STD.DEV.	MIN.VALUE	MAX.VALUE	NBR.OBS.
TSYS JOB1	196.227	44.892	51.388	287.239	23

QUEUE STATISTICS

NAME	AVERAGE	STD.DEV.	MIN.VALUE	MAX.VALUE	TIME PRD.
LOAD	3.411	1.153	.000	7.000	480.
FMS	.000	.000	.000	.000	480.
WASH	.452	.639	.000	3.000	480.
GAGE	.119	.330	.000	2.000	480.
TRANSPORTER QUEUE	.045	.215	.000	2.000	480.
RESOURCE NO. 1	.009	.093	.000	1.000	480.
RESOURCE NO. 2	.000	.000	.000	.000	480.
RESOURCE NO. 3	.035	.183	.000	1.000	480.

UTILIZATION STATISTICS

NAME		AVERAGE	STD.DEV.	MIN.VALUE	MAX.VALUE	TIME PRD.
LOAD	1 BUSY	.702	.457	.000	1.000	480.
LOAD	1 DOWN	.000	.000	.000	.000	480.
LOAD	1 BLCK	.298	.457	.000	1.000	480.
FMS	1 BUSY	.869	.337	.000	1.000	480.
FMS	1 DOWN	.000	.000	.000	.000	480.
FMS	1 BLCK	.001	.033	.000	1.000	480.
FMS	2 BUSY	.877	.329	.000	1.000	480.
FMS	2 DOWN	.000	.000	.000	.000	480.
FMS	2 BLCK	.011	.104	.000	1.000	480.
FMS	3 BUSY	.817	.386	.000	1.000	480.
FMS	3 DOWN	.000	.000	.000	.000	480.
FMS	3 BLCK	.004	.061	.000	1.000	480.
FMS	4 BUSY	.751	.433	.000	1.000	480.
FMS	4 DOWN	.000	.000	.000	.000	480.
FMS	4 BLCK	.005	.071	.000	1.000	480.
WASH	1 BUSY	.842	.364	.000	1.000	480.
WASH	1 DOWN	.000	.000	.000	.000	480.
WASH	1 BLCK	.014	.119	.000	1.000	480.
GAGE	1 BUSY	.844	.362	.000	1.000	480.
GAGE	1 DOWN	.000	.000	.000	.000	480.
GAGE	1 BLCK	.014	.119	.000	1.000	480.
GAGE	2 BUSY	.795	.404	.000	1.000	480.
GAGE	2 DOWN	.000	.000	.000	.000	480.
GAGE	2 BLCK	.013	.113	.000	1.000	480.
TRANSPORTER	1 BUSY	.573	.495	.000	1.000	480.
TRANSPORTER	2 BUSY	.472	.499	.000	1.000	480.
TRANSPORTER	3 BUSY	.412	.492	.000	1.000	480.
FIXT10	1 BUSY	.440	.496	.000	1.000	480.
FIXT10	2 BUSY	.363	.481	.000	1.000	480.
FIXT10	3 BUSY	.299	.458	.000	1.000	480.
FIXT10	4 BUSY	.239	.426	.000	1.000	480.
FIXT10	5 BUSY	.146	.353	.000	1.000	480.
FIXT20	1 BUSY	.507	.500	.000	1.000	480.
FIXT20	2 BUSY	.374	.484	.000	1.000	480.
FIXT20	3 BUSY	.251	.433	.000	1.000	480.
FIXT20	4 BUSY	.271	.445	.000	1.000	480.
FIXT20	5 BUSY	.173	.378	.000	1.000	480.
FIXT30	1 BUSY	.567	.495	.000	1.000	480.
FIXT30	2 BUSY	.268	.443	.000	1.000	480.
FIXT30	3 BUSY	.298	.458	.000	1.000	480.
FIXT30	4 BUSY	.260	.439	.000	1.000	480.
FIXT30	5 BUSY	.236	.425	.000	1.000	480.

Figure 3.4: Results Summary for FMS Example

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Dr. Duersch is involved in the development and analysis of automated machining centers and the use of simulation to evaluate their performance. He is interested in improving simulation languages by using interactive graphics and developing automatic programming software and dynamic workflow presentations. He has been active in simulation and Decision Support Systems during most of his career, and is familiar with a number of simulation languages and has used them in numerous applications. Dr. Duersch is the author of over 50 papers and internal reports. He is a licensed professional engineer in the State of New York and a Senior Member of the IEEE. Dr. Duersch also serves as an Adjunct Professor in the Institute of Industrial Administration and Management at Union College.

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