ARGESIM Report no. 8

EUROSIM Comparison C2 "Flexible Assembly System"

Solutions and Results

F. Breitenecker, I. Husinsky
editors

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FOREWORD

EUROSIM, the Federation of European Simulation Societies, started in 1990 the publication of the journal **EUROSIM Simulation News Europe** (SNE), a newsletter distributed to all members of the European simulation societies under **EUROSIM's** umbrella and to people and institutions interested in simulation. **SNE** is also part of **Simulation Practice and Theory** (SIMPRA), the scientific journal of **EUROSIM**.

The idea of the journal **SNE** (circulation 2500; edited by F. Breitenecker and I. Husinsky, ARGE Simulation News (**ARGESIM**) , Technical University of Vienna, Austria; three issues per year) is to disseminate information related to all aspects of modeling and simulation.

The contents of **SNE** are news in simulation, simulation society information, industry news, calendar of events, essays on new developments, conference announcements, simulation in the European Community, introduction of simulation centers and comparison of simulation software, simulators and (parallel) simulation techniques.

The series on comparisons of simulation software has been very successful. Based on simple, easily comprehensible models the software comparisons compare special features of modeling and experimentation within simulation languages:

- modeling technique
- event handling
- submodel features
- numerical integration
- steady-state calculation
- frequency domain
- plot features
- parameter sweep
- postprocessing
- statistical features
- statistical processors
- control strategies
- optimization
- random numbers
- complex strategies
- animation, etc.

Seven Software Comparisons, four continuous ones and three discrete have been set up. Furthermore, a second type of comparisons, the Parallel Comparison has been initiated.

The continuous comparisons are:

- Comparison 1 (C1; Lithium-Cluster Dynamics under Electron Bombardment, November 1990) deals with a stiff system;
- Comparison 3 (C3; Analysis of a Generalized Class-E Amplifier, July 1991) focusses on simulation of electronic circuits and eigenvalue analysis;
- Comparison 5 (C5; Two State Model, March 1992) requires very high accuracy computation;
- Comparison 7 (C7; Constrained Pendulum, March 1993) deals with state events.

The discrete comparisons are:

- Comparison 2 (C2; Flexible Assembly System, March 1991) gives insight into flexible structures of discrete simulators;
- Comparison 4 (C4; Dining Philosophers, November 1991) involves not only simulation but also different modeling techniques like Petri nets;
- Comparison 6 (C6; Emergency Department - Follow-up Treatment, November 1992) deals with complex control strategies;

SNE 10 introduced a new type of comparison dealing with the benefits of distributed and parallel computation for simulation tasks. Three test examples have been chosen to investigate the types of parallelization techniques best suited to particular types of simulation tasks.

Up to now, 100 solutions have been sent in. The table at the end of this ARGESIM report shows the number of solutions for the Software Comparisons as well as for the Parallel Comparison. The series will be continued.

This ARGESIM Report summarizes and discusses the solutions and results sent in for Comparison 2 (C2) ***Flexible Assembly System***.

The report starts with a summary of Mr. Krauth (from BIBA Bremen, who defined the comparison) and Mr. Klußmann. This summary is a reprint from a contribution to the congress EUROSIM'95 entitled „Results and Experiences derived from a Comparison between Simulation Systems" and refers to a „Preliminary Evaluation" by Mr. Krauth, published in SNE 4, March 1992, which is the second contribution in this report.

The following two contributions, introducing the EUROSIM comparisons and discussing in some detail the Comparison 2, are reprints from papers written by the editors of SNE and published in Conference Proceedings or Reports, resp.

The presentation of the solutions sent in starts with the definition of this EUROSIM comparison (definition and definition with remarks, resp.)
In the following the solutions sent in up to now are printed in chronological order. Each solution is represented by the page printed in SNE and, if available, by the originals sent in by the originators. It is evident that early solutions are accompanied by more original paper work.

As reference a study with DESMO, by D. Martinssen and A. Häuslein (Universität Hamburg), discusses in detail many aspects of this comparison.

In 1993 / 1994 the solutions sent in were used to enrich a study on Efficiency and Availability of discrete simulation software. This study (in German, supported by a grant of the Austrian Ministry for Research) is reprinted at the end of the report.

As conclusion a Table of the EUROSIM Comparisons and the number of solutions sent in is given.

F. Breitenecker, I. Husinsky, Editors

About ARGESIM

ARGE Simulation News (ARGESIM) is a non-profit working group providing the infra structure for the administration of **EUROSIM** activities and other activities in the area of modelling and simulation.

ARGESIM organizes and provides the infra structure for
- the production of the journal EUROSIM Simulation News Europe
- the comparison of simulation software (EUROSIM Comparisons)
- the organisation of seminars and courses on modelling and simulation
- COMETT Courses on Simulation
- "Seminare über Modellbildung und Simulation"
- development of simulation software, for instance: mosis - continuous parallel simulation, D_SIM - discrete simulation with Petri Nets, GOMA - optimization in ACSL
- running a WWW - server on EUROSIM activities and on activities of member societies of EUROSIM
- running a FTP-Server with software demos, for instance
    * demos of continuous simulation software
    * demos of discrete simulation software
    * demos of engineering software tools
    * full versions of tools developed within ARGESIM

At present ARGESIM consists mainly of staff members of the Dept. Simulation Technique and of the Computing Services of the Technical University Vienna.

In 1995 ARGESIM became also a publisher and started the series **ARGESIM Reports**. These reports will publish short monographs on new developments in modelling and simulation, course material for COMETT courses and other simulation courses, Proceedings for simulation conferences, summaries of the EUROSIM comparisons, etc.

Up to now the following reports have been published:

No.	Title	Authors / Editors	ISBN
# 1	Congress EUROSIM'95 - Late Paper Volume	F. Breitenecker, I. Husinsky	3-901608-01-X
# 2	Congress EUROSIM'95 - Session Software Products and Tools	F. Breitenecker, I. Husinsky	3-901608-02-8
# 3	EUROSIM'95 - Poster Book	F. Breitenecker, I. Husinsky	3-901608-03-6
# 4	Seminar Modellbildung und Simulation - Simulation in der Didaktik	F. Breitenecker, I. Husinsky, M. Salzmann	3-901608-04-4
# 5	Seminar Modellbildung und Simulation - COMETT - Course "Fuzzy Logic"	D. Murray-Smith, D.P.F. Möller, F. Breitenecker	3-901608-05-2
# 6	Seminar Modellbildung und Simulation -COMETT - Course "Object-Oriented Discrete Simulation"	N. Kraus, F. Breitenecker	3-901608-06-0
# 7	EUROSIM Comparison 1 - Solutions and Results	F. Breitenecker, I. Husinsky	3-901608-07-9
# 8	EUROSIM Comparison 2 - Solutions and Results	F. Breitenecker, I. Husinsky	3-901608-08-7

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Results and Experiences derived from a Comparison between Simulation Systems

J. Klußmann[1], J. Krauth[1] and R. Splanemann[2]
Bremen Institute of Industrial Technology and Applied Work Science at the University of Bremen (BIBA)[1], Degussa AG[2]

0. Abstract

This paper investigates if different simulation tools produce the same results when applied to the same system. Two comparisons have been carried out using the same test model of an assembly system. First a number of researchers carried out simulation experiments independent from each other, only on the basis of a written model definition. The results varied considerably, partly due to unclear model definition. In a second step a smaller number of tools has been compared by the authors themselves, thus excluding misunderstandings of the model definition. In this comparison the tools produced identical results once the models had been made really identical. But it was difficult to produce exactly identical models using different tools. Each tool has its inherent assumptions on "normal" behaviour, and if these assumptions are not known to the modeller, he is likely to generate a model with slight errors.

1. Introduction

Nowadays a wide variety of simulation tools is available on the market, especially in the field of material flow simulation in manufacturing systems. They all claim to be precise, but they all claim to be different. Hence the question arises: If used to simulate the same system, will they produce the same results? This question actually implies two questions: First, is it possible to create identical models using different tools? Especially with the modern comfortable tools which require no more programming but offer ready-made building blocks, this seems to be a problem. Building blocks are certainly very comfortable for quick and easy modelling, but they limit flexibility. So it is not clear if different simulation tools allow to generate identical models at all. The second question then is: In case the models can be made identical, do the tools then produce the same simulation results? Apparently these questions are very critical for the credibility of simulation.

The answer to both questions is "Yes, but..." In principle we can trust simulation results, but we have to be careful. This result is not surprising, but we feel it is often ignored in practical applications.

The paper is structured as follows: The next section describes the test system which is a simplification of a real assembly system. Section 3 reports on the result of a "distributed" comparison carried out by a number of researchers who each had only the written definition of the test system. The last section 4 represents own experiences of modelling the test system with three, different simulation tools and draws some conclusions about it.

2. The test system

We published the following test system definition in the journal "Eurosim Simulation News" in 1992 [1] and asked all interested persons or institutes to send us their solutions.

The test system consists of 7 assembly stations and a load/unload station all linked by an automated flexible conveyor system. This system is sketched in figure 1. An inner rectangular conveyor circulates clockwise and transports pallets on which the products to be assembled are fixed. The inner conveyor connects 8 subsystems as shown in figure 2. Each subsystem comprises one of the eight stations (assembly or load/unload) Ax, a buffer conveyor B2 of variable lenght in front of the station, a one-place buffer behind it, a bypass conveyor B1, and two connecting elements Sx and Sy. Here B1 is part of the inner rectangle. A pallet coming from the left can either be shifted to B2 in Sx or move along on B1. It is shifted to B2 if the following two conditions are satisfied:

- the product on the pallet has not yet undergone the operation(s) carried out in station Ax,
- there is enough space on the conveyor B2 in front of station Ax.

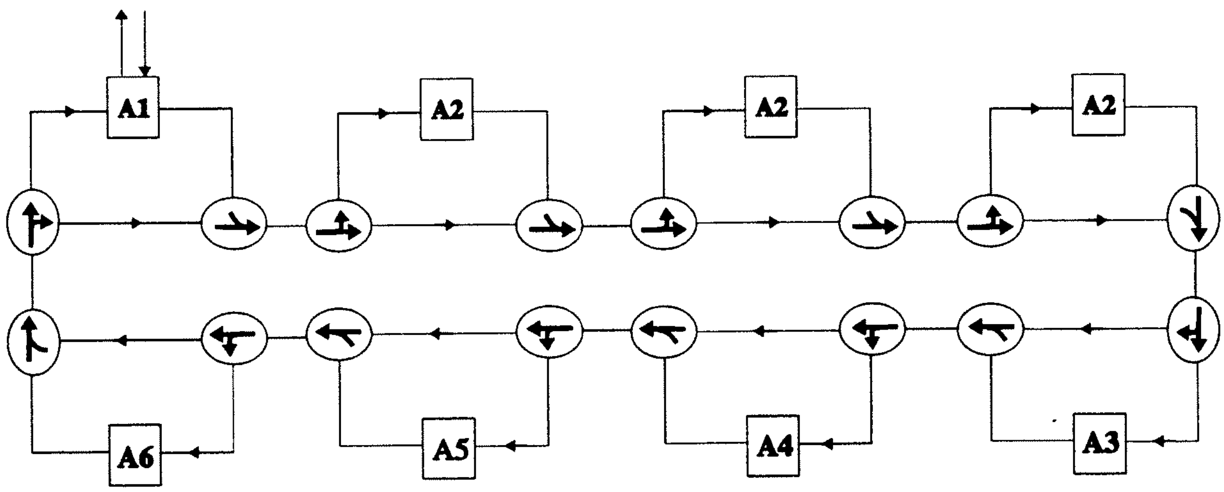


Figure 1: Flexible assembly line as test system

Finished products are taken from pallets and replaced by unprocessed parts in station A1. The sequence of operations the products undergo is arbitrary with the only exception that A2 has to be the first or the last station. All three stations A2 perform the same operations, hence only one of them has to process each product. Station A6 functions as a substitute of stations A3, A4, and A5. It performs all of the missing operations of these three whenever a product is being processed in A6.

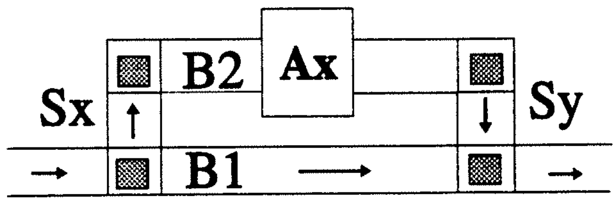


Figure 2: Subsystem of the flexible line

The processing times and the buffer sizes in front of all stations as well as the lenght of the respective bypass conveyors are given in table 1.

Station	Operation time (seconds)	Length of buffer in front of station (m)	Length of bypass conveyor (m)
A1	15	2.0	1.2
A2	60	1.6	0.8
A3	20	1.6	0.8
A4	20	1.6	0.8
A5	20	1.6	0.8
A6	30	2.0	1.2

Table 1: System parameters

After publishing this model definition we received a letter pointing out some ambiguous details of the definition. So we published a second, more precise definition in the following issue of Eurosim Simulation News [2] which we do not repeat here.

3. First Comparison

In the first comparison many scientists were involved, and their communication was very limited. The result has already been documented in Eurosim Simulation News [3], so we only repeat a summary here:

Table 2 (on the next page) gives the results obtained with 19 different simulation tools for a simulation time of eight hours. All tools have been applied by different researchers. The table shows a surprising diversity of results.

From this table it is impossible to tell to what degree the diversity of results is due to different understanding of the model definition or to errors in either the model implementation or the simulation software itself. From some researchers we received a note afterwards that they had misunderstood the model definition.

One ambiguous point is the question wether the time needed to feed a pallet into a station is part of the processing time or not. In case it is the bottleneck stations are A2, A3, A4, and A5, and the maximum number of products that can be processed in eight hours is 1440 because in this case every 20 sec. a product can be finished. In case it is not the bottleneck are stations A2 with a processing time of 61.3 sec., hence every 20.4 sec. a product can be finished, and therefore the maximum number of products is 1411. Most of the results obtained are close to one of these numbers.

Simulation system	Distributor	Author of test model	Number of assembled parts (with 20 pallets)
POSES	University of Chemnitz (D)	Ges. f. Prozeßautom. & Consult., Chemnitz (D)	1462
TAYLOR	F&H, Düsseldorf (D)	F&H, Düsseldorf (D)	1441
EXTEND	Imagine That, San Jose (USA)	University of Rostock	1440
SLAM II	Schröder GmbH, Düsseldorf (D)	AIC, Turin (I)	1440
SIMPLE-mac	AESOP, Stuttgart (D)	Unseld&Partner, Vienna (A)	1439
WITNESS	AT&T Istel, Düsseldorf (D)	BIBA, Bremen (D)	1439
DSIM	University of Vienna (A)	University of Vienna (A)	1425
CASSANDRA	KFKI, Budapest (H)	KFKI, Budapest (H)	1415
MICRO SAINT	Rapid Data, Worthing (GB)	Micro Analysis and Design, Boulder (USA)	1411
GPSS/H	Dr. Staedler GmbH, Nürnberg (D)	University of Michigan (USA)	1409
SIMFLEX/2	University of Kassel (D)	University of Kassel (D)	1409
DESMO	University of Hamburg (D)	University of Hamburg (D)	1408
DOSIMIS-3	SDZ, Dortmund (D)	IML, Dortmund (D)	1408
SIMUL_R	Simutech, Vienna (A)	Simutech, Vienna (A)	1405
EXAM	Russian Academy of Science, Moscow	Russian Academy of Science, Moscow	1404
PC SIMDIS	University of Magdeburg (D)	University of Magdeburg (D)	1384
MOSYS	IPK, Berlin (D)	IPK, Berlin (D)	1346
SIMAN	Domier-System GmbH, Friedrichshafen (D)	CIMulation Centre, Chippenham (GB)	919
TOMAS	DVZ, Neubrandenburg (D)	DVZ, Neubrandenburg (D)	884

Table 2: Simulation results with different simulation systems

What was particularly remarkable about this first comparison was the little feeedback we received after having published the model definition the first time: Only one researcher asked for clarification of several ambiguous points. These are pointed out and clarified in [2]. All other researchers seemed to understand immediately what we meant. But the diversity of results proved that their understandings deviated from ours, and also from each other. When we had published the clarification, nobody else asked for any more information, even though there were still many points unclear.

What does this mean? It is obviously very difficult to define a model in an unambiguous way. And it seems to be equally difficult to even notice where there are ambiguities. When one person defines something very precisely, and another person understands him perfectly well, it does not necessarily mean both have the same understanding. And it may take a very long time until they notice they have not. We believed our first - and even more our second - definition was clear enough to build a model, and the majority of researchers thought so, too. But what we defined and what they understood was not always the same. At least in some cases we definitely know differences in understanding the model definition.

With respect to simulation this implies there is always a risk of misunderstanding when a simulationist and an engineer cooperate and communicate about a model. This risk can of course be avoided when the engineer builds the model himself. But in order to enable him to do so, the tool must provide him with constructs he understands. Nowadays a considerable number of simulation tools provides such domain-specific building blocks as - in the case of manufacturing simulation - machines, buffers, conveyour, etc. Their dynamics are predefinded, so the user does not have to define them any more, he simply selects and combines them. But as we shall see below, this creates a new source of misunderstanding.

4. Experiences derived from a second Comparison

In the next step our aim was to exclude all sources of misunderstanding. Therefore we built the models on our own, using three different simulation systems: Dosimis-3 [4], Simple++ [5], and Witness [6]. These tools are frequently used in German manufacturing industry. They are particularly suited to model manufacturing and assembly systems, they support graphical modelling, and they provide the user with pre-defined domain-specific building blocks.

First simulation runs showed small differences between the results of the different simulation systems. A very detailed validation process proved that the three models were not identical. With each of the tools we had made some mistakes in modelling, mainly based on misunderstandings of the functionality and the behaviour of the pre-defined building blocks or modules the simulation tools provide. The detailed problems in modelling with the three simulation systems is published in [7]. In the following we represent the results and conclusions of this comparison.

The same results have been achieved with all three simulation systems. As well with all systems small mistakes first showed a little impact on the result. The mistakes happened mostly by modelling the distributing and connecting elements Sx and Sy. The reasons for all the mentioned mistakes are misunderstandings of the detailed behaviour of simulation system building blocks.

We assume the same results could also have been obtained using any of the other tools involved in the first comparison - or at least with the majority of them. It may be easy with some of them, and more tricky with others. But this does not mean some are good and some are bad. It only means they have primarily been designed for different purposes, by designers who had different perceptions of what a "normal" manufacturing system does.

The problem is that the user is quite often not aware of these differences in details. He himself has his own understanding of "normal" behaviour, and he tends to assume these comfortable modern simulation tools provide him with precisely the building blocks he expects.

Why should he think a "conveyor " block e.g. does not behave the way the conveyors he knows behave in reality? Unfortunately this assumption is often wrong. And - even worse - the exact description of the dynamics is often not available in the manual.

One solution of this problem is of course to make users aware of the potential diversity of builiding block behaviour, and to document precisely the behaviour of all building blocks in the manual. Another solution might be to provide the user with techniques to define his own building blocks. These techniques however have to be very simple, otherwise we would be back at simulation languages or even programming languages. Moreover the verification of user-defined blocks must be supported because he is likely to make mistakes, he will probably not test and validate them with sufficient rigour, and he is likely to use his own blocks again and again. And finally, we expect that user-defined building blocks will be documented even less, and therefore they will only be useful for the author himself, and after some months maybe not even for him. Hence simulation tools which allow the user to define his own building blocks have to provide solutions for these three subsequent problems of comfort and simplicity, of correctness, and of documentation.

A prototype of such an advanced simulation tool, allowing for user-defined building blocks and providing some techniques for rigorous verification, has been described in [8]. Petri nets have been used to define or modify application oriented building blocks. The mathematical theory of Petri nets allows for some rigorous testing of user-defined blocks, thus supporting their verification and validation to some extent. To our knowledge not much has been done since then to investigate further possibilities of validation support. However, more recent work towards tools which enable the user to define his own building blocks can be found in [9] and [10].

References:

[1] J. Krauth: Comparison 2: Flexible Assembly System. Eurosim Simulation News 1, March 1991, p.28.

[2] J. Krauth: Comparison 2: Flexible Assembly System. Eurosim Simulation News 2, July 1991, pp.25-26.

[3] J. Krauth: Comparison 2: Preliminary Evaluation. Eurosim Simulation News 4, March 1992, p.31.

[4] DOSIMIS-3, Benutzerhandbuch, SDZ GmbH, Dortmund (D).

[5] SIMPLE++, Referenzhandbuch, AESOP GmbH, Stuttgart (D).

[6] WITNESS User Manual, AT&T ISTEL Visual Interactive Systems Ltd., Highfield (UK).

[7] J. Krauth, R. Meyer: Comparison of simulation systems based on a test model. In: Systems Analysis, Modelling and Simulation, 17 (1995), pp. 1-12

[8] J. Krauth: Modellierung und Simulation flexibler Montagesysteme mit Petri-Netzen. OR-Spektrum (1990)12, pp 239-248

[9] J. Pirron: Simple++: The revolution in object-oriented simulation. Proceedings SIM94, Waseda University Tokyo, July 1994

[10] Schürholz, A: CREATE! Entwicklungsstand und Funktionsumfang einer objektorientierten Simulatorentwicklungsumgebung. In: Tavangarian, D. (Hrsg.): Fortschritte in der Simulationstechnik, Band 4, Simulationstechnik, 7. Symposium, Hagen, 1991, pp. 10-14

Comparison 2: Preliminary Evaluation

Issues 2, 3, and this one of EUROSIM - Simulation News :urope contain a number of reports on tests of simulation ɔols applied to a test example described in issues 1 and 2 Simulation of a Flexible Assembly System, Comparison 2). ome of the tools reported so far have produced results of ːmarkable conformity, whereas others are so different that 'e assume the model description has not been sufficiently recise. It is known to us that the colleagues who used Micro aint had a different understanding of the operation time of ation A1 (Load/Unload) than we had: They assumed 15 sec ɔr loading and 15 sec for unloading, whereas we meant 15 ːc for both operations. i.e. 7.5 sec each (cf. issue 2, p. 26), ıerefore their numbers are very different from the majority. robably other ambiguities have led to other strongly deviing results (SIMAN, TOMAS, SLAM II, PS SIMDIS). It ould be interesting to know what these ambiguities were, ɪt it would also be interesting to know why no two tools ıve produced precisely the same results. Some of them are ːry close to each other. It seems that the authors have had e same understandig of the system, but that the software ols work a little bit different somehow. We will try to :plain some of these little differences in a later issue. The llowing table shows the findings for twenty pallets in the stem:

ɔol	Total throughput	Average throughput (time in sec)
; SIMDIS	1384	-
ɔSIMIS	1408	436.9
MAN	919	627.6
.AM II	1082	400.0
icro Saint	-	603.0
SIMUL_R	1405	409.5
GPSS/H	1409	409.2
CASSANDRA	1415	410.7
DESMO	1408	408.0
TOMAS	884	623.8
SIMPLE-mac	1439	400.2
WITNESS	1439	409.3

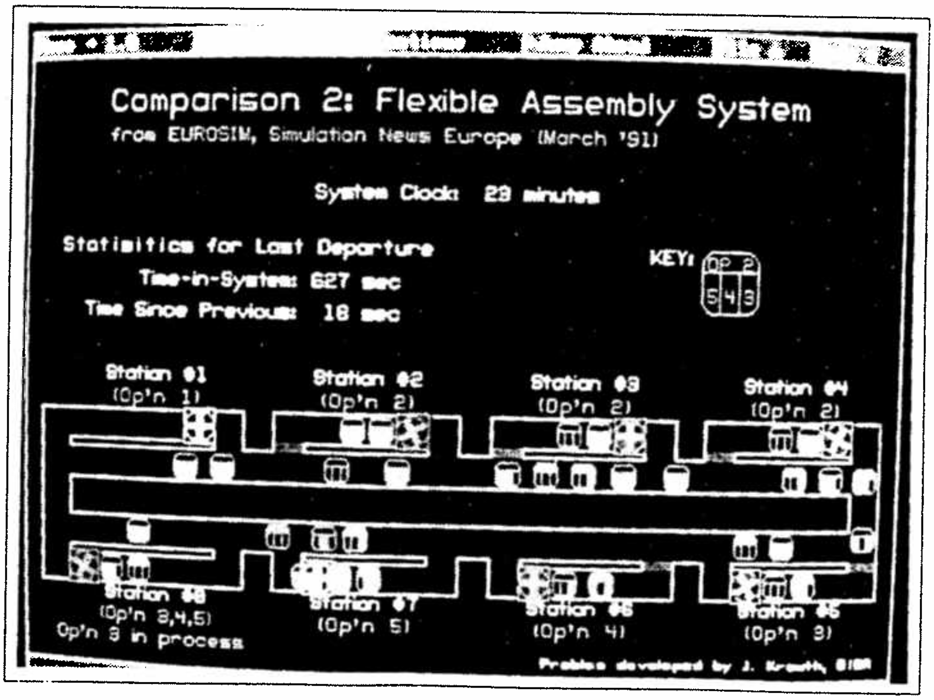
This summary does not intend to close the comparison. Further contributions are still welcome. We would however encourage every colleague who intends to test another tool to contact us in case of any questions concerning the definition of the test model. One of the reasons why we chose this model was that it allows to check two features of discrete event simulation systems that we consider very important for the simulation of complex production systems:

- the possibility to define and combine submodels (the model consists of 8 slightly different submodels!)
- the method to describe complex control strategies

Unfortunately most of the contributions we received so far do not discuss these topics. So no evaluation of such properties of tools is possible at the moment. Maybe future contributions will include some remarks on these points, too.

We want to thank all the authors for their interesting reports and hope to receive more!

Contact: J. Krauth, BIBA (Bremer Institut für Betriebstechnik und angewandte Arbeitswissenschaft), Postfach 33 05 60, D-2800 Bremen 33, Tel: +49-421-22 009 51 Fax: +49-421-22 009 79.



Animated GPSS/H comparison model,
available from Wolverine Software Corporation, 4115 Annandale Road, Annandale, Virginia 22003-2500 USA

: editors also received an animation diskette of the comparison 2 SIMAN model from The CIMulation Centre in England (see title page of this issue), comparison solution published in EUROSIM - Simulation News Europe, Number 2, July 1991, page 29.

Comparison of Simulation Software

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Abstract

In the last years simulation languages have become quite numerous. The catalog of simulation software is quite comprehensive today. An attempt to obtain information about the properties of the different simulation languages has been started by Software Comparisons within the journal EUROSIM - Simulation News Europe.
Before the idea and first results of these software comparisons are explained the question is discussed what the requirements for simulation languages should be and what features should be taken into account in a comparison.

Keywords: Simulation languages, comparison of features

FEATURES OF SIMULATION SOFTWARE

Features of simulation software may be seen as features for modelling, features for experimentation and general features. Modelling features may differ in the type of model description, in what complexity may be obtained, how events can be handled, if there is modularity, how submodels can be realized, how implicit models can be managed, etc. Experimentation features are type and efficiency of experimentation tools, like time domain analysis, calculation of steady states, linearization, frequency domain analysis, parameter studies, Monte Carlo studies, etc. General features deal with the 'handling' of the simulation software in general: modes, interfaces to other languages, etc.

Another classification may follow aspects regarding to computer science, software design and algorithms: input/output, state of implementation, documentation; program (model) structure (parallel or procedural structure, handling of events, submodels, hierarchical models, initialisation, macro description); efficiency of numerical algorithms (integration algorithms, algebraic loop solvers, steady state computation, special handling of linear systems, linearization, frequency domain methods, interpolation, error

control, error analysis, etc.); identification and validation (parameter identification, model comparison, sensitivity analysis, analysis of linearized models, etc.); program compilation and program execution; date storage and data access; statistical evaluation; table fuctions; etc.
A third classification may be based on analysis methods. In case of continuous simulation typical analysis methods (to be performed with a model) are deterministic analysis in the time domain, parameter studies, Monte Carlo Studies, computation of steady states, end game, analysis of linearized models, etc. In case of discrete simulation this point becomes very important, too: long term runs, iterated runs, output analysis of different runs, hypothesis testing, etc.

2. BENCHMARKS

First efforts in comparing simulation software were done after standardization in 1968 (CSSL-standard). Benchmark problems have been developed, they try to compare features of simulation languages within application models.
A few of the best known simulation benchmarks, that can be found in user manuals, are: control loop (testing macros for transfer functions), PHYSBE (physiological benchmark, testing 'literal' macros), pilot ejection study (state event, different model descriptions), discrete sample compensator (testing features for difference equations or/and time events), Joe's barbers shop, etc.
Solutions of these benchmark problems offer deep insight into the efficiency of a particular simulation software, concentrating on a few features, usually depending on the application area. Disadvantages of these benchmark problems are that the models are relatively large, that the user has to become familiar with a specific application area and that they may be difficult to reproduce.

3. EUROSIM COMPARISONS

As a consequence of the lack on concentrated information, software comparisons were developed, which on the one hand are concentrated enough to be overviewed within short time and on the other hand provide enough information for showing the implementation of the features, for showing how the features work and for reproducing the results within any language.
These comparisons started in 1990 within the journal EUROSIM - Simulation News Europe ([1]). EUROSIM - Simulation News Europe (in the following abbreviated with 'SNE') is the official newsletter of EUROSIM, the federation of European simulation societies. This newsletter is distributed to all members of these societies and to persons and institutions interested in. From the end of 1992 regular subscription will be available. The comparisons are based on simple, easily comprehensible models taken from different application areas. Up to four tasks (checking features mentioned above) have to be solved. The comparisons are selected and prepared by the editors of SNE.
People developing or using different simulation tools are asked to participate in this comparison by simulating the problem in a simulation language of their choice, to solve the given tasks, and to send a short report. The reports are published in SNE, one page

per solution. The reports contain a short description of the language used, the model description (source code or diagram), the results of the tasks (commands, tables, plots), and any comments.
Up to now five different comparisons have been introduced in SNE, continuous and discrete problems alternatively, comparisons are numbered 1 to 5 (table 1). Preliminary evaluations will be published from time to time, a comparison will be closed after three years with a final evaluation. The idea has become quite successful. Many solutions have been sent to the editors, demonstrating a broad spectrum of different simulation software.

No. SNE No.	TITLE	TASKS
No. 1 SNE 0	Lithium-Cluster - Dynamics	stiff system solution parameter sweep steady state calculation
No. 2 SNE 1/2	Flexible Assembly System	submodel features average throughput optimal throughput
No. 3 SNE 2	Generalized Class-E Amplifier	eigenvalue calculation stiff system solution table parameter sweep
No. 4 SNE 3	Dining Philosophers Problem	modelling technique control strategies deadlocks, reachability
No. 5 SNE 4/5	Two State Model	discontinuity modelling discontinuity location high-accur. simulations

Table 1: EUROSIM Comparisons 1990-1992

RESULTS OF TWO SOFTWARE COMPARISONS

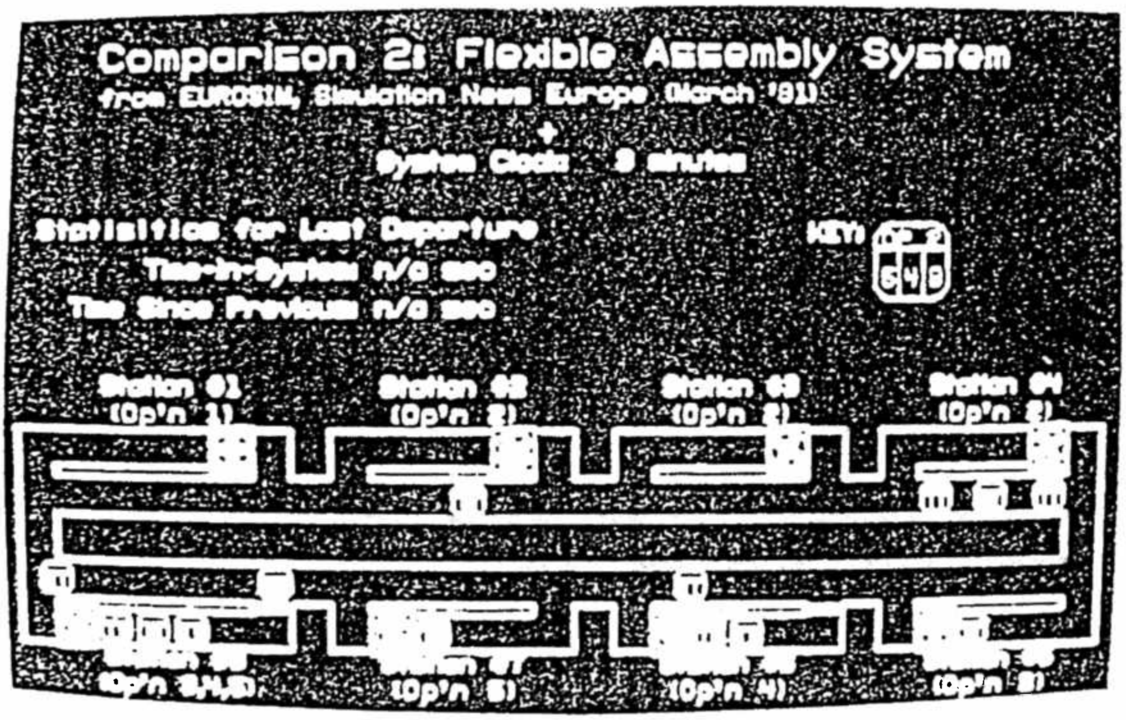
This section summarizes preliminary results of the first continuous and the first discrete comparison (both comparisons are still running).
Comparison 2 deals with a flexible assembly system testing submodel features and complex control strategies and will be discussed in more detail (discrete simulation). Comparison 1 is a problem taken from solid state physics, a nonlinear stiff third-order model describes the concentration of certain aggregates (continuous simulation).

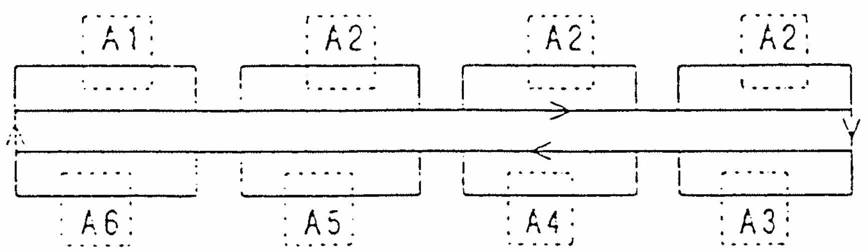
EUROSIM Comparison 2: Flexible Assembly System

Up to now twelve simulation languages took the challenge to solve EUROSIM Comparison 2. This comparison checks two important features of discrete event simulation tools:

- features for defining and combining submodels
- features for describing complex control strategies.

The model formulated in [4] consists of a number of almost identical assembly stations Ax placed on two linked belts B1 and B2 (fig. 1). Parts to be processed and assembled are put into the system on pallets in station A1, where they leave the system, too - the pallets become free for new parts. The parts on pallets are processed in the stations A2 - A6 due to a complex strategy; some stations are identical (A2), some are 'intelligent' performing different operations (A6), etc.





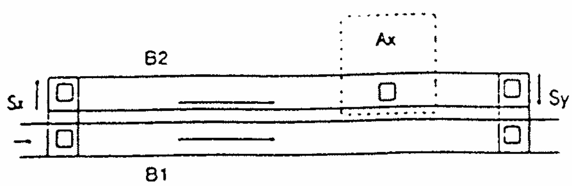


Fig. 1: Comparison 2, model layout and animation (GPSS/H)

The tasks are:

a) modelling the system by means of submodel features,
b) evaluation of the total throughput and the average throughput time of parts with 20, 40 and 60 pallets
c) determining the number of pallets with the maximal throughput and with a deadlock.

A preliminary evaluation ([5]) first showed, that because of the stochastic nature of the processes the results must differ. Some of the simulation tools have produced results of remarkable conformity, others are so different that different modelling techniques have to be assumed - based on different understandings of the problem.

LANGUAGE	TOTAL TROUGHPUT	AVERAGE THROUGHPUT
PS SIMDIS	1384	-
DOSIMIS	1408	436.9
SIMAN	919	627.6
SLAM II	1082	400.0
Micro Saint	-	603.0
SIMUL_R	1405	409.5
GPSS/H	1409	409.2
CASSANDRA	1415	410.7
DESMO	1408	408.0
TOMAS	884	623.8
SIMPLE-mac	1439	400.2
WITNESS	1439	409.3

Table 2: Comparison 2, results task b) ([4])

Table 2 shows the results for twenty pallets in the system for the results sent in up to now. Some of the tools have produced results of remarkable conformity, whereas others are different because of misunderstandings of the model description. The summary will be updated with results of other simulation tools and corrected results, the comparison is running up to 1993.

The simulation languages compared in table 2 are of different nature. There are classical languages, like GPSS/H (results in table 3, animation in fig. 1, there are new (combined) languages with powerful postprocessing features (SIMUL_R, fig. 2), and there are the 'graphical' languages (MicroSaint, fig. 3).

Number of Pallets	Jobs Completed in Final 8 Hours	Job Completion Time (Minutes) Mean	Std. Dev.	Number of Jobs Needing 1 or 2 or 3 or More Laps to Finish 1	2	3	>3	Number of Uses of Station A6
15	1350	5.33	0.89	1350	0	0	0	0
16	1350	5.69	0.89	1350	0	0	0	0
17	1371	5.96	0.82	1371	0	0	0	88
18	1408	6.13	0.79	1408	0	0	0	293
19	1409	6.47	0.53	1409	0	0	0	118
20	1409	6.82	0.50	1289	115	5	0	116
25	1408	8.52	2.75	682	300	180	246	252

Table 3: Results Comparison 2, GPSSH

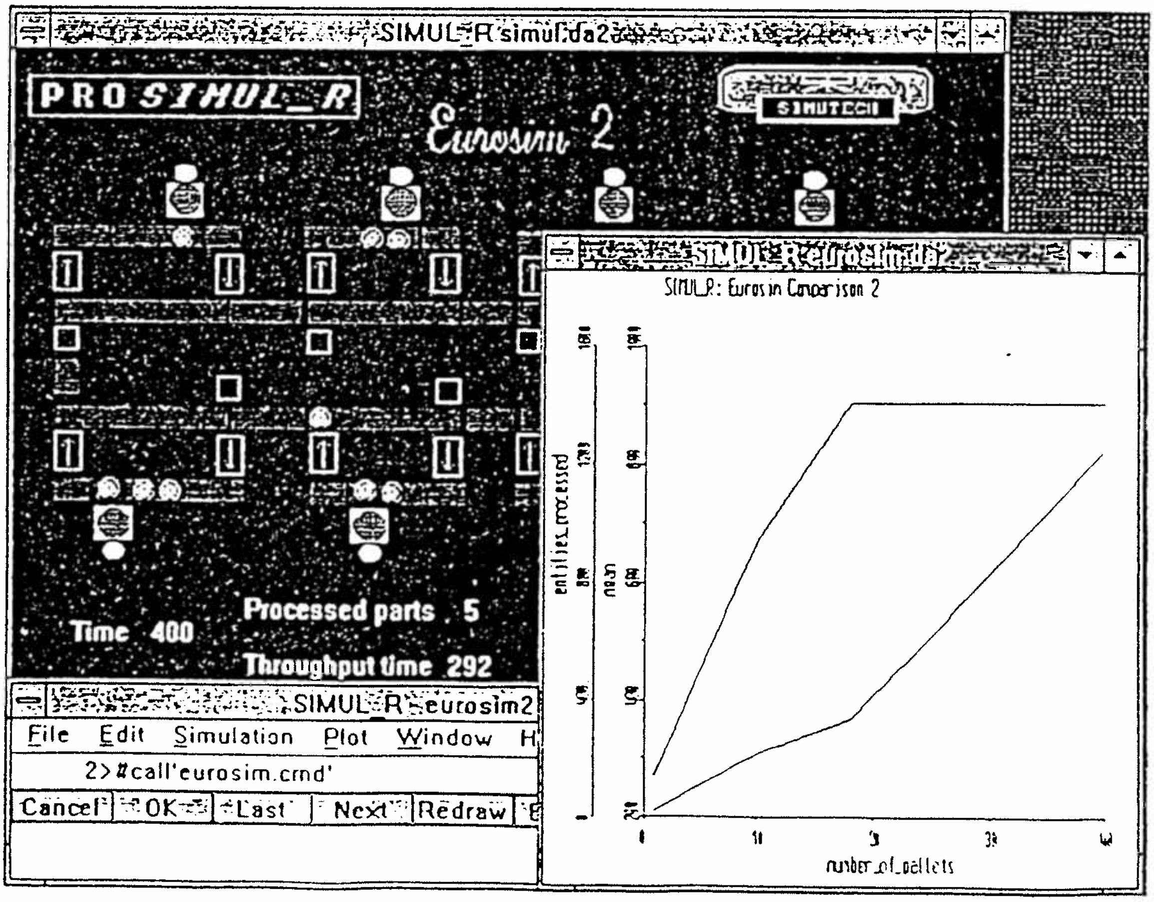


Fig. 2: Results Comparison 2, SIMUL_R: pallet variation and animation

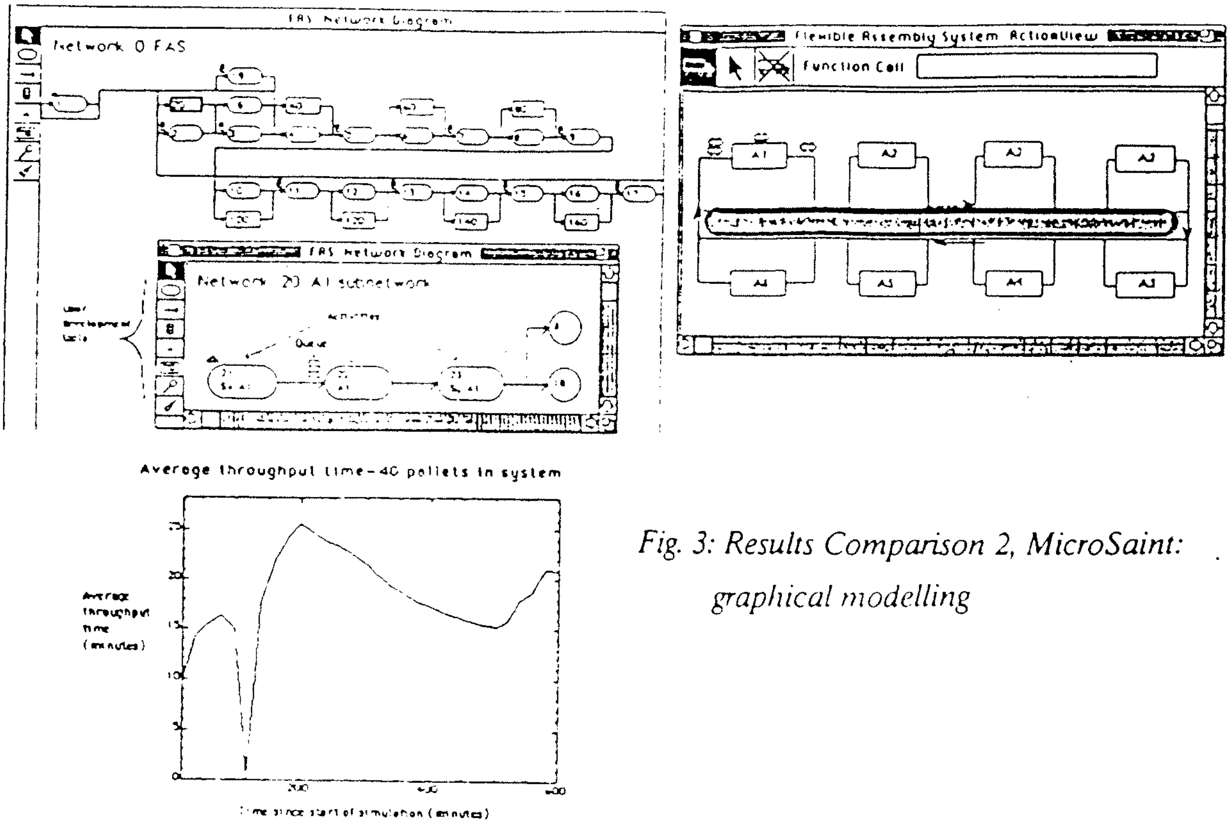


Fig. 3: Results Comparison 2, MicroSaint: graphical modelling

EUROSIM Comparison 1: 'Lithium-Cluster Dynamics' Model

The 'Lithium-Cluster Dynamics' Model describes the behaviour of defects under electron (and photon) bombardment of alkali halides. One of the important consequences of these electronic defects is the desorption of surface atoms ([2]). The dynamic model is based on the equations for the concentrations of different aggregates, resulting in three states governed by nonlinear stiff equations: at the beginning and after the end of the electronic bombardment the transients are very rapid, then they become relatively slow (solution with ESL, fig. 4).

The tasks to be performed are:

a) simulation of the stiff system (testing integration algorithms)
b) parameter study and plot (fig. 1)
c) steady state calculation.

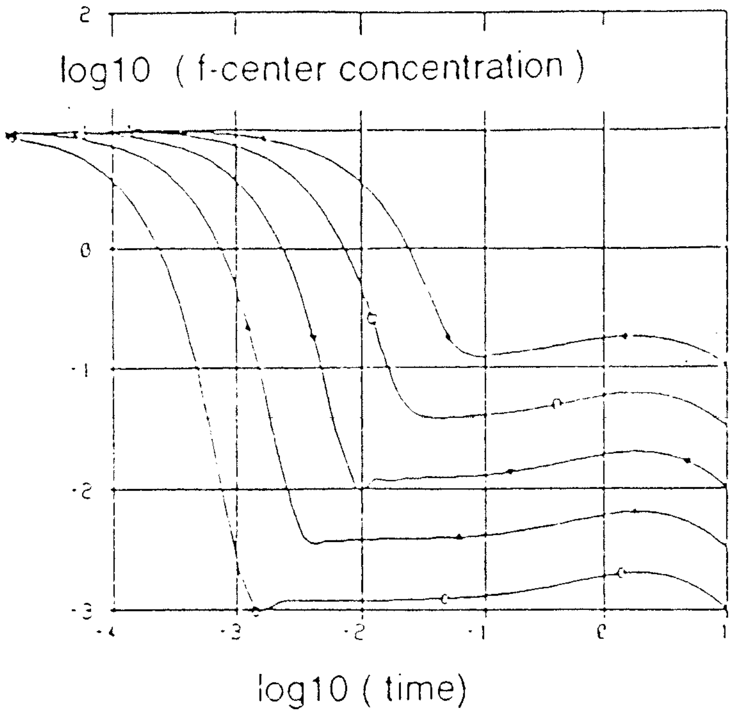


Fig. 4: Comparison 1, result task b) (ESL)

Up to now 17 simulation languages took the challenge to solve EUROSIM Comparison 1.
First it has to be noted that all simulation languages fulfilled the tasks with sufficient accuracy. The main results of the comparison are: i) comparison of modeling techniques, ii) effectiveness of numerical algorithms, iii) comfortability of parameter sweep, iv) features for steady state calculation, and v) preventing problems by analytical transformations. A detailed preliminary evaluation can be found in [3].
The languages can be divided roughly into three groups: equation-oriented languages, (graphical) block-oriented languages, and application-oriented languages. Table 4 summarizes the modelling features of the languages in general, indicates the modelling technique used (marked with (*)) and gives remarks.

It is relatively difficult to compare the results of taks a). For comparison of the algorithms the relation between the different algorithms within one language may be of more importance than the absolute CPU-times. A comprehensive table on these results will be published in the next issue of SNE ([3]). The second task clearly answered which language offers runtime commands for parameter loops, where the loop can be programmed in the model description and where the parameter variation has to be done 'manually'. The third tasks checks which languages offer features for steady state calculation of the system.

LANGUAGE	MODEL DESCRIPTION	REMARKS
ACSL	equations (ODE's)	General purpose simulator, event handling
DESIRE	equations (ODE's)	Combination with neural network simulation
DYNAST	equations (DAE's) (*) graphical blocks (submodels) port diagrams (graphical)	For linear systems semi-symbolic analysis
ESACAP	equations (DAE's) (*) nodes/branches arbitrary expressions	Based on numerical algorithms for circuit analysis
ESL	equations (ODE's) (*) graphical blocks (submodels)	Interpretative and Compile Mode, graphic postprocessor
EXTEND	graphical blocks	Continuous and next event modelling
FSIMUL	graphical blocks (submodels)	'Control-Engineering' - features, optimization features
HYBSYS	blocks (elementary) (*) equations	Interpretative simulator, direct data base compilation
I Think	graphical blocks	Modelling based on System Dynamics
MATLAB	equations (MATLAB-functions)	Tool for mathematical and engineering calculations
NAP 2	blocks (electronic circuits)	Specialized for circuit simulation
PROSIGN	equations (ODE's) (*) graphical blocks (submodels) application-oriented components	Comb.of modelling techniques, interfaces to C, etc.
SIL	equations (ODE's, DAE's) (*)	Simulation of continuous and discrete systems
SIMULAB	graphical blocks (submodels) (*) equations (MATLAB-function)	Based on MATLAB, analytical solution of linear parts
SIMUL_R	equations (ODE's) (*) bond graphs (graphical preproc.) blocks (graphical preprocessor)	Open system (C-based), combined simulation
STEM	equations (ODE's)	Based on Turbo Pascal
XANALOG	graphical blocks (submodels) (*)	Sophisticated linearization realtime - features

Table 4: Comparison 1 - Modelling features of simulation languages

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[2] W. Husinsky: EUROSIM-Comparison 1: Lithium-Cluster Dynamics. EUROSIM Simulation News Europe; no. 0, November 1990, p. 25; no. 1, March 1991, p. 22

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[4] J. Krauth: EUROSIM Comparison 2: Flexible Assembly System. EUROSIM Simulation News Europe, no. 1, March 1991, p. 28; no.2, July 1991, p. 25.

[5] J. Krauth: EUROSIM Comparison 2: Flexible Assembly System - Preliminary Evaluation. EUROSIM Simulation News Europe, no. 4, March 1992, p. 31.

EUROSIM COMPARISONS ON SIMULATION TOOLS

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ABSTRACT

This contribution gives an overview on the comparisons of simulation tools and their results, published in *EUROSIM's* journal *„EUROSIM Simulation News Europe"*. Among general developments and trends (also negative ones) special aspects as object oriented approaches, standards for simulation tools and the question of a „common denominator" for simulation languages, and parallel simulation are sketched briefly.

EUROSIM, the Federation of European Simulation Societies was set up in 1989. The purpose of *EUROSIM* is to provide a European forum for regional and national simulation societies to promote the advancement of modeling and simulation in industry, research, and development.

EUROSIM started in 1990 the journal ***„EUROSIM Simulation News Europe" (SNE)***, a newsletter distributed to all members of the *EUROSIM* member societies and to people and institutions interested in simulation. In 1993 the first issue of ***„Simulation Practice and Theory"***, the scientific journal of *EUROSIM*, was published.

1 THE EUROSIM COMPARISONS

The idea of the journal ***SNE*** is to promote simulation in Europe by dissemination of information related to all aspects of modeling and simulation. ***SNE*** is edited by I. Husinsky and F. Breitenecker, Technical University of Vienna, Austria. ***SNE*** has a circulation of 2500 copies. There are three issues per year (March, July, November). Furthermore ***SNE*** is also included in the scientific journal ***„Simulation Practice and Theory"*** in three issues per volume, 1000 copies each.

The contents of ***SNE*** are news in simulation, simulation society information, industry news, calendar of events, essays, conference announcements, simulation in the European Community, introduction of simulation centers, discussion forum, and comparison of simulation software and hardware and of simulation tools.

The series on comparisons of simulation software is very successful. Based on simple, easily comprehensible models special features of modeling and experimentation within simulation languages, also with respect to an application area, are compared:

- modeling technique
- event handling
- submodel features
- numerical integration
- steady-state calculation
- frequency domain
- plot features
- parameter sweep
- postprocessing
- output analysis
- optimization
- animation

2 DEFINITION OF COMPARISONS

Seven *„Software Comparisons"*, four continuous ones and three discrete ones, have been defined up to now. This series will be continued.

Furthermore, another type of comparisons, a comparison on parallel simulation techniques (*„Parallel Comparison"*) has been initiated.

2.1 Software Comparisons

The continuous comparisons are: Comparison 1 (C1; Lithium-Cluster Dynamics under Electron Bombardment, November 1990) addressed all kinds of simulation software. 22 solutions have been sent in, a summery can be found in ***SNE 6***, November 1992.

Comparison 3 (C3; Analysis of a Generalized Class-E Amplifier, July 1991) focused on simulation of electronic circuits resulting in up to now 11 solutions.

Comparison 5 (C5; Two State Model, March 1992, revised July 1992) takes more into account a very high accuracy computation than state events.

Comparison 7 (C7; Constrained Pendulum, March 1993) is a continuous comparison which addresses all kinds of simulation software, with nine solutions up to now.

The discrete comparisons are: Comparison 2 (C2; Flexible Assembly System, March 1991, comments July 1991) resulted in 21 solutions. A preliminary evaluation can be found in *SNE 4*.
Comparison 4 (C4; Dining Philosophers, November 1991) is more general task involving not only simulation but also different modeling techniques like Petri nets. Up to now eight solutions have been sent in.
Comparison 6 (C6; Emergency Department - Follow-up Treatment, November 1992) deals with complex control strategies. Six solutions have been presented up to now.

2.2 Parallel Comparison

SNE 10 introduced a new type of comparison dealing with the benefits of distributed and parallel computation for simulation tasks. Three test examples have been chosen to investigate the types of parallelization techniques best suited to particular types of simulation task.
Each test example should be first solved in a serial fashion to provide a reference for the investigation of speed-up factors. The examples should then be tested using the parallel facilities (software and hardware) available. Performance should be assessed in terms of a numerical value found by dividing the time for serial solution by the time for the parallel solution. Information must be provided about the method of parallelization or distribution of subtasks.
The objective is to make comparisons of different types of methods for the parallelization of simulation tasks, not to comparie the hardware performance.

The first test example is a *Monte-Carlo-study* of the influence of the damping parameter in a damped second order mass-spring system. The second example is concerned with *coupled predator-prey population* models. Five predator-prey populations are interacting. The model is strongly coupled. The third example is based on the a second order *partial differential equation* describing a swinging rope. Discretization by the method of lines results in a set of weakly coupled differential equations.
Table 1 shows the number of solutions published in each issue of *SNE*.

3 RESULTS OF THE COMPARISONS

The results of the comparisons have the following form:

- short description of the language
- model description
- results of tasks with experimentation comments

In the following results of two comparisons and preliminary results of the Parallel Comparions will be sketched briefly.
Comparison 1 is a problem taken from solid state physics, a nonlinear stiff third-order model describes the concentration of certain aggregates.
Comparison 2 deals with a flexible assembly system testing submodel features and complex control strategies and will be discussed in more detail.

3.1 Results Comparison 1 (C1)

The 'Lithium-Cluster Dynamics' Model describes the behavior of defects under electron (and photon) bombardment of alkali halides. The dynamic model is based on the equations for the concentrations of different aggregates, resulting in three states governed by nonlinear stiff equations: at the beginning and after the end of the electronic bombardment the transients are very rapid, then they become relatively slow.

	C1	C2	C3	C4	C5	C6	C7	CP
SNE 0	Def							
SNE 1	5	Def						
SNE 2	4	4	Def					
SNE 3	4	3	5	Def				
SNE 4	1	5	3	3	Def			
SNE 5	4	-	1	1	2			
SNE 6	-	2	-	2	1	Def		
SNE 7	1	2	1	2	-	1	Def	
SNE 8	-	1	-	-	-	1	3	
SNE 9	-	-	-	-	-	2	3	
SNE 10	1	2	-	-	-	2	2	Def / 1
SNE 11	2	2	1	-	1	-	1	2
Total	**22**	**21**	**11**	**8**	**4**	**6**	**9**	**2**

Table 1: SNE - Comparisons, publication of solutions

The tasks to be performed are:
1. simulation of the stiff system
2. parameter study and plot
3. steady state calculation.

Up to now 22 simulation languages took the challenge to solve Comparison 1. First it has to be noted that all simulation languages fulfilled the tasks with sufficient accuracy.

The languages can be divided roughly into three groups:
- equation-oriented languages,
- (graphical) block-oriented languages,
- and application-oriented languages.

Table 2 summarizes the modeling features of the languages in general, indicates the modeling technique used (marked with (*)) and gives remarks.

It is relatively difficult to compare the results of task 1. For comparison of the algorithms the relation between the different algorithms within one language may be of more importance than the absolute CPU-times. The model equations are very stiff, so Gear algorithms turned out to be the best ones.
The second task clearly answered which language offers runtime commands for parameter loops, where the loop can be programmed in the model description and where the parameter variation has to be done „manually“.
The third tasks checks which languages offer features for steady state calculation of the system. It first seems, that a simulation language must have a steady state finder, but it turns out, that such algorithms may fail by reaching only a local minimum. Consequently, for bigger models with a lot of switching elements, etc., only a long term run is able to determine a steady state.

LANGUAGE	MODEL DESCRIPTION	REMARKS
ACSL	equations (ODE's)	General purpose simulator, event handling
DESIRE	equations (ODE's)	Combination with neural network simulation
DYNAST	equations (DAE's) (*)	For linear systems semi-symbolic analysis
	graphical blocks (submodels) port diagrams	
ESACAP	equations (DAE's) (*) nodes/branches arbitrary expressions	Based on numerical algorithms for circuit analysis
ESL	equations (ODE's) (*) graphical blocks (submodels)	Interpretative and Compile Mode, graphic postprocessor
EXTEND	graphical blocks	Continuous and next event modeling
FSIMUL	graphical blocks (submodels)	'Control-Engineering' - features, optimization features
HYBSYS	blocks (elementary) (*) equations	Interpretative simulator, direct data base compilation
I Think	graphical blocks	Modeling based on System Dynamics
MATLAB	equations (MATLAB-functions)	Tool for mathematical and engineering calculations
NAP 2	blocks (electronic circuits)	Specialized for circuit simulation
PROSIGN	equations (ODE's) (*) graphical blocks (submodels) application-oriented components	Combin. of modeling techniques, interfaces to C, etc.
SIL	equations (ODE's, DAE's) (*)	Simulation of continuous and discrete systems
SIMULINK	graphical blocks (submodels) (*) equations (MATLAB-function)	Based on MATLAB, analytical solution of linear parts
SIMUL_R	equations (ODE's) (*) bond graphs (graphical preproc.) blocks (graphical preprocessor)	Open system (C-based), combined simulation
STEM	equations (ODE's)	Based on Turbo Pascal
TUTSIM	equations / blocks (ODE's)	Bond graph preprocessor
XANALOG	graphical blocks (submodels) (*)	Sophisticated linearization, real-time - features

Table 2: Comparison 1 - modeling features of simulation languages

3.2 Results Comparison 2 (C2)

Up to now twelve simulation languages took the challenge to solve *EUROSIM* Comparison 2. This comparison checks two important features of discrete event simulation tools:

- features for defining and combining submodels
- features for describing complex control strategies.

The model consists of a number of almost identical assembly stations Ax placed on two linked belts B1 and B2 (fig. 1). Parts to be assembled are put into the system on pallets in station A1, where they leave the system, too - (free pallets for new parts). The parts on pallets are processed in the stations A2 - A6 due to a complex strategy; some stations are identical (A2), some are 'intelligent' performing different operations (A6), etc.

The tasks are:

1. modeling the system by means of submodel features,
2. evaluation of the total throughput and the average throughput time
3. determining the number of pallets with the maximal throughput and with a deadlock.

A preliminary evaluation first showed, that because of the stochastic nature of the processes the results must differ. Some of the simulation tools have produced results of remarkable conformity, others are so different that different modeling techniques have to be assumed - based on different understandings of the problem.

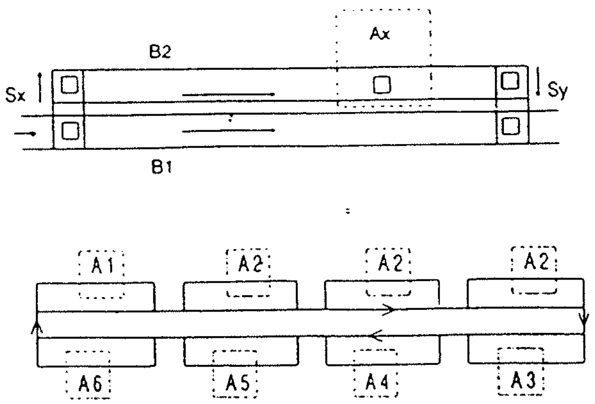


Fig.1: Comparison 2, model layout

Table 3 shows the results for twenty pallets in the system for some results sent in. Some of the tools have produced results of remarkable conformity, whereas others are different because of misunderstandings of the model description.

The simulation languages compared in table 3 are of different nature. There are classical languages like *GPSS/H*, there are new (combined) languages with powerful postprocessing features (*SIMUL_R*) and there are the „graphical" languages like *MicroSaint*.

LANGUAGE	Troughput total	Troughput average
PS SIMDIS	1384	-
DOSIMIS	1408	436,9
SIMAN	919	627,6
SLAM II	1082	400
MicroSaint	-	603,0
SIMUL_R	1405	409,5
GPSS/H	1409	409,2
CASSANDRA	1415	410,7
DESMO	1408	408,2
TOMAS	884	623,8
SIMPLE	1439	400,2
WITNESS	1439	409,3

Table 3: Comparison 2, results task 2

3.3 Results Parallel Comparison

Until now, three solutions (one with only one of three tasks implemented) have been received by editors. Two solutions come from the Technical University of Vienna, one from the University of Glasgow.

The first solution (published in *SNE 10* as a sample solution) was programmed directly in the programming languages FORTRAN and „C", using the message passing system „PVM". The programs were developed on a IBM RS6000-cluster (8 workstations) connected by a Token-Ring network and using PVM version 3.2.6.
The second solution came from the University of Glasgow using the continuous system simulation tool **SLIM** developed there. The hardware used was a Parsytec Supercluster, consisting of several Transputers working with the PARIX operating system. By now, only the first comparison could be provided (Monte Carlo simulation, master-slave approach).
The third solution came from TU Vienna: The three tasks were implemented within the parallel simulation language ***MOSIS*** developed there. The hardware used was the 20-transputer system Cogent XTM with operating system QIX and communication system „Kernel Linda". ***MOSIS*** itself provides the the communication between the processors (simulation tasks) and can work with different operating communication systems (Linda, PVM, PC's etc.).

The *MOSIS* - models (CSSL-type) are compiled to „C" and linked to the run time system. Eight processors were used for comparability with the C+FORTRAN/PVM solution.

The first task, the Monte-Carlo simulation, is hierachically structured (fig. 2). In two cases the solutions sent in, did not achieve a linear increase of time because of commu-nication overhead: A speed-up factor of 4.4 (**MOSIS** - because of message polling within Linda) and 5.5 (direct programming in PVM). The PARIX solution achieved nearly a linear speed-up factor with different numbers of processors, but from 16 processors on the communication becomes a significant bottle-neck with 7-9% of simulation time.

The second sample gave similar results at the first and the third solution (PARIX solution expected in *SNE 12*): the coupled predator-prey system became significantly slower with a parallel implementation (communication at each integration step resulted in solutions 20 times slower than the serial example). When communication was cut (only each n-th simulation step), the „speed-up-factor" could reach 0.61 to 0.77. Parallelisation by means of submodels results in too small subtask with too high communication overhead (fig. 2).

The third sample (partial differential equation) gave different results with the first and the third comparison (no PARIX solution). While the PVM factor was only 0.72 with communication every integration step, the *MOSIS* solution proved a value of 4.33 with 8 processors. When communication was cut, this could be improved to 3.2 (PVM) and 5.6 (*MOSIS*).

5. DEVELOPMENTS AND TRENDS

The results of the comparisons give an interesting insight into the development of existing languages and tools. Although within the commercial tools the US market is the leading one, there are interesting new developments in Europe:

- Big enterprises tend to develop their own language, which are marketed, too
- Universities and related institutions develop also new languages, which partially are successfully marketed
- In continuous simulation on the one side CSSL standard - languages become a common denominator for modeling, on the other hand a block-oriented graphical description based on control technique is frequently used.
- In discrete simulation there are two competing new approaches: object-oriented / time event based and object-oriented / Petri net - based
- In continuous simulation there are projects for normalizing the model description in order to use model descriptions of different languages in one simulation environment.

In more detail, the following trends (developments vs. problems) can be seen in continuous simulation:

- Implicit model descriptions - Loss of input-output relations
- Submodel features - Conflicts with macro features
- Graphical model descriptions - Loss of segment structure
- Graphical preprocessors - Too many generated equations
- Sophisticated integr. algorithms - Overhead for 80%
- State event handling - Depending on modeling
- New analysis methods - CSSL structure to weak
- Separation model-experiment - Powerful runtime system
- Windows - Implementations - Loss of speed, esp. on PC

In discrete simulation, each software is implemented with on an event mechanism. Developments and problems are similar to continuous simulation, but there are additional aspects:

- Petri net modeling - Implementation with events
- Object oriented approaches - Powerful hardware (no PCs)
- Predefined strategies - Description of complex strategies
- Interfaces for non-expert users - Validation of models
- Improved animation - Simulation = Video game ?

Parallel techniques may offer advantages for certain kind of problems. In case of hierachically structured tasks the useof parallel processors promise the best results (1st task). But if a problem is relatively small, and the subproblems are connected to each other, parallelsisation results in lower speed (2nd task). In case of bigger subtasks as in case of of the 3rd task the parallelisation results in a speed up - the subproblems are relatively big, and they are weakly coupled.
Recent and future developments let hope for a model - independent features for automatic parallelisation in high level simulation languages.

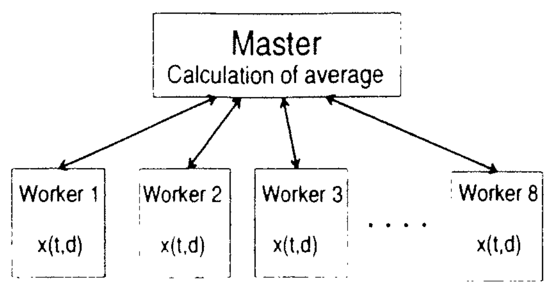


Fig. 2: Parallelisation for Monte-Carlo simulation

Comparison 2: Flexible Assembly System

A new comparison in this issue deals with discrete simulation, a flexible assembly system. We invite all institutes and companies developing or distributing simulation software to participate in this comparison:

Please, simulate the model described and send a report to the editors in the following form:

- short description of the language
- model description (source code, diagram, ...)
- results of the tasks with experimentation comments
- approx. 1 page A4

Reports will be published in the next issues of EUROSIM - Simulation News Europe.

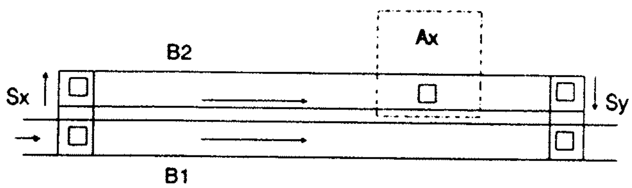
New comparisons will be prepared for the next issues, too. As it is difficult to find suitable "simple" models and relevant tasks we would like to ask you to contact the editors if you have an idea for a model to be compared in different simulation languages.

The following example of a flexible assembly system has been chosen because it checks two important features of discrete event simulation tools:

- the possibility to define and combine submodels,
- the method to describe complex control strategies.

The model consists of a number of almost identical submodels of the following structure (figure 1):

Figure 1



Two parallel conveyor belts, B1 and B2, are linked together at both ends. An assembly station Ax is placed at B2. Pallets are coming in on belt B1. If they are to be processed in Ax they are shifted in Sx to B2 and possibly enter a queue in front of Ax. If there is no more empty buffer space on B2 or the pallet is not to be processed in Ax it continues its way along B1. Parts that have been processed in Ax are shifted back to B1 in Sy, having priority over those coming from the left on B1.

The total system now consists of 8 of these subsystems, varying in length, operation and operation time (see figure 2). Between two subsequent subsystems there is a space of 0.4 m, whereas pallets from the third subsystem A2 can be shifted directly to A3, and from A6 directly to A1. The shifting parts, however, cannot function as buffers, i.e. a pallet can only enter an Sx if it can leave it immediately.

Figure 2

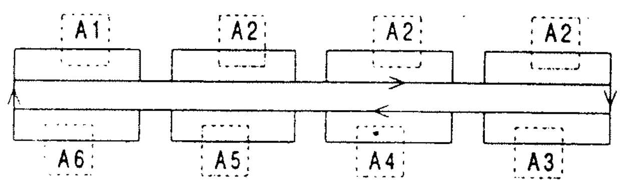


Table 1 shows the operation time of each station, the total length of B1 and the length of the buffer in front of the station.

Table 1

Station	Operation time (sec.)	Length of B 1 (m)	Length of buffer in front station (m)
A 1	15	2.0	1.2
A 2	60	1.6	0.8
A 3	20	1.6	0.8
A 4	20	1.6	0.8
A 5	20	1.6	0.8
A 6	30	2.0	1.2

There are three identical stations A2 in the system, because the operation in A2 takes much longer than the other operations.

Unprocessed parts are put on pallets in A1. They can either be processed in A2 first, and then in A3, A4, A5, or in A3, A4, A5 first, and then in A2. The sequence of operations among A3, A4, and A5 is arbitrary. Station A6 is a substitute for any of the stations A3, A4, A5, i.e. whenever one of these stations is down, or the buffer in front of it is free, the corresponding operation can be executed in A6. Finished parts are unloaded in A1, unfinished parts enter another circle.

All conveyors are running with a speed of 18 m/min., any shifting takes 2 sec., and pallet length is 0.36 m. Assuming that no station ever has a breakdown, the optimum number of pallets in the system is to be found. Therefore the total throughput and the average throughput time of the parts have to be evaluated, when 20, 40, and 60 pallets are circulating in the system.

To simplify comparison of results we suggest starting simulation experiments with empty pallets and collecting data from the 120th to the 600th minute (8 hours).

Comparison 2: Flexible Assembly System

The following example of a flexible assembly system has been chosen because it checks two important features of discrete event simulation tools:

- the possibility to define and combine submodels,
- the method to describe complex control strategies.

The model consists of a number of almost identical submodels of the following structure (figure 1):

Figure 1

Two parallel conveyor belts, B1 and B2, are linked together at both ends. An assembly station Ax is placed at B2. Pallets are coming in on belt B1. If they are to be processed in Ax they are shifted in Sx to B2 and possibly enter a queue in front of Ax. If there is no more empty buffer space on B2 or the pallet is not to be processed in Ax it continues its way along B1. Parts that have been processed in Ax are shifted back to B1 in Sy, having priority over those coming from the left on B1.

The total system now consists of 8 of these subsystems, varying in length, operation and operation time (see figure 2). Between two subsequent subsystems there is a space of 0.4 m, whereas pallets from the third subsystem A2 can be shifted directly to A3, and from A6 directly to A1. The shifting parts, however, cannot function as buffers, i.e. a pallet can only enter an Sx if it can leave it immediately.

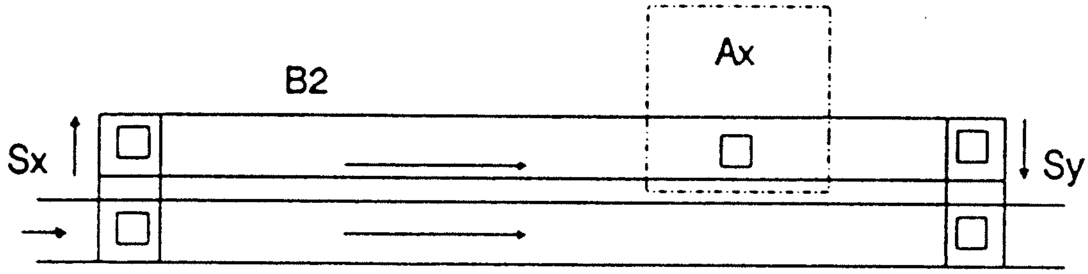


Table 1 shows the operation time of each station, the total length of B1 and the length of the buffer in front of the station.

Table 1

Station	Operation time (sec.)	Length of B 1 (m)	Length of buffer in front station (m)
A 1	15	2.0	1.2
A 2	60	1.6	0.8
A 3	20	1.6	0.8
A 4	20	1.6	0.8
A 5	20	1.6	0.8
A 6	30	2.0	1.2

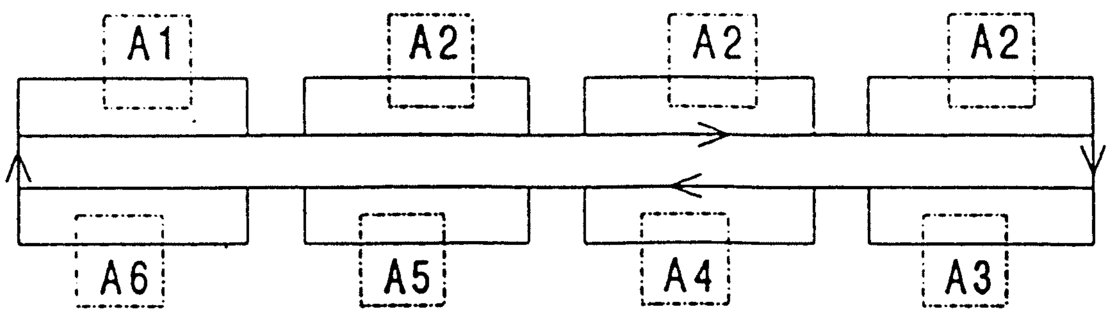
There are three identical stations A2 in the system, because the operation in A2 takes much longer than the other operations.

Unprocessed parts are put on pallets in A1. They can either be processed in A2 first, and then in A3, A4, A5, or in A3, A4, A5 first, and then in A2. The sequence of operations among A3, A4, and A5 is arbitrary. Station A6 is a substitute for any of the stations A3, A4, A5, i.e. whenever one of these stations is down, or the buffer in front of it is free, the corresponding operation can be executed in A6. Finished parts are unloaded in A1, unfinished parts enter another circle.

All conveyors are running with a speed of 18 m/min., any shifting takes 2 sec., and pallet length is 0.36 m. Assuming that no station ever has a breakdown, the optimum number of pallets in the system is to be found. Therefore the total throughput and the average throughput time of the parts have to be evaluated, when 20, 40, and 60 pallets are circulating in the system.

To simplify comparison of results we suggest starting simulation experiments with empty pallets and collecting data from the 120th to the 600th minute (8 hours).

Figure 2



Remarks

In number 1 of EUROSIM - Simulation News Europe (March 1991) we had proposed to test discrete event simulators using an example flexible assembly system. Some letters from readers however made it clear that the description of the system has been somewhat incomplete. We therefore try to answer the open questions and ask you not to hesitate to contact us if any other questions arise.

What follows is not a full definition of the model but only some details in addition to the description in EUROSIM - Simulation News Europe 1.

1. The subsystems contain two parallel conveyors B1 and B2. The total length of B2 between Sy and Sy is given in table 1. Sx and Sy themselves are 0.4 m wide. A pallet can either pass Sx or Sy without any delay with its normal speed along B1 or can be shifted to B2 in 2.0 sec. The lengths of B1 and B2 are the same. B2, however, is divided into three parts: the buffer in front of the station (its length being given in table 1), the station's positioning unit of length 0.4 cm, and the buffer behind the station (the remaining part of B2).

2. The conveyors themselves can function as buffers. Pallets can queue up in front of the stations or in front of Sx and Sy but the conveyor will move on with its normal speed. Also during the shifting of one pallet or while it is being processed on one of the positioning units in an Ax the other pallets are being transported without any delay. The capacity of each buffer can be easily calculated by dividing its length by the pallet length (0.36 cm). Of course, only integers are feasible results.

3. If the buffer in front of Ax is full, all pallets move on along B1 even if they require processing in Ax. They may either be processed when the pass Ax the next time, or they may be processed in A6 (if x = 3, 4, or 5).

4. The transportation time from Sx to Ax (i.e. its positioning unit) is not part of the operation time as given in table 1. The same holds for the transportation time from Ax to Sy.

5. In the beginning empty pallets are circulating in the system. Their positions on the conveyors B1 (not B2!) can be chosen randomly. Unprocessed pieces are put on them in A1 (operation time 7.5 sec), and finished parts are unloaded in A1, too (operation time 7.5 sec, hence total time for load/unload is 15.0 sec). A1 is only used for these load/unload operations.

6. Pallets are being brought to A6 if they have not undergone one or more of the operations of A3, A4, or A5. They can then undergo all the missing operations at a time.

We hope we have clarified the open questions now. Again: if any other questions come up during modelling, don't hesitate to contact us.

Finally we ask everybody who has tried or will try to model the system to send us a report on the experiences he/she has made even if no results have been achieved. We believe it is as important to learn why certain approaches or tools are not appropriate, as it is to learn how other colleagues have solved the problem. Unfortunately scientists do not communicate their unsolved problems and unsuccessful approaches as freely as they communicate their solutions. Please help us to change this and tell us if you have not been able to model this system with a simulation tool, and what the difficulties were. Thank you very much!

Contact:

J. Krauth, BIBA Bremer Institut für Betriebstechnik und angewandte Arbeitswissenschaft, Postfach 33 05 60, D - 2800 Bremen 33, Tel: +49 421 22009-51, Fax: +49 421 22009-79

Comparison 2 - PS SIMDIS

Description of PS SIMDIS OS/ES

PS SIMDIS is a block-oriented simulation language for discrete systems. It is a system of the GPSS family. Model elements are divided in static (storages, facilities, chains, queues...) and dynamic elements (transactions). Transactions can be generated and annihilated during the simulation process. A PC version (SIM-PC) of this simulation language was developed at the department of informatics at the Technical University Magdeburg. This PC-version consists of all features of the PS SIMDIS OS/ES and additional components for animation.

Model description

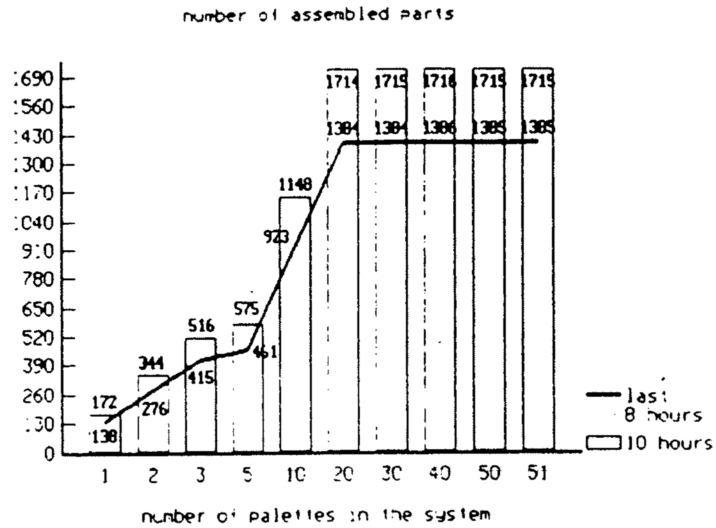
The model was programmed on a 80386 SX AT-type system. The parallel conveyor belts are modeled as static elements (storages). The capacities of these storages are equivalent with the length of the belts. The static element 'facility' represents an assembly station. The palettes are the dynamic elements in the system. The combination of the properties of the transactions, facilities and storages controls the whole system.

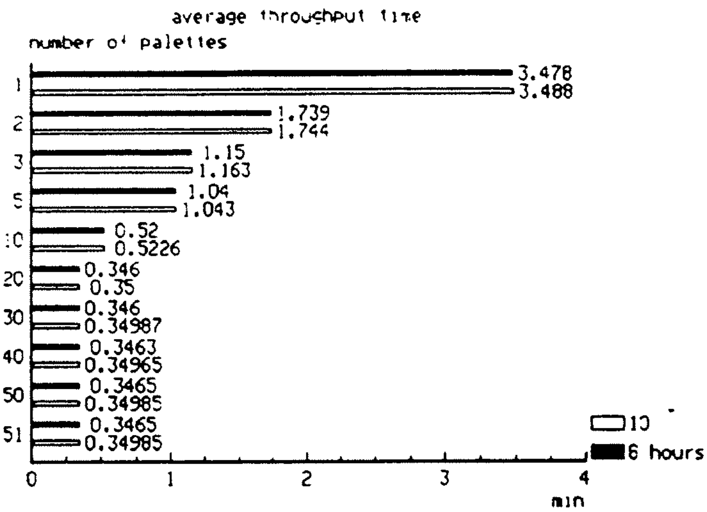
Results

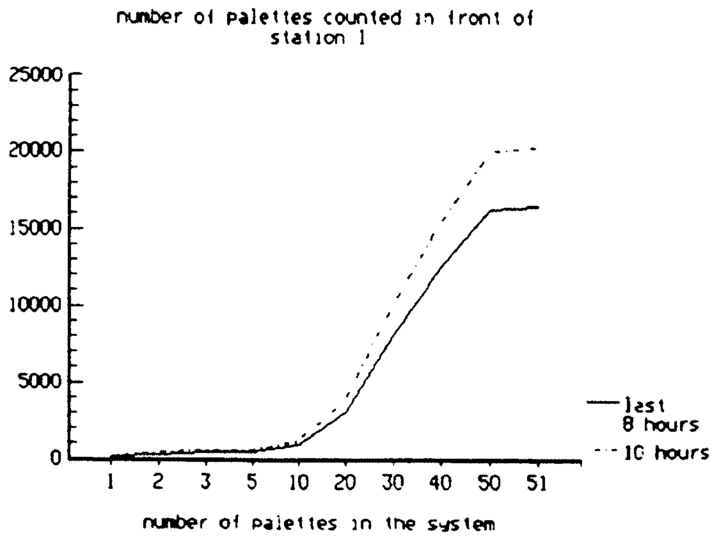
The system was not able to work with more than 51 palettes. The optimum number of palettes is 40. The figures show the results of some simulation passes.

```
SYB   ADVANCE    AV#SHI_T          shifting the palette
*
      SEIZE      WAYB
      LOGIC R    TORB              open second way
      TRANSFER   ,BBBB

* Here begins the belt B1.
*
BBA1  ENTER      SBB1,AV#PAL_L     OK, entering this belt B1
      RELEASE    WAYA
      ADVANCE    SK#SBB1
      GATE LR    TORB
      SEIZE      WAYB

BBE1  LEAVE      SBB1,AV#PAL_L     leaving the belt

* This is the end of this belt.
*
BBBB  ADVANCE    AV#WAY_L          between two subsystems

*
* This is subsystem C
*

MMC3  TEST E     PB1,1,BCA1        we have to skip - no part loaded

      TEST E     PB2,0,HCA1        we can skip - nothing to do

* OK. We have something to do.

      TEST E     AV#SBQU,0,HCA1    sorry, not allowed to do anything

* OK. Let's do it.

      TEST GE    SP#SCB2,AV#PAL_L,BCA1
      RELEASE    WAYB
* The buffer in front of station C is not full.

SXC   ADVANCE    AV#SHI_T          shifting palette to belt B2

* Here begins the buffer in front of station C.
*
BCA2  ENTER      SCB2,AV#PAL_L     OK, palette enters the buffer
      ADVANCE    SK#SCB2           move palette to the station

* Station C is empty.

      SEIZE      STC               entering the station C
      ADVANCE    AV#PAL_L
BCE2  LEAVE      SCB2,AV#PAL_L     leaving the buffer

* Here is the end of the buffer in front of station C.
*
```

Part of the model description







Diethard Wettrau, Im Winkel 1, O-3701 Abbenrode, Bundesrepublik Deutschland (student of informatics at the Technical University Magdeburg).

```
****************************************************************************
*                                                                          *
*  Flexible Assembly System   Version 5       5-18-91  5:27:45 pm          *
*                                             Diethard Wettrau             *
*                                             Im Winkel 1                  *
*                                             O-3701 Abbenrode             *
*                                             Bundesrepublik Deutschland   *
*                                                                          *
****************************************************************************

      REALLOCATE BLO,300
      REALLOCATE VAR,50

 PAL_L VARIABLE   36                 length of a palette {cm}

 PAL_N VARIABLE   40                 number of palettes in system

 CON_S VARIABLE   30                 speed of a conveyor {cm/sec}

* We have to define the shortest time in the system as a conclusion of the
* conveyors speed. For that reason we have to define one step of time as:
* 1 δt:=1/30 sec

 DTIME VARIABLE   AV#CON_S           helps by computing

 SHI_T VARIABLE   AV#DTIME*2         shifting takes 2 sec.

 WAY_L VARIABLE   40                 distance between two subsystems

* A palette have to pass a distance of 200 cm  means it have to wait 200 δt.

 SIMTI VARIABLE   AV#DTIME*60*60*10   { 10 hours }
*                                     simulation time {sec}
*--------------------------------------------------------------------------*
 FIRST VARIABLE   AV#DTIME*60*60*2    first observation
       INITIAL    LR#COLLE
*--------------------------------------------------------------------------*
       INITIAL    SK#SAB1,200         length of belt B1 {cm}
       INITIAL    SK#SBB1,160
       INITIAL    SK#SCB1,160
       INITIAL    SK#SDB1,160
       INITIAL    SK#SEB1,160
       INITIAL    SK#SFB1,160
       INITIAL    SK#SGB1,160
       INITIAL    SK#SHB1,200
*--------------------------------------------------------------------------*
       INITIAL    SK#SAB2,120         length of buffer in front of a station {cm}
       INITIAL    SK#SBB2,80          belt B2
       INITIAL    SK#SCB2,80
       INITIAL    SK#SDB2,80
       INITIAL    SK#SEB2,80
       INITIAL    SK#SFB2,80
       INITIAL    SK#SGB2,80
       INITIAL    SK#SHB2,120
```

```
*-----------------------------------------------------------------------*
 LBA    VARIABLE   SK#SAB1-SK#SAB2-AV#PAL_L
        INITIAL    SK#LBA,AV#LBA     length of buffer in back of a station {cm}
 LBB    VARIABLE   SK#SBB1-SK#SBB2-AV#PAL_L
        INITIAL    SK#LBB,AV#LBB
 LBC    VARIABLE   SK#SCB1-SK#SCB2-AV#PAL_L
        INITIAL    SK#LBC,AV#LBC
 LBD    VARIABLE   SK#SDB1-SK#SDB2-AV#PAL_L
        INITIAL    SK#LBD,AV#LBD
 LBE    VARIABLE   SK#SEB1-SK#SEB2-AV#PAL_L
        INITIAL    SK#LBE,AV#LBE
 LBF    VARIABLE   SK#SFB1-SK#SFB2-AV#PAL_L
        INITIAL    SK#LBF,AV#LBF
 LBG    VARIABLE   SK#SGB1-SK#SGB2-AV#PAL_L
        INITIAL    SK#LBG,AV#LBG
 LBH    VARIABLE   SK#SHB1-SK#SHB2-AV#PAL_L
        INITIAL    SK#LBH,AV#LBH
*-----------------------------------------------------------------------*
        INITIAL    LR#TORA
        INITIAL    LR#TORB
        INITIAL    LR#TORC
        INITIAL    LR#TORD
        INITIAL    LR#TORE
        INITIAL    LR#TORF
        INITIAL    LR#TORG
        INITIAL    LR#TORH
*-----------------------------------------------------------------------*
 OPTIM FUNCTION    PB9,D6            operation time of a station {sec}
1/15,2/60,3/20,4/20,5/20,6/30

 OTIME VARIABLE    FN#OPTIM*AV#DTIME
*                                    gives the real operation time of a station
*-----------------------------------------------------------------------*
 DONE   VARIABLE   PB1*PB2*PB3*PB4*PB5
*                                    Is there anything to do ?
 SEQU   VARIABLE   PB8:4             Is the working sequence OK ?
*-----------------------------------------------------------------------*
        INITIAL    XF#AUS1,0
        INITIAL    XF#EIN1,0
        INITIAL    XF#CYC1,0
        INITIAL    XF#AUS2,0
        INITIAL    XF#EIN2,0
        INITIAL    XF#CYC2,0
*-----------------------------------------------------------------------*

* Now we create the palettes.

        GENERATE   AV#PAL_L,0,0,AV#PAL_N,0,9PB

* Entering the system.

        TRANSFER   ,MMM1

 MMM0   TEST G     AV#DONE,0,MMM1    there is nothing to do
```

```
        ASSIGN      1-8,0,,PB           get assembled part from palette

 CNTR   SAVEVALUE   AUS1+,1,XF          count all assembled parts
        GATE LS     COLLE,*+2
        SAVEVALUE   AUS2+,1,XF          count assembled parts after 2nd hour
*----------------------------------------------------------------------------*
* This is subsystem A
*----------------------------------------------------------------------------*

 MMM1   SEIZE       OEHRZ
        SAVEVALUE   CYC1+,1,XF          count all palettes
        GATE LS     COLLE,*+2
        SAVEVALUE   CYC2+,1,XF          count palettes after 2nd hour
        TEST E      PB1,0,BAA1          we can skip this subsystem

* Oh, there is no part loaded. Try to load!

        TEST GE     SP#SAB2,AV#PAL_L,BAA1

* The buffer in front of station A is not full.
        RELEASE     OEHRZ
 SXA    ADVANCE     AV#SHI_T            shifting palette to belt B2

* Here begins the buffer in front of station A.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 BAA2   ENTER       SAB2,AV#PAL_L       OK, palette enters the buffer
        ADVANCE     SK#SAB2             move palette to the station

* Station A is empty.

        SEIZE       STA                 entering the station A
        ADVANCE     AV#PAL_L
 BAE2   LEAVE       SAB2,AV#PAL_L       leaving the buffer

* Here is the end of the buffer in front of station A.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
        ASSIGN      9,1,,PB             store number of current station type to get
*                                       the operation time of this station
 STA    ADVANCE     AV#OTIME            now we have to work, assembly parts

        SAVEVALUE   EIN1+,1,XF          count loaded parts
        GATE LS     COLLE,*+2
        SAVEVALUE   EIN2+,1,XF          count all loaded parts after 2nd hour
        ASSIGN      1,1,,PB             write the signum of a station of type 1

* Here begins the buffer at the back of station A.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 LBA    ENTER       LBA,AV#PAL_L        enter buffer after station
        ADVANCE     AV#PAL_L
        RELEASE     STA                 leaving the station

 XLA    VARIABLE    AV#LBA-AV#PAL_L
        ADVANCE     AV#XLA
```

```
        LOGIC S     TORA              close the second way
        GATE FNU    WAYA              try to leave station
        LEAVE       LBA,AV#PAL_L      leave buffer after station

* Here is the end of the buffer at the back of station A.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*

SYA     ADVANCE     AV#SHI_T          shifting the palette

*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
        SEIZE       WAYA              between two subsystems
        LOGIC R     TORA              open second way
        TRANSFER    ,AAAA

* Here begins the belt B1.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
BAA1    RELEASE     OEHRZ
        ENTER       SAB1,AV#PAL_L     OK, entering this belt B1

        ADVANCE     SK#SAB1
        GATE LR     TORA
        SEIZE       WAYA

BAE1    LEAVE       SAB1,AV#PAL_L     leaving the belt

* This is the end of this belt.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
AAAA    ADVANCE     AV#WAY_L          between two subsystems

*------------------------------------------------------------------*
* This is subsystem B
*------------------------------------------------------------------*

MMM2    TEST E      PB1,1,BBA1        we have to skip - no part loaded
        TEST E      PB2,0,BBA1        we can skip - nothing to do

* OK. We have something to do.

        TEST E      AV#SEQU,0,BBA1    sorry, not allowed to do anything

* OK. Let's do it.

        TEST GE     SP#SBB2,AV#PAL_L,BBA1
        RELEASE     WAYA

* The buffer in front of station B is not full.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
SXB     ADVANCE     AV#SHI_T          shifting palette to belt B2

* Here begins the buffer in front of station B.

BBA2    ENTER       SBB2,AV#PAL_L     OK, palette enters the buffer
        ADVANCE     SK#SBB2           move palette to the station
```

```
* Station B is empty.

        SEIZE       STB                   entering the station B
        ADVANCE     AV#PAL_L
 BBE2   LEAVE       SBB2,AV#PAL_L         leaving the buffer

* Here is the end of the buffer in front of station B.
*----------------------------------------------------------------------*
        ASSIGN      9,2,,PB               store number of current station type to get
*                                         the operation time of this station

 STB    ADVANCE     AV#OTIME              now we have to work, assembly parts

        ASSIGN      2,2,,PB               write the signum of a station of type 2

 LBB    ENTER       LBB,AV#PAL_L          enter buffer after station
        ADVANCE     AV#PAL_L
        RELEASE     STB                   leaving the station

 XLB    VARIABLE    AV#LBB-AV#PAL_L
        ADVANCE     AV#XLB

        LOGIC S     TORB                  close the second way
        GATE FNU    WAYB                  try to leave station
        LEAVE       LBB,AV#PAL_L          leave buffer after station

* Here is the end of the buffer at the back of station B.
*----------------------------------------------------------------------*
 SYB    ADVANCE     AV#SHI_T              shifting the palette

*----------------------------------------------------------------------*
        SEIZE       WAYB
        LOGIC R     TORB                  open second way
        TRANSFER    ,BBBB

* Here begins the belt B1.
*----------------------------------------------------------------------*
 BBA1   ENTER       SBB1,AV#PAL_L         OK, entering this belt B1
        RELEASE     WAYA
        ADVANCE     SK#SBB1
        GATE LR     TORB
        SEIZE       WAYB

 BBE1   LEAVE       SBB1,AV#PAL_L         leaving the belt

* This is the end of this belt.
*----------------------------------------------------------------------*
 BBBB   ADVANCE     AV#WAY_L              between two subsystems

*----------------------------------------------------------------------*
* This is subsystem C
*----------------------------------------------------------------------*

 MMM3   TEST E      PB1,1,BCA1          we have to skip - no part loaded
```

```
        TEST E      PB2,0,BCA1      we can skip - nothing to do

* OK. We have something to do.

        TEST E      AV#SEQU,0,BCA1  sorry, not allowed to do anything

* OK. Let's do it.

        TEST GE     SP#SCB2,AV#PAL_L,BCA1
        RELEASE     WAYB
* The buffer in front of station C is not full.

SXC     ADVANCE     AV#SHI_T        shifting palette to belt B2

* Here begins the buffer in front of station C.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
BCA2    ENTER       SCB2,AV#PAL_L   OK, palette enters the buffer
        ADVANCE     SK#SCB2         move palette to the station

* Station C is empty.

        SEIZE       STC             entering the station C
        ADVANCE     AV#PAL_L
BCE2    LEAVE       SCB2,AV#PAL_L   leaving the buffer

* Here is the end of the buffer in front of station C.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
        ASSIGN      9,2,,PB         store number of current station type to get
*                                   the operation time of this station
STC     ADVANCE     AV#OTIME        now we have to work, assembly parts

        ASSIGN      2,2,,PB         write the signum of a station of type 2

LBC     ENTER       LBC,AV#PAL_L    enter buffer after station
        ADVANCE     AV#PAL_L
        RELEASE     STC             leaving the station

XLC     VARIABLE    AV#LBC-AV#PAL_L
        ADVANCE     AV#XLC

        LOGIC S     TORC            close the second way
        GATE FNU    WAYC            try to leave station
        LEAVE       LBC,AV#PAL_L    leave buffer after station

* Here is the end of the buffer at the back of station C.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*

SYC     ADVANCE     AV#SHI_T        shifting the palette

*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
        SEIZE       WAYC            between two subsystems
        LOGIC R     TORC            open second way
        TRANSFER    ,CCCC
```

```
* Here begins the belt B1.
*-----------------------------------------------------------------------*
 BCA1  ENTER      SCB1,AV#PAL_L     OK, entering this belt B1
       RELEASE    WAYB
       ADVANCE    SK#SCB1
       GATE LR    TORC
       SEIZE      WAYC
 BCE1  LEAVE      SCB1,AV#PAL_L     leaving the belt

* This is the end of this belt.
*-----------------------------------------------------------------------*
 CCCC  ADVANCE    AV#WAY_L          between two subsystems

*-----------------------------------------------------------------------*
* This is subsystem D
*-----------------------------------------------------------------------*

 MMM4  TEST E     PB1,1,BDA1       we have to skip - no part loaded
       TEST E     PB2,0,BDA1       we can skip - nothing to do

* OK. We have something to do.

       TEST E     AV#SEQU,0,BDA1   sorry, not allowed to do anything

* OK. Let's do it.

       TEST GE    SP#SDB2,AV#PAL_L,BDA1
       RELEASE    WAYC
* The buffer in front of station D is not full.

 SXD   ADVANCE    AV#SHI_T          shifting palette to belt B2

* Here begins the buffer in front of station D.
*-----------------------------------------------------------------------*
 BDA2  ENTER      SDB2,AV#PAL_L     OK, palette enters the buffer
       ADVANCE    SK#SDB2           move palette to the station

*      GATE FNU   STD

* Station D is empty.

       SEIZE      STD               entering the station D
       ADVANCE    AV#PAL_L
 BDE2  LEAVE      SDB2,AV#PAL_L     leaving the buffer

* Here is the end of the buffer in front of station D.
*-----------------------------------------------------------------------*
       ASSIGN     9,2,,PB           store number of current station type to get
*                                   the operation time of this station

 STD   ADVANCE    AV#OTIME          now we have to work, assembly parts

       ASSIGN     2,2,,PB           write the signum of a station of type 2
```

```
        ENTER       LBD,AV#PAL_L      enter the buffer in back of station
        ADVANCE     AV#PAL_L
        RELEASE     STD               leaving station

 XLD    VARIABLE    AV#LBD-AV#PAL_L
        ADVANCE     AV#XLD

        LOGIC S     TORD              close second way

        SEIZE       OEHRD
        TEST E      PB3,3,CHEE1       which belt we can choose

* We must not enter the next station - only belt B1.

        TEST GE     SP#SEB1,AV#PAL_L
        TRANSFER    ,CHEE2

* We can choose between both belts.

 SPE    VARIABLE    (SP#SEB2+SP#SEB1)/2
 CHEE1  TEST GE     AV#SPE,AV#PAL_L

 CHEE2  RELEASE     OEHRD
        LEAVE       LBD,AV#PAL_L      leaving the station

* Here is the end of the buffer at the back of station D.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*

 SYD    ADVANCE     AV#SHI_T          shifting the palette

*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
        LOGIC R     TORD
        TRANSFER    ,DDDD

* Here begins the belt B1.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 BDA1   ENTER       SDB1,AV#PAL_L     OK, entering this belt B1
        RELEASE     WAYC
        ADVANCE     SK#SDB1
        GATE LR     TORD

        SEIZE       OEHRD
        TEST E      PB3,3,CHEE3       which belt we can choose

* We must not enter the next station - only belt B1.

        TEST GE     SP#SEB1,AV#PAL_L
        TRANSFER    ,BDE1

* We can choose between both belts.

 CHEE3  TEST GE     AV#SPE,AV#PAL_L   waiting - next belt is not full

 BDE1   RELEASE     OEHRD
```

```
        LEAVE      SDB1,AV#PAL_L      leaving the belt

* This is the end of this belt.
*-------------------------------------------------------------------*
 DDDD   CONTINUE

*-------------------------------------------------------------------*
* This is subsystem E
*-------------------------------------------------------------------*

 MMM5   TEST E     PB1,1,BEA1         we have to skip - no part loaded
        TEST E     PB3,0,BEA1         we can skip - nothing to do

* OK. We have something to do.

        TEST GE    SP#SEB2,AV#PAL_L,BEA1

* The buffer in front of station E is not full.

 SXE    ADVANCE    AV#SHI_T           shifting palette to belt B2

* Here begins the buffer in front of station E.
*-------------------------------------------------------------------*
 BEA2   ENTER      SEB2,AV#PAL_L      OK, palette enters the buffer
        ADVANCE    SK#SEB2            move palette to the station

* Station E is empty.

        SEIZE      STE                entering the station E
        ADVANCE    AV#PAL_L
 BEE2   LEAVE      SEB2,AV#PAL_L      leaving the buffer

* Here is the end of the buffer in front of station E.
*-------------------------------------------------------------------*
        ASSIGN     9,3,,PB            store number of current station type to get
*                                     the operation time of this station

 STE    ADVANCE    AV#OTIME           now we have to work, assembly parts

        ASSIGN     3,3,,PB            write the signum of a station of type 3
        ASSIGN     8+,1,,PB           I'm a part of three.

 LBE    ENTER      LBE,AV#PAL_L       enter buffer after station
        ADVANCE    AV#PAL_L
        RELEASE    STE                leaving the station

 XLE    VARIABLE   AV#LBE-AV#PAL_L
        ADVANCE    AV#XLE

        LOGIC S    TORE               close the second way
        GATE FNU   WAYE               try to leave station
        LEAVE      LBE,AV#PAL_L       leave buffer after station

* Here is the end of the buffer at the back of station E.
```

```
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*

 SYE   ADVANCE    AV#SHI_T          shifting the palette

*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
       SEIZE      WAYE              between two subsystems
       LOGIC R    TORE              open second way
       TRANSFER   ,EEEE

* Here begins the belt B1.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 BEA1  ENTER      SEB1,AV#PAL_L     OK, entering this belt B1
       ADVANCE    SK#SEB1
       GATE LR    TORE
       SEIZE      WAYE
 BEE1  LEAVE      SEB1,AV#PAL_L     leaving the belt

* This is the end of this belt.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 EEEE  ADVANCE    AV#WAY_L          between two subsystems

*----------------------------------------------------------------------------*
* This is subsystem F
*----------------------------------------------------------------------------*

 MMM6  TEST E     PB1,1,BFA1        we have to skip - no part loaded
       TEST E     PB4,0,BFA1        we can skip - nothing to do

* OK. We have something to do.

       TEST GE    SP#SFB2,AV#PAL_L,BFA1
       RELEASE    WAYE
* The buffer in front of station F is not full.

 SXF   ADVANCE    AV#SHI_T          shifting palette to belt B2

* Here begins the buffer in front of station F.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 BFA2  ENTER      SFB2,AV#PAL_L     OK, palette enters the buffer
       ADVANCE    SK#SFB2           move palette to the station

* Station F is empty.

       SEIZE      STF               entering the station F
       ADVANCE    AV#PAL_L
 BFE2  LEAVE      SFB2,AV#PAL_L     leaving the buffer

* Here is the end of the buffer in front of station F.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
       ASSIGN     9,4,,PB           store number of current station type to get
*                                   the operation time of this station
 STF   ADVANCE    AV#OTIME          now we have to work, assembly parts

       ASSIGN     4,4,,PB           write the signum of a station of type 4
```

```
        ASSIGN      8+,1,,PB            I'm a part of three.
LBF     ENTER       LBF,AV#PAL_L        enter buffer after station
        ADVANCE     AV#PAL_L
        RELEASE     STF                 leaving the station

XLF     VARIABLE    AV#LBF-AV#PAL_L
        ADVANCE     AV#XLF

        LOGIC S     TORF                close the second way
        GATE FNU    WAYF                try to leave station
        LEAVE       LBF,AV#PAL_L        leave buffer after station

* Here is the end of the buffer at the back of station F.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
SYF     ADVANCE     AV#SHI_T            shifting the palette

*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
        SEIZE       WAYF
        LOGIC R     TORF                open second way
        TRANSFER    ,FFFF

* Here begins the belt B1.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
BFA1    ENTER       SFB1,AV#PAL_L       OK, entering this belt B1
        RELEASE     WAYE
        ADVANCE     SK#SFB1
        GATE LR     TORF
        SEIZE       WAYF

BFE1    LEAVE       SFB1,AV#PAL_L       leaving the belt

* This is the end of this belt.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
FFFF    ADVANCE     AV#WAY_L            between two subsystems

*--------------------------------------------------------------------------*
* This is subsystem G
*--------------------------------------------------------------------------*

MMM7    TEST E      PB1,1,BGA1          we have to skip - no part loaded
        TEST E      PB5,0,BGA1          we can skip - nothing to do

* OK. We have something to do.

        TEST GE     SP#SGB2,AV#PAL_L,BGA1
        RELEASE     WAYF
* The buffer in front of station G is not full.

SXG     ADVANCE     AV#SHI_T            shifting palette to belt B2

* Here begins the buffer in front of station G.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
BGA2    ENTER       SGB2,AV#PAL_L       OK, palette enters the buffer
        ADVANCE     SK#SGB2             move palette to the station
```

```
*       GATE FNU    STG

* Station G is empty.

        SEIZE       STG              entering the station G
        ADVANCE     AV#PAL_L
 BGE2   LEAVE       SGB2,AV#PAL_L    leaving the buffer

* Here is the end of the buffer in front of station G.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
        ASSIGN      9,5,,PB          store number of current station type to get
*                                    the operation time of this station

 STG    ADVANCE     AV#OTIME         now we have to work, assembly parts

        ASSIGN      5,5,,PB          write the signum of a station of type 5
        ASSIGN      8+,1,,PB         I'm a part of three.
 LBG    ENTER       LBG,AV#PAL_L     enter buffer after station
        ADVANCE     AV#PAL_L
        RELEASE     STG              leaving the station

 XLG    VARIABLE    AV#LBG-AV#PAL_L
        ADVANCE     AV#XLG

        LOGIC S     TORG             close the second way
        GATE FNU    WAYG             try to leave station
        LEAVE       LBG,AV#PAL_L     leave buffer after station

* Here is the end of the buffer at the back of station G.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 SYG    ADVANCE     AV#SHI_T         shifting the palette

*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
        SEIZE       WAYG             between two subsystems
        LOGIC R     TORG             open second way
        TRANSFER    ,GGGG

* Here begins the belt B1.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 BGA1   ENTER       SGB1,AV#PAL_L    OK, entering this belt B1
        RELEASE     WAYF
        ADVANCE     SK#SGB1
        GATE LR     TORG
        SEIZE       WAYG
 BGE1   LEAVE       SGB1,AV#PAL_L    leaving the belt

* This is the end of this belt.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
 GGGG   ADVANCE     AV#WAY_L         between two subsystems

*---------------------------------------------------------------------*
* This is subsystem H
*---------------------------------------------------------------------*
```

```
MMM8  TEST E      PB1,1,BHA1        we have to skip - no part loaded
      TEST NE     PB8,3,BHA1        we can skip - nothing to do

* OK. We have something to do.

      TEST E      PB3,0,HHH1        nothing to do for type 3

* OK. I'll do your job 'type 3'

      ASSIGN      3,3,,PB           write the signum of a station of type 3
      TRANSFER    ,HHH3

HHH1  TEST E      PB4,0,HHH2        nothing to do for type 4

* OK. I'll do your job 'type 4'

      ASSIGN      4,4,,PB           write the signum of a station of type 4
      TRANSFER    ,HHH3

* Not '3', not '4' ... OK. Let's do it like 'type 5'.

HHH2  ASSIGN      5,5,,PB           write the signum of a station of type 5

HHH3  TEST GE     SP#SHB2,AV#PAL_L,BHA1
      RELEASE     WAYG
* The buffer in front of station H is not full.

SXH   ADVANCE     AV#SHI_T            shifting palette to belt B2

* Here begins the buffer in front of station H.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
BHA2  ENTER       SHB2,AV#PAL_L       OK, palette enters the buffer
      ADVANCE     SK#SHB2             move palette to the station

* Station H is empty.

      SEIZE       STH                 entering the station H
      ADVANCE     AV#PAL_L
BHE2  LEAVE       SHB2,AV#PAL_L       leaving the buffer

* Here is the end of the buffer in front of station H.
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*
      ASSIGN      9,6,,PB             store number of current station type to get
*                                     the operation time of this station
STH   ADVANCE     AV#OTIME            now we have to work, assembly parts
      ASSIGN      8+,1,,PB            I'm a part of three.

LBH   ENTER       LBH,AV#PAL_L
      ADVANCE     AV#PAL_L
      RELEASE     STH

XLH   VARIABLE    AV#LBH-AV#PAL_L
      ADVANCE     AV#XLH
```

```
        LOGIC S      TORH

        SEIZE        OEHRH
        TEST E       PB1,1,CHEA1

* We must not enter next station.

        TEST GE      SP#SAB1,AV#PAL_L
        TRANSFER     ,CHEA2

* We can choose between both belts.

SPA     VARIABLE     (SP#SAB2+SP#SAB1)/2
CHEA1   TEST GE      AV#SPA,AV#PAL_L

CHEA2   RELEASE      OEHRH
        LEAVE        LBH,AV#PAL_L        leaving the station

* Here is the end of the buffer at the back of station H.
*-------------------------------------------------------------------*
SYH     ADVANCE      AV#SHI_T            shifting the palette

*-------------------------------------------------------------------*
        LOGIC R      TORH
        TRANSFER     ,HHHH

* Here begins the belt B1.
*-------------------------------------------------------------------*
BHA1    ENTER        SHB1,AV#PAL_L       OK, entering this belt B1
        RELEASE      WAYG
        ADVANCE      SK#SHB1
        GATE LR      TORH
        SEIZE        OEHRH
        TEST E       PB1,1,CHEA3         which belt can we choose

* We must not enter next station.

        TEST GE      SP#SAB1,AV#PAL_L
        TRANSFER     ,BHE1

* We can choose between both belts.

CHEA3   TEST GE      AV#SPA,AV#PAL_L

BHE1    RELEASE      OEHRH
        LEAVE        SHB1,AV#PAL_L       leaving the belt

* This is the end of this belt.
*-------------------------------------------------------------------*
HHHH    TRANSFER     ,MMMO
*-------------------------------------------------------------------*

        GENERATE     ,,,1,127,0PB,0PH,1PF  We'll control the time of simulation.
```

```
       SPLIT      1,OBSER
       ADVANCE    AV#SIMTI
       TERMINATE  1                 The time is over.

OBSER  ADVANCE    AV#FIRST
       LOGIC S    COLLE             Now we are collecting data.
       TERMINATE

       START      1                 Run!
```

Comparison 2 - DOSIMIS3

1. Description of language

The simulator DOSIMIS3 used for solving the given task is an element oriented simulator. DOSIMIS3 is based upon chronological event lists and is particularly designed for analysing discrete Material Flow Systems (MFS). Being element oriented, DOSIMIS3 does not provide a simulator language as other simulation packages. Instead, it is possible to build a complete MFS by combining so called elements on the screen. The 20 standard elements are similar to those of real MFS and they can be placed via a menu oriented, graphic user interface. The characteristics of the elements are to be specified by parameters (length, speed, etc.) within a parameter mask, which can be popped up for each single element. Elements with more than one input or output can be equipped with a local intelligence by which strategies such as FIFO, priorities of input, etc. can be realized. Postrun animation and presentation of simulation results in tables and graphs allow for the evaluation of the simulation results. If control of the model via standard DOSIMIS3 strategies is insufficient, decision tables can be employed to model functional and informational interrelationships. These decision tables can be entered via the graphic user interface, such that no programming skills are required. In case of highly complex problems, the system's control can be improved by additionally using the DOSIMIS3 programming interface (PASCAL).

The given task was solved entirely by using decision tables. No extra programming was necessary.

2. Model Description

To solve this problem the following DOSIMIS3 elements were used

elements	function
1 source *	create new parts
1 sink *	terminate completely processed parts
1 assembly element*	put unprocessed parts on pallets
1 disassembly element *	unload parts from pallets
7 workstations	assembly stations A2(3x), A3 - A6
8 junctions 8 discharging devices	shiftplaces between conveyor belts B1-B2
30 buffer sections	sections of conveyor belts B1 and B2

* the station A1 consists of these elements

3. Parametrization of the elements

length of a segment	0.4 m
length of an object	0.36 m
conveying speed	0.3 m/s

Number of segments for each belt according to belt length in given task. The empty pallets were put in the buffer sections of all conveyor belts B1 and B2 before start.

4. Results and experimentation comments

numbers of pallets	total through-put	average through-put time	min through-put time	max through-put time
10	939	314.3	293.0	335.6
15	1350	327.5	225.3	413.0
20	1408	436.9	263.6	1222.3
30	1410	620.9	340.0	2436.3
35	1408	722.6	350.3	3160.7
40	1408	825.0	345.6	3145.3

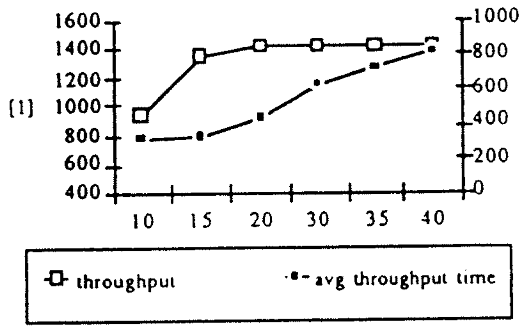
collecting data from 120 th to 600 th minute

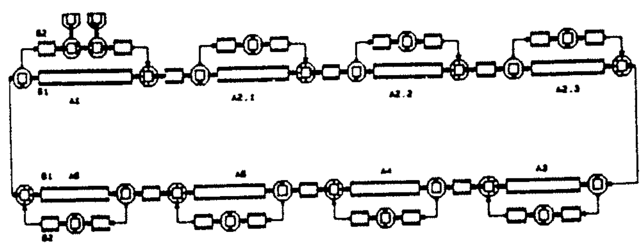
a) 20 is the optimum number of pallets in the system (see diagram below)

b) with increasing number of pallets, the total throughput approaches the optimum value of 1440 parts. This figure is based on the following idea: The longest operation time of an assembly station is 20 s, (A2's is 60 s divided by the number of stations A2 equals 20 s again). Thus the best case will be: 8 hours divided by 20 s equals 1440 parts.

c) With 60 pallets the system couldn't work because of a deadlock.

It seems to be possible to increase the number of pallets by changing the priority of the shift places Sy, thus, that pallets in B1 have priority over pallets on B2. The tradeoff would be longer throughput times.





For information and comments, please phone or fax or write to:

Ariane Beese or Michael Kluger, Fraunhofer Institute for Material Flow and Logistics, Emil Figgestr. 75, W - 4600 Dortmund, Germany, Tel: +49-(0)231 7549 171, Fax: +49-(0)231 7549 211

Comparison 2 - SIMAN

This report discusses the method used to simulate and optimize the Flexible Assembly/Manufacturing System using the Simulation Language SIMAN/CINEMA:

SIMAN is a general purpose SIMulation ANalysis program for modelling combined discrete continuous systems.

SIMAN is designed around a logical modelling framework that separates the model structure and experimental frame into two distinct elements. This allows different experimentation runs to be performed yet, keeping the control and flow logic unaltered in the model frame.

SIMAN runs on various types of computers and offers animation with the CINEMA system. This powerful tool allows not only a visual presentation of the system but is interactive with the debugger and allows rapid validation with the real world system.

A menu generator is available to allow the model builder to develop a series of menus so that the simulation can be run by an unskilled user. Output analysis is performed via the Output Processor.

Model description

For the purpose of this exercise the model was described as a Flexible Manufacturing (rather than Assembly) System. There is a 60 second drilling process at the A2 stations. Stations A3, A4 and A5 are mill, lathe and broach respectively. A6 is a multi-purpose (except drilling). The FMS model has some noteworthy features:

(a) The workstations are submodelled using the 'macro station' feature, allowing all 8 workstations to be modelled as one, as are all entrances to and exits from the conveyor belts.

The workstation belts are modelled as a single 'accumulating conveyor' SIMAN element. The loop conveyor is another.

(b) Two 'FINDJ' blocks determine the appropriate station with the lowest buffer level.

(c) Control for the system is via a 'BRANCH' block. In addition to the information from the FINDJ blocks, the branch statement determines whether the pallet has started on the mill/lathe/broach sequence. From this a decision is made to which process the pallet will visit next. Failing to find a station to visit, results in the pallet being conveyed to the next station and repeating the 'FINDJ, BRANCH' routine.

(d) All buffer levels before workstations, process times, number of pallets in system and conveyor dimensions/velocities can be adjusted in the experimental frame.

Experimentation results

The various pallet configurations were run in 'Batch Mode' and results of flowtime, cycle time and total throughput (number of pallets through system in 8 hours), recorded for 20, 40 and 60 pallets in the system. The SIMAN Output Processor was used to produce the graphs and associated confidence calculations and correlograms.

(a) Results from the first output show the system becomes congested at the 60 pallet level (the loop conveyor reaches its full capacity). The 20 pallet and 40 pallet runs yielded a 919 and 920 pallet throughput in 8 hours. The 20 pallet option is clearly more desirable as the work in progress and flowtimes are halved. More detailed experimentation was necessary around the 20 pallet figure to see if we could reduce these further.

(b) Figures 1 and 2 are plots of number of pallets in system against flowrate and throughput. It was decided 13 pallets are the optimum as it maintains the throughput of 919 pallets, yet has the lowest WIP figure and very low flowtime.

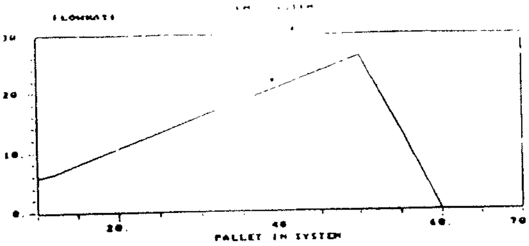


Fig1.

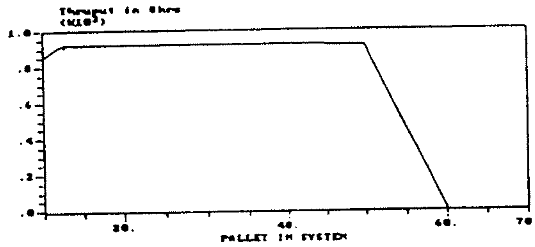


Fig2.

No.of Pallets in System.	Average Flow Time.	No.of Pallets Through System in 8hrs.
10	5.6289	853
12	6.2983	914
13	6.7884	919
14	7.3118	919
15	7.8307	919
20	10.462	919
25	13.054	919
30	15.748	919
40	20.927	920
50	26.047	917
60	0.0	0.0

Fig3.

IDENTIFIER	AVERAGE	STANDARD DEVIATION	.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
CycTime	.522	2.132E-03	1.380E-04	.522	.587	919
FlowTime	6.79	1.29	8.373E-02	4.24	14.1	919

Fig4.

Remarks

Interpretation of whether the length of buffer in front of the work stations included the space for the pallet (while being processed) or not could produce different results. This would effect the congestion on the loop conveyor, throughput and flow times.

J.F.S. Heffernan, The CIMulation Centre, Avon House, P.O. Box 46, Chippenham, Wiltshire SN15 1JH, England

A Flexible Assembly Model

This report discusses the method used to simulate & optimise the Flexible Assembly/Manufacturing System using the Simulation Language SIMAN/CINEMA.

SIMAN is a general-purpose SIMulation ANalysis program for modelling combined Discrete-Continuous systems.

(a) SIMAN is designed around a logical modelling framework that separates the model structure & experimental frame into two distinct elements. This allows different experimentation runs to be performed yet, keeping the Control & flow logic unaltered in the Model frame.

(b) SIMAN runs on a mainframe, mini & microcomputers. All versions are compatible. Models can be moved between computer systems without modifications.

(c) SIMAN can be used within the CINEMA system to generate real-time,high-resolution colour graphics animation of the system dynamics. This powerful tool allows not only a visual presentation of the system but, is interactive with the debugger and allows rapid validation with the real world system.

(d) SIMAN's debugger allows the user to monitor & control the execution of the modelled system,without the need to recompile,relink and rerun the simulation.

(e) A Menu generator is available to allow the model builder to develop a series of menus so that the simulation can be run by an unskilled user. These menus allow variables to be changed, the data collected & stored for subsequent analysis.

(f) Output analysis is via the Output Processor.This can represent graphically Plots,Tables, Histograms etc. Using this feature, the optimum Pallet number can be confirmed.

Model Description

For the purpose of this exercise, the model ·as described as a Flexible Manufacturing (rather than Assembly) System. There is a 60 second irilling process at the A2 Stations. Stations A3, \4 & A5 are Mill, Lathe & Broach respectively. A6 is Multi-Purpose (except Drilling).The FMS Model ias some noteworthy features:

a) The Workstations are submodelled using the Macro Station' feature, allowing all 8 orkstations to be modelled as one, as are all ntrances to,and exits from, the Conveyor Belts.

The Workstation belts are modelled as a ingle 'Accumulating Conveyor' SIMAN element. The oop Conveyor is another.

(b) Two 'FIND J' Blocks determine the appropriate Station with the lowest Buffer level.

(c) Control for the system is via a 'BRANCH' Block. In addition to the information from the FINDJ Blocks, the Branch statement determines whether the Pallet has started on the Mill/Lathe/Broach sequence. From this a decision is made to which process the Pallet will visit next.Failing to find a station to visit, results in the Pallet being Conveyed to the next station and repeating the 'FINDJ, BRANCH' routine.

(d) All Buffer levels before Workstations, Process times, Number of Pallets in system and Conveyor dimensions/velocities can be adjusted in the Experimental Frame.

Experimentation Results

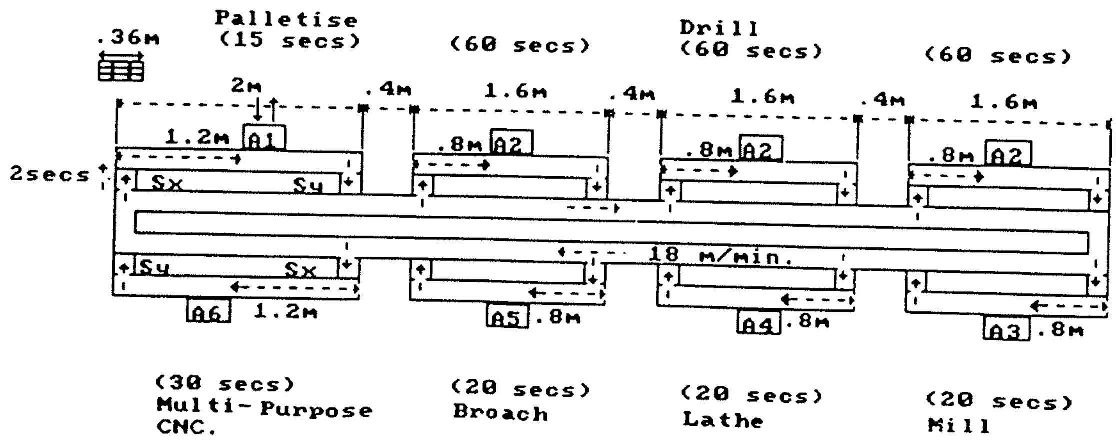
The various Pallet configurations were run in 'Batch Mode' and results of Flowtime, Cycle time and total Throughput (Number of Pallets through system in 8 hrs), recorded for 20, 40 and 60 Pallets in the system. The SIMAN Output Processor was used to produce the graphs and associated confidence interval calculations and correlograms.

(a) Results from the first output show the system becomes congested at the 60 Pallet level (the Loop Conveyor reaches its full capacity). The 20 Pallet & 40 Pallet runs yielded a 919 and 920 Pallet throughput in 8 hrs. The 20 Pallet option is clearly more desirable as the Work in Progress and Flowtimes are halved. More detailed experimentation was necessary around the 20 Pallet figure to see if we could reduce these further.

(b) Figures 1 & 2 are plots of number of pallets in system against Flowrate & Throughput. It was decided 13 Pallets are the optimum as it maintains the throughput of 919 Pallets, yet has the lowest WIP figure and very low Flowtime.

Remarks:

Interpretation of whether the length of Buffer in front of the Work Stations included the space for the Pallet (while being processed) or not could produce different results. This would effect the congestion on the Loop Conveyor, Throughput and Flow times.



SEQUENCE = A1 (Load) | A2 then A3 A4 A5 (A6) | or | A3 A4 A5 (A6) then A2 | A1 (Unload)

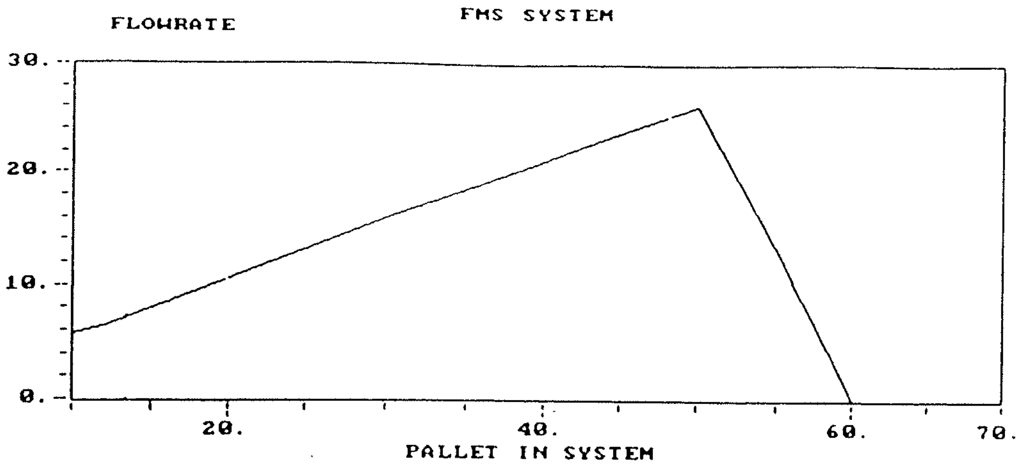


Fig1.

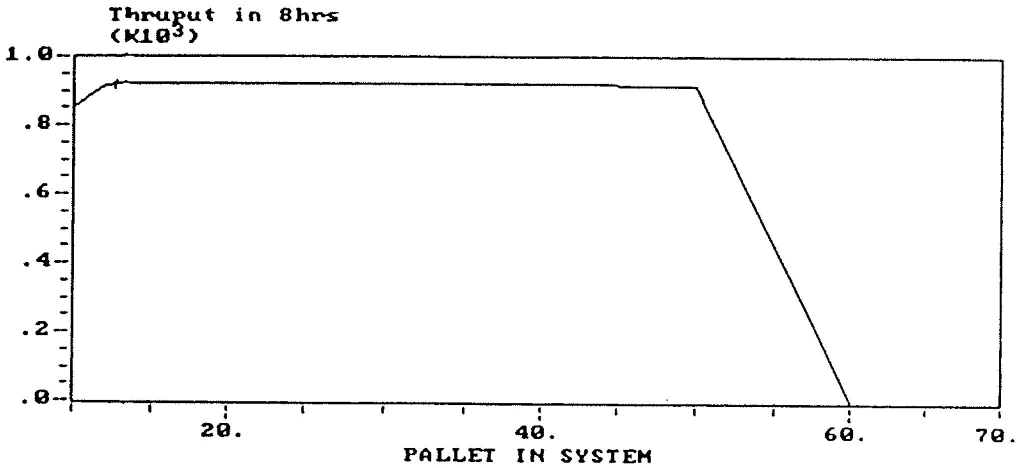


Fig2.

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Fig3.

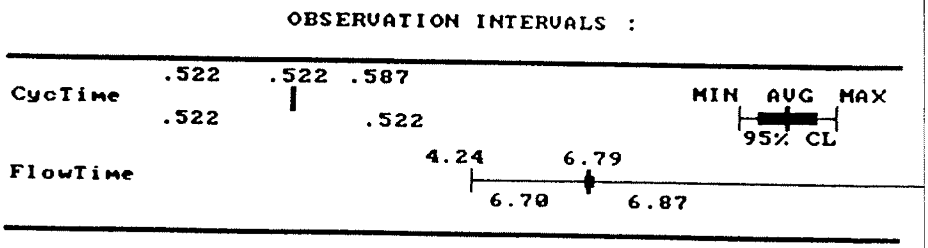

Fig4.

INTERVALS:

IDENTIFIER	AVERAGE	STANDARD DEVIATION	.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBEI OF OB:
CycTime	.522	2.132E-03	1.380E-04	.522	.587	9·
FlowTime	6.79	1.29	8.373E-02	4.24	14.1	9·

Fig5.

```
;
;EUROSIM MODEL WITH ACCUMULATING CONVEYORS
;By John Heffernan   16/04/91
;
;************************************************************************
;
;Arrival Job Section.
;
Loop1    QUEUE,PallInQ;                  !Queue for palletizer.
         SEIZE:Dummy:Worker(1);          !Seize palletizer & Dummy resources.
         ASSIGN:M = Sta1:MARK(ArrTime);  !Set to Station 1.Mark time into system
;
         QUEUE,InQ;                      !Queue for Belt Conveyor 1.
         ACCESS:Belt,NumCells;           !Access belt.
         DELAY:DelTime(1)*(LastSta<>10); !Delay Pallet time (unless new entity)
         RELEASE:Worker(1):Dummy;        !Release first Dummy,then Palletizer.
         CONVEY:Belt,OutSta1;            !Convey to 1st. Shifter. (Sy).
;------------------------------------------------------------------------
;Entrance to all WorkStation Belts.  !Stations 1 - 8

         STATION,InBelt1 - InBelt8;      !Stations to enter Belts 1-8.

         FINDJ,2,4:MIN(BuffLevel(J));    !Find A2 with Minimum Buffer Level.
         ASSIGN:A2Chosen=J;              !Set Variable 'A2Chosen' to = J.

         FINDJ,5,8:MIN(BuffLevel(J)-     !Find A3,4,5 or 6 with Minimum
            ((J==8)*(BuffLevel(8)<>0))!Buffer that hasn't been visited.
               +((A(J-2)==1)*100));!Assign to A345Chosen.Decrement 1 if St
         ASSIGN:A345Chosen=J;            !8 unless Buffer level = 0,as
                                         !Bufferlevel is 1 > 3,4 & 5.

         BRANCH,1:                          !Branch to see if entity can enter
           IF,A(2)==0.AND.                  !this Station.
              ((A(3)+A(4)+A(5)==0).OR.      !If not Drilled,and either none
              (A(3)+A(4)+A(5)==3)).AND.     !or all Process 3,4 or 5 completed
              BuffLevel(A2Chosen)           !& entity at this chosen drill Sta.
              <MaxBuff(A2Chosen).AND.       !(Use Drill Station previously
              M==A2Chosen,PickA2:           !selected).
           IF,(A345Chosen==5.AND.A(3)<>1.AND.!If Process 3,4 or 5 selected &
              BuffLevel(5)<MaxBuff(5)).AND. !at one of these,do this.
              M==A345Chosen.OR.
              (A345Chosen==6.AND.A(4)<>1.AND.
              BuffLevel(6)<MaxBuff(6)).AND.
              M==A345Chosen.OR.
              (A345Chosen==7.AND.A(5)<>1.AND.
              BuffLevel(7)<MaxBuff(7)).AND.
              M==A345Chosen,PickA345:
           IF,(A345Chosen==8.AND.           !If Station 8 selected & not all
              A(3)+A(4)+A(5)<3).AND.        !Processes 3,4 or 5 done & at
              M==A345Chosen,PickA6:         !this Station 8,do this.
           IF,A(2)+A(3)+A(4)+A(5)==4.AND.   !If all Processes complete,exit.
              BuffLevel(1)<MaxBuff(1).AND.
              M==InBelt1,DedPalet:
           ELSE,Loop2;                      !Else, go to next In-Station.
;
PickA2   ASSIGN:BuffLevel(A2Chosen)=        !Increment Buffer Level.
               BuffLevel(A2Chosen)+1:
               NEXT(Trip);
;
PickA345 ASSIGN:BuffLevel(A345Chosen)=      !As above but for Stations 5,6 or
               BuffLevel(A345Chosen)+1:     !7.(Processes 3,4 & 5).
               NEXT(Trip);
;
PickA6   ASSIGN:BuffLevel(8)=BuffLevel(8)+1: !As above but for Station 8.
               NEXT(Trip);
;
DedPalet ASSIGN:BuffLevel(1)=BuffLevel(1)+1: !Pallet at 1st Station,& Unit
               NEXT(Trip);                   !complete & ready to send out.
;
Loop2    CONVEY:Spine,M+1-((M==8)*8);        !Go On to next In-Station until
;                                            !St. 8 - then go to Station 1.
;
Trip     EXIT:Spine,NumCells;            !Exit Spine (Loop Conveyor).
         ROUTE:ShifTime,M + 8;           !Shift across to enter Belt.(Sx).
;------------------------------------------------------------------------
;Convey up to Process Area.  !Stations 9 - 16
;
         STATION,InSta1 - InSta8;        !Stations for start of all Belts.
         QUEUE,M;                        !Queue for respective Belt.
         ACCESS:Belt,NumCells;           !Access that Belt.
         CONVEY:Belt,((M+8)*(M<>InSta1))!Convey on belt up to Process station.
                  +((M==InSta1)*41);     !If at In - Station 1,Convey to Dummy
;                                        !Station 41.
;------------------------------------------------------------------------
;Dummy Process Station Prior InStation 1.!Station 41
         STATION,DumSta;                 !This ensures circulating entities
         QUEUE,DumQ;                     !have 2nd priority to seize Palletize
         SEIZE:Dummy;                    !Process.Once the dummy resource is
         CONVEY:Belt,Sta1;               !seized the pallet can convey to St.1
;------------------------------------------------------------------------
;Process Stations.  !Stations 17 - 24
;
         STATION,Sta1 - Sta8;            !Stations for processes.
         QUEUE,M;                        !Queue for respective Workstation.
         SEIZE:Worker(M-16);             !Seize respective Workstation.
         ASSIGN:BuffLevel(M-16)=         !Reduce Buffer Level (on Conveyor
               BuffLevel(M-16)-1;        !leading to WorkStation) by 1.
;
         BRANCH,1:
           IF,M==Sta8.AND.A(3)==0,Del1: !Branch statement to determine the
           IF,M==Sta8.AND.A(4)==0,Del2: !Process time.If at Multi-Purpose
           IF,M==Sta8.AND.A(5)==0,Del3: !Station 8,& one of Processes 3,4 or 5
           IF,M==Sta2.OR.M==Sta3.OR.    !not done,do these.If at one of drill-
              M==Sta4,Del4:             !ing stations,drill.If at 1st Station
           IF,M==Sta1,Del5:             !Palletise.Else at Station 5,6 or 7.
           ELSE,Del6;
;
Del1     ASSIGN:A(3)=1:A(1)=A(1)+2:      !Set A(3) (Process 3 to be executed)
               ProcessTime=DelTime(5):   !Set Icon & assign Process time.
               NEXT(Process);
Del2     ASSIGN:A(4)=1:A(1)=A(1)+5:      !As above,but for Process 4.
               ProcessTime=DelTime(6):
               NEXT(Process);
Del3     ASSIGN:A(5)=1:A(1)=A(1)+10:     !As above,but for Process 5.
               ProcessTime=DelTime(7):
               NEXT(Process);
Del4     ASSIGN:A(2)=1:A(1)=A(1)+1:      !As above,but for Process 2.
               ProcessTime=DelTime(2):
               NEXT(Process);
Del5     ASSIGN:A(2)=0:A(3)=0:A(4)=0:    !Reset all attribs.so pallet c
               A(5)=0:                   !cycle,set Palletise time.
               ProcessTime=DelTime(1):
               NEXT(Process);
Del6     ASSIGN:A(M-18)=A(M-18)+1:       !Set A(3),A(4) or A(5) dependi
               A(1)=A(1)+((M==21)*2)+    !Process.Set Icon according to
               ((M==22)*5)+((M==23)*10):
               ProcessTime=DelTime(M-16);
;
Process  DELAY:ProcessTime;              !Delay by Process time.
         ASSIGN:A(1)=(A(1)*(M<>17))+     !If M = station A1,set.
                    ((M==17)*100);       !to 100,else leave.
;
         BRANCH,2:                       !Pallets that have just circul
           IF,A(1)==100,OldPal:          !sent out of the system via th
           IF,A(1)==100,OldPal1:         !Palletizer.
           ELSE,NewPal;
;
OldPal   EXIT:Belt,NumCells;                 !Exit Belt.
         TALLY:FlowTime,Int(ArrTime);        !Record FlowTime & Cycle t
         TALLY:CycTime,Between:NEXT(Loop1);  !Pallets.Send back to recyc
OldPal1  RELEASE:Dummy:Worker(M-16):DISPOSE;!Release Palletizer & Dummy
;                                            !then kill entity.
NewPal   RELEASE:Worker(M-16);           !Release respective Workstation
         CONVEY:Belt,M+8;                !Convey to end of Belt.
;------------------------------------------------------------------------
;All Out - Shifters (Sy's)  !Stations 25 - 32
;
         STATION,OutSta1 - OutSta8;      !Stations at end of Belt.
         ASSIGN:M=M+8;                   !Reset to Stations 33 - 40 (on S
         QUEUE,M-8;                      !Queue for Spine Conveyor.
         ACCESS:Spine,NumCells;          !Access Spine with the reqd. 10
         EXIT:Belt,NumCells;             !Exit Belt Conveyor releasing 10
         DELAY:ShifTime,M-32;            !Delay transfer time on Sy (2 se
;                                        !Put Symbol in Storage 1 - 8.
;------------------------------------------------------------------------
;Stations on Spine - after Sy Shift.     !Stations 33 - 40
;
         STATION,OutBelt1 - OutBelt8;    !Stations entering Spine.
;
         ASSIGN:A(6)=M-32;               !Set LastSta attrib. to last Stat
;                                        !Visited.
         CONVEY:Spine,M-31-((M==40)*8);  !Convey to next In - Station.
;
;------------------------------------------------------------------------
END;
```

```
BEGIN,
;
;EUROSIM EXPERIMENTAL FRAME WITH ACCUMULATING CONVEYORS
;
PROJECT, EuroSim Accum Conv,JK;
;                                                 !Icon = animation attribute.
ATTRIBUTES: Icon:A2Job:A3Job:A4Job:A5Job:LastSta: !A2Job-A5Job = Process flags.
           ArrTime;                               !LastSta = previous Wrk.Stn.
;                                                 !ArrTime = Time into System.
;
ARRIVALS:   1,BLOCK(1),0,30,100,,,,,10,;!Send arriving entities to Que PallInQ.
;                                    !20,40 or 60 arriving pallets.
;                                    !Set A(1) to = 100.A(6) ie.LastSta = 10.
;                                    !so this is set as an incoming Pallet.
;
VARIABLES:  DelTime(8),0.25,1,1,1,0.33333,0.33333,0.33333,0.5:!Process delays.
           BuffLevel(8),0:           !Current Buffer Levels.
           MaxBuff(8),3,2,2,2,2,2,2,3: !Max.Buffer Levels for Process Stations
           ProcessTime,0:            !Set to Process times.
           NumCells,9:               !(10 * 0.04m = UnAccumulated 0.4m)
           ShifTime,0.033333:        !Time to shift a/c Sx & Sy = 2 Secs.
           A2Chosen,0:               !Varible for A2 Station to Convey
           A345Chosen,0;             !to ,A345 = Chosen 3,4 or 5 Station.
;
STATIONS:   InBelt1:InBelt2:InBelt3:InBelt4:        !Stations.
           InBelt5:InBelt6:InBelt7:InBelt8:
           InSta1:InSta2:InSta3:InSta4:
           InSta5:InSta6:InSta7:InSta8:
           Sta1:Sta2:Sta3:Sta4:
           Sta5:Sta6:Sta7:Sta8:
           OutSta1:OutSta2:OutSta3:OutSta4:
           OutSta5:OutSta6:OutSta7:OutSta8:
           OutBelt1:OutBelt2:OutBelt3:OutBelt4:
           OutBelt5:OutBelt6:OutBelt7:OutBelt8:
           DumSta;
;
QUEUES:     InBelt1Q:InBelt2Q:InBelt3Q:InBelt4Q:  !Queues.
           InBelt5Q:InBelt6Q:InBelt7Q:InBelt8Q:
           InSta1Q:InSta2Q:InSta3Q:InSta4Q:
           InSta5Q:InSta6Q:InSta7Q:InSta8Q:
           Sta1Q:Sta2Q:Sta3Q:Sta4Q:
           Sta5Q:Sta6Q:Sta7Q:Sta8Q:
           OutBelt1Q:OutBelt2Q:OutBelt3Q:OutBelt4Q:
           OutBelt5Q:OutBelt6Q:OutBelt7Q:OutBelt8Q:
           PallInQ:InQ:DumQ;
;
RESOURCES   Worker(8),1:                           !8 * Process Stations.
           Dummy;                                 !1 Dummy resource.
;
CONVEYORS:  Belt, 1,450,1,Active,9,Accum,9:       !Conveyor Spec.
           Spine,2,450,1,Active,9,Accum,9;
;
SEGMENTS:
      1,InSta1,DumSta-21,Sta1-9,OutSta1-11,      !Station to Station distances
        InSta2-19,Sta2-20,OutSta2-11,            !for Conveyors.
        InSta3-19,Sta3-20,OutSta3-11,
        InSta4-19,Sta4-20,OutSta4-11,            !Belt Conveyors.
        InSta5-10,Sta5-20,OutSta5-11,
        InSta6-19,Sta6-20,OutSta6-11,
        InSta7-19,Sta7-20,OutSta7-11,
        InSta8-19,Sta8-30,OutSta8-11:
      2,InBelt1,OutBelt1-41,InBelt2-19,OutBelt2-31,
        InBelt3-19,OutBelt3-31,InBelt4-19,OutBelt4-31,
        InBelt5-9,OutBelt5-31,InBelt6-19,OutBelt6-31,
        InBelt7-19,OutBelt7-31,InBelt8-19,OutBelt8-41,
        InBelt1-9;
;
TALLIES:FlowTime:                                 !Record time through sys
       CycTime;                                   !& Cycle time of Pallets
;
OUTPUTS:TAVG(FlowTime),"D:\EUROSIM\Flow30.Dat":   !Output to respective fi
       TAVG(CycTime),"D:\EUROSIM\Cyc30.Dat";
;
LAYOUTS:"EurSim.Lay",Icon,0.001;                  !Name of Layout screen.
;
REPLICATE,1,0.0,600,Yes,Yes,120;                  !Experimentation run leng
;                                                 !Remove 1st 120 mins Warm
;
END;
```

Comparison 2 - SLAM II

Short description of the simulation environment used

SLAM II is one of the most popular simulation languages available: it has been developed by Pritsker Corp. during the 70's, and then constantly improved. SLAM II is a discrete-event oriented language, but it includes a network-oriented approach and continuous features as well. For discrete systems modeling with SLAM II, indeed, the network approach is the most direct one. A SLAM II graphic network is a graph with nodes and arrows: the nodes represent typical functions such as queuing points, and the arrows connecting them stand for delays and/or routings. In early versions of SLAM II the graphic network was described in a normal textual form, but in the last years, MS-Windows and OS/2 Presentation Manager versions became available, including a graphic network editor, and a powerful animation building system.

Work description

The model was described with the SLAM II language on an Olivetti PC (with 80386/387 20 MHz) with OS/2. An average simulation run of the model (8 hours) lasts approximately 9 minutes.

The model includes a network (the source is included), with all the conveyor lines modeled as resources. The dynamic entities (pallets) go through them during the simulation, by means of a main loop in the network in which the current resource is incremented: so, we need to define only once the basic submodel, as we can parametrize it. The next resource than an entity needs to go through is allocated by a user function ALLOC that let wait if it is not possible: so the control strategy is implemented in a very simple, readable, and straightforward manner.

Results

We have conducted many experiments with the model, all of them for a time of eight hours, and collecting statistics for the last six, as suggested.

A table is included that summarizes the average throughput time (cycle time) and the total throughput, as well as as the average time in system and the average number of laps for the pallets, for the most interesting experiments (the parameter that changes through experiments is the total number of pallets).

One can see that we found a threshold number of pallets, beyond which the system gets blocked because there are some pallets that cannot go their way in the B1 line even if there could be the theoretical alternative of making it go through B2 without being worked by the machine, but the proposed model didn't provide such a deadlock solving rule.

Number of pallets	Average throughput time (cycle time)	Total throughput (in 6 hours)	Average time in system	Average number of laps
[pure number]	[s]	[pallets]	[s]	[pure number]
10	24.00	900.00	240.00	1.00
14	21.00	1028.00	294.00	1.38
15	20.30	1062.00	305.00	1.49
16	20.00	1080.00	320.00	1.72
17	20.00	1078.00	340.00	2.09
18	20.00	1080.00	360.00	2.45
19	20.00	1081.00	380.00	2.82
20	20.00	1082.00 *	400.00	3.37
30	20.00	1080.00	540.00	6.00
40	20.00	1080.00	800.00	10.70
50	Blocked within the first two hours			
60	Blocked within the first two hours			

(*) Different from the following in spite of the same cycle time, because the cycle times were rounded at two decimal digits

```
;------------------------------------------------------------------------
;      MAIN NETWORK FLOW
;------------------------------------------------------------------------
; CREATION OF A PREDEFINED NUMBER OF PALLETS
ZAAB  CREATE,,,1,1;
      ACTIVITY;
      ASSIGN,PALLETS=PALLETS-1,2;
      ACTIVITY;
      ACTIVITY,20,PALLETS.GT.0,ZAAB;
;
; ATTRIBUTES INITIALIZATION
ASS1  ASSIGN,OP2=0,OP3=0,OP4=0,OP5=0;
      ACTIVITY;
ASS2  ASSIGN,STATION=1,PREC=16,UP=0;
      ACTIVITY;
;
; OBTAIN THE FIRST RESOURCE FOR THE FIRST TIME
AW0   AWAIT(9),PREC/36;
      ACTIVITY/9;
;
; MAIN LOOP
; OBTAIN THE NEXT RESOURCE, WAITING IN A QUEUE NUMBERED AS THE CURRENT STATIC
; NUMBER, WITH PRIORITY (PREVIOUSLY DECLARED) FOR PALLETS COMING FROM 'UP',
; I. E. THOSE WITH ATRIB(7)=1
; (ALLOC IS THE FORTRAN-WRITTEN NEXT RESOURCE SELECTION RULE)
LOOP  AWAIT(STATION=1,8),ALLOC(1);
      ACTIVITY/10;
PREC  FREE,PREC/36,1;
; SELECT WHERE TO GO, DEPENDING ON ATTRIBUTE UP
      ACTIVITY/STATION=1,8,SPACE/SPEED+SHIFTIME+TRASFA/SPEED,UP.EQ.1;
      ACTIVITY/11,SPACE/SPEED+TRASFB/SPEED,UP.EQ.0,INCR;
; 'UP' SIDE: PASS THROUGH THE MACHINE, OBTAINING THE RELATED RESOURCES
AWMAC AWAIT(MACHINE=25,32),MACHINE,,1;
      ACTIVITY,WTIME,STATION.EQ.1;
      ACTIVITY,WTIME,,AWBU;
; STATISTICS COLLECTION AT THE STATION 1 PASSAGE (OPERATION END FOR THE PALLE
      COLCT(1),BET,CYCLE TIME;
      ACTIVITY;
      COLCT(2),INT(1),TIME IN SYSTEM;
      ACTIVITY;
      COLCT(3),LAPS,NUMBER OF LAPS,10/0.0/1.0;
      ACTIVITY;
; ATTRIBUTE RESET: THE ENTITY BECOMES A 'NEW' PALLET
RST0  ASSIGN,MARK=TNOW,LAPS=0;
      ACTIVITY;
RST1  ASSIGN,OP2=0,OP3=0,OP4=0,OP5=0;
      ACTIVITY,,,AWBUF;
AWBUF AWAIT(BUFFER=17,24),BUFFER/36;
      ACTIVITY;
CURR  FREE,CURR/36;
      ACTIVITY;
MACH  FREE,MACHINE;
      ACTIVITY;
      ASSIGN,CURR=BUFFER;
      ACTIVITY.TRASFC/SPEED+SHIFTIME,,INCR;
```

Part of the model description

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```
;------------------------------------------------------------------------
; CONTROL FILE (VARIABLES EQUIVALENCES AND INITIALIZATIONS)
;------------------------------------------------------------------------
GEN,SIMGROUP,EUROSIM,16/05/1991,1,Y,Y,Y/Y,Y,Y/1,132;
;
;TIMES IN SECONDS, LENGHTS IN CM
;
LIMITS,32,12,100;
;
; DYNAMIC ENTITIES (PALLETS) ATTRIBUTES
EQUIVALENCE/ATRIB(1),MARK;      CYCLE ENTERING TIME
EQUIVALENCE/ATRIB(2),OP2;       FLAG FOR OPER. 2 (1=ALREADY DONE, ELSE 0)
EQUIVALENCE/ATRIB(3),OP3;       FLAG FOR OPER. 3 (1=ALREADY DONE, ELSE 0)
EQUIVALENCE/ATRIB(4),OP4;       FLAG FOR OPER. 4 (1=ALREADY DONE, ELSE 0)
EQUIVALENCE/ATRIB(5),OP5;       FLAG FOR OPER. 5 (1=ALREADY DONE, ELSE 0)
EQUIVALENCE/ATRIB(6),STATION;   NUMBER OF CURRENT STATION (BASIC SUBMODEL)
EQUIVALENCE/ATRIB(7),UP;        TELLS IF IT SHOULD GO THROUGH THE MACHINE
EQUIVALENCE/ATRIB(8),CURR;      CURRENT RESOURCE (CONVEYOR LINE) USED
EQUIVALENCE/ATRIB(9),PREC;      OLD RESOURCE (CONVEYOR LINE) USED
EQUIVALENCE/ATRIB(10),MACHINE;  MACHINE RESOURCE NUMBER (SET ONLY IF UP=1)
EQUIVALENCE/ATRIB(11),BUFFER;   CONVEYOR LINE AFTER MACHINE (SET ONLY IF UP=1)
EQUIVALENCE/ATRIB(12),LAPS;     NUMBER OF CIRCUIT LAPS CURRENTLY DONE
;
; WORK TIMES
ARRAY(1,8)/15,60,60,60,20,20,20,30;
; A-LINES LENGHTS (CONVEYORS BEFORE MACHINES)
ARRAY(2,8)/120,80,80,80,80,80,80,120;
; B-LINES LENGHTS (CONVEYORS THAT DOESN'T PASS THROUGH THE MACHINES)
ARRAY(3,8)/200,160,160,160,160,160,160,200;
; C-LINES LENGHTS (CONVEYORS AFTER MACHINES)
ARRAY(4,8)/80,80,80,80,80,80,80,80;
;SPACES BETWEEN STATIONS
ARRAY(5,8)/0.0,40,40,40,0.0,40,40,40;
;
; TIMES AND DISTANCES PARAMETRIZED BY THE STATION NUMBER
EQUIVALENCE/ARRAY(1,STATION),WTIME;
EQUIVALENCE/ARRAY(2,STATION),TRASFA;
EQUIVALENCE/ARRAY(3,STATION),TRASFB;
EQUIVALENCE/ARRAY(4,STATION),TRASFC;
EQUIVALENCE/ARRAY(5,STATION),SPACE;
;
EQUIVALENCE/XX(1),SPEED/XX(2),SHIFTIME/XX(3),PALLETS;
INTLC,SPEED=30,SHIFTIME=2;
;
; PRIORITIES FOR ENTITIES COMING OUT FROM THE MACHINE CONVEYOR LINES,
; THAT IS, THOSE WHO HAVE ATRIB(7) (UP) SET TO 1
PRIORITY/1,HVF(7)/2,HVF(7)/3,HVF(7)/4,HVF(7);
PRIORITY/5,HVF(7)/6,HVF(7)/7,HVF(7)/8,HVF(7);
;
STAT,4,NUMB. OF PALLETS;
NETWORK;
;
; EXPERIMENT DURATION (28800 s = 8 h)
; (THE STATISTICS RESET AFTER THE FIRST TWO IS DEFINED ELSEWHERE)
INITIALIZE,,28800,Y;
;
FIN;
;------------------------------------------------------------------------
; NETWORK DESCRIPTION
;------------------------------------------------------------------------
; RESOURCE (CONVEYOR LINES AND MACHINES) DESCRIPTION
;
       RESOURCE/ 1,BA1 (120), 1;
       RESOURCE/ 2,BA21( 80), 2;
       RESOURCE/ 3,BA22( 80), 3;
       RESOURCE/ 4,BA23( 80), 4;
       RESOURCE/ 5,BA3 ( 80), 5;
       RESOURCE/ 6,BA4 ( 80), 6;
       RESOURCE/ 7,BA5 ( 80), 7;
       RESOURCE/ 8,BA6 (120), 8;
       RESOURCE/ 9,BB1 (200), 1;
       RESOURCE/10,BB21(160), 2;
       RESOURCE/11,BB22(160), 3;
       RESOURCE/12,BB23(160), 4;
       RESOURCE/13,BB3 (160), 5;
       RESOURCE/14,BB4 (160), 6;
       RESOURCE/15,BB5 (160), 7;
       RESOURCE/16,BB6 (200), 8,9;
```

```
      RESOURCE/18,BC21 (80),18;
      RESOURCE/19,BC22 (80),19;
      RESOURCE/20,BC23 (80),20;
      RESOURCE/21,BC3  (80),21;
      RESOURCE/22,BC4  (80),22;
      RESOURCE/23,BC5  (80),23;
      RESOURCE/24,BC6  (80),24;
;
; MACHINES
;
      RESOURCE/25,A1       ,25;
      RESOURCE/26,A21      ,26;
      RESOURCE/27,A22      ,27;
      RESOURCE/28,A23      ,28;
      RESOURCE/29,A3       ,29;
      RESOURCE/30,A4       ,30;
      RESOURCE/31,A5       ,31;
      RESOURCE/32,A6       ,32;
;---------------------------------------------------------------------
;     MAIN NETWORK FLOW
;---------------------------------------------------------------------
; CREATION OF A PREDEFINED NUMBER OF PALLETS
ZAAB  CREATE,,,1,1;
      ACTIVITY;
      ASSIGN,PALLETS=PALLETS-1,2;
      ACTIVITY;
      ACTIVITY,20,PALLETS.GT.0,ZAAB;
;
; ATTRIBUTES INITIALIZATION
ASS1  ASSIGN,OP2=0,OP3=0,OP4=0,OP5=0;
      ACTIVITY;
ASS2  ASSIGN,STATION=1,PREC=16,UP=0;
      ACTIVITY;
;
; OBTAIN THE FIRST RESOURCE FOR THE FIRST TIME
AW0   AWAIT(9),PREC/36;
      ACTIVITY/9;
;
; MAIN LOOP
; OBTAIN THE NEXT RESOURCE, WAITING IN A QUEUE NUMBERED AS THE CURRENT STATION
; NUMBER, WITH PRIORITY (PREVIOUSLY DECLARED) FOR PALLETS COMING FROM 'UP',
; I. E. THOSE WITH ATRIB(7)=1
; (ALLOC IS THE FORTRAN-WRITTEN NEXT RESOURCE SELECTION RULE)
LOOP  AWAIT(STATION=1,8),ALLOC(1);
      ACTIVITY/10;
PREC  FREE,PREC/36,1;
; SELECT WHERE TO GO, DEPENDING ON ATTRIBUTE UP
      ACTIVITY/STATION=1,8,SPACE/SPEED+SHIFTIME+TRASFA/SPEED,UP.EQ.1;
      ACTIVITY/11,SPACE/SPEED+TRASFB/SPEED,UP.EQ.0,INCR;
; 'UP' SIDE: PASS THROUGH THE MACHINE, OBTAINING THE RELATED RESOURCES
AWMAC AWAIT(MACHINE=25,32),MACHINE,,1;
      ACTIVITY,WTIME,STATION.EQ.1;
      ACTIVITY,WTIME,,AWBU;
; STATISTICS COLLECTION AT THE STATION 1 PASSAGE (OPERATION END FOR THE PALLET)
      COLCT(1),BET,CYCLE TIME;
      ACTIVITY;
      COLCT(2),INT(1),TIME IN SYSTEM;
      ACTIVITY;
      COLCT(3),LAPS,NUMBER OF LAPS,10/0.0/1.0;
      ACTIVITY;
; ATTRIBUTE RESET: THE ENTITY BECOMES A 'NEW' PALLET
RST0  ASSIGN,MARK=TNOW,LAPS=0;
      ACTIVITY;
RST1  ASSIGN,OP2=0,OP3=0,OP4=0,OP5=0;
      ACTIVITY,,,AWBUF;
AWBUF AWAIT(BUFFER=17,24),BUFFER/36;
      ACTIVITY;
CURR  FREE,CURR/36;
      ACTIVITY;
MACH  FREE,MACHINE;
      ACTIVITY;
      ASSIGN,CURR=BUFFER;
      ACTIVITY,TRASFC/SPEED+SHIFTIME,,INCR;
; 'DOWN' SIDE: DO NOT PASS THROUGH THE MACHINE
; UPDATE STATION NUMBER (IF IT BECOMES 9 THEN IT'S RESET TO 1)
INCR  ASSIGN,PREC=CURR,STATION=STATION+1,1;
      ACTIVITY,,STATION.EQ.9;
```

```
      ACTIVITY,,,LOOP;
      ASSIGN,STATION=1,LAPS=LAPS+1;
; BACK TO THE LOOP
      ACTIVITY,,,LOOP;
      END;

C-----------------------------------------------------------------------
      SUBROUTINE ALLOC(I,IFLAG)
C-----------------------------------------------------------------------
$INCLUDE:'PARAM.INC'
$INCLUDE:'SCOM1.COM'
$INCLUDE:'PARAM.USR'

      LOGICAL GOMACHINE,A,B,G

C-----------------------------------------------------------------------
      GOMACHINE=.FALSE.

C-----------------------------------------------------------------------
      IF (STATION.EQ.1) THEN

         IF (OP2*OP3*OP4*OP5.EQ.1) GOMACHINE=.TRUE.

C-----------------------------------------------------------------------
      ELSE IF (STATION.EQ.2.OR.STATION.EQ.3.OR.STATION.EQ.4) THEN

         IF ((OP2.EQ.0).AND.
     +       ((OP3+OP4+OP5.EQ.3).OR.(OP3*OP4*OP5.EQ.0))) THEN
            OP2=-1
            GOMACHINE=.TRUE.
         ENDIF

C-----------------------------------------------------------------------
      ELSE IF (STATION.EQ.5) THEN

         IF (OP3.EQ.0) THEN
            OP3=-1
            GOMACHINE=.TRUE.
         ENDIF

C-----------------------------------------------------------------------
      ELSE IF (STATION.EQ.6) THEN

         IF (OP4.EQ.0) THEN
            OP4=-1
            GOMACHINE=.TRUE.
         ENDIF

C-----------------------------------------------------------------------
      ELSE IF (STATION.EQ.7) THEN

         IF (OP5.EQ.0) THEN
            OP5=-1
            GOMACHINE=.TRUE.
         ENDIF
      ELSE IF (STATION.EQ.8) THEN

         IF (OP3*OP4*OP5.EQ.0) GOMACHINE=.TRUE.
         IF (OP3.EQ.0) THEN
            OP3=-1
         ELSE IF (OP4.EQ.0) THEN
            OP4=-1
         ELSE IF (OP5.EQ.0) THEN
            OP5=-1
         ENDIF

      ELSE

         WRITE(*,*) 'ERROR'
         STOP

      ENDIF
      ISTATION=STATION
      A=NNRSC(ISTATION).GE.36        ! CONVEYOR BEFORE THE MACHINE FREE
```

```
      B=NNRSC(8+ISTATION).GE.36     ! LOWER CONVEYOR FREE
      G=GOMACHINE                   ! IT SHOULD GO THROUGH THE MACHINE

      IF (A.AND.G) THEN
         UP=1                       ! FLAG: IT MUST GO THROUGH THE MACHINE
         CURR=STATION               ! CONVEYOR BEFORE THE MACHINE (RES.)
         MACHINE=24+STATION         ! MACHINE RESOURCE NUMBER
         BUFFER=16+STATION          ! CONVEYOR AFTER THE MACHINE (RES.)
         IF (OP2.LT.0) OP2=-OP2
         IF (OP3.LT.0) OP3=-OP3
         IF (OP4.LT.0) OP4=-OP4
         IF (OP5.LT.0) OP5=-OP5
      ELSE IF (B) THEN
         UP=0                       ! FLAG: IT MUST GO AHEAD
         CURR=8+STATION             ! CONVEYOR RESOURCE NUMBER
         MACHINE=0
         BUFFER=0
         IF (OP2.LT.0) OP2=0
         IF (OP3.LT.0) OP3=0
         IF (OP4.LT.0) OP4=0
         IF (OP5.LT.0) OP5=0
      ELSE                          ! IF IT CAN'T GO ON...
         IFLAG=0                    ! UNDO ATRIB MODIFICATIONS (IFLAG=0)
         RETURN                     ! AND KEEP WAITING
      ENDIF
      ICURR=CURR
      CALL SEIZE(ICURR,36)          ! ALLOCATE 36 CM OF CONVEYOR
      IFLAG=1                       ! KEEP ATRIB CHANGES

      RETURN

C-------------------------------------------------------------------------
      END
C-------------------------------------------------------------------------
```

Comparison 2 - Micro Saint

Micro Saint is a full-featured, discrete event simulation software tool that includes iconic animation. It is designed to simulate any type of process that consists primarily of discrete activities (e.g., manufacturing systems, service systems, human-machine systems), although it includes features for limited continuous modeling. In Micro Saint, users interact with menus or graphical interface elements such as windows and dialog boxes to create their models (which are compiled automatically during model execution).

The activity network for the FAS model includes 51 activities in all, 24 of which are in subnetworks. Figure 1 shows the Micro Saint user interface and diagrams for the main network and the A1 subnetwork. The queues at the reentry points in the main network are sorted to ensure that reentering parts have priority, while the subnetwork queues representing waiting lines for each station are designated as First In, First Out (FIFO).

The constraints, timing, effects, and routing logic for each activity (or "task") are defined by expressions and menu choices.

Assumptions made in building the model

- The buffers in front of each station function as FIFO queues, with buffer length limiting queue size according to the following formula: buffer length/pallet length = max queue size
- A pallet moving along conveyer belt B1 can be paused momentarily if it reaches an Sy station at the same time as a pallet switching over from a B2 belt, which has priority.
- Station A6 emulates A3 if A3 is needed, otherwise A4 if A4 is needed, otherwise A5.
- The operation at station A1 is either loading or unloading, each of which takes 15 seconds.

The last assumption in the preceding list is not one we felt entirely comfortable with, since it makes A1 into a bottleneck station, but it seemed the most reasonable interpretation of the information provided (i.e., "Unprocessed parts are put on pallets in A1," "Finished parts are unloaded in A1," and the 15-second operation time for A1).

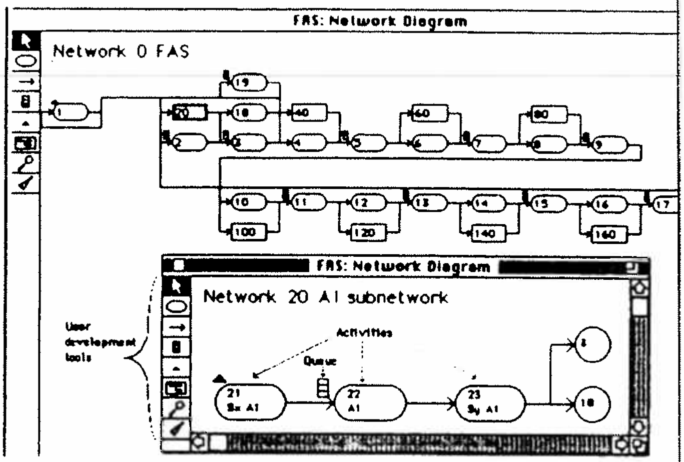
Results of running the model with 20, 40, and 60 pallets

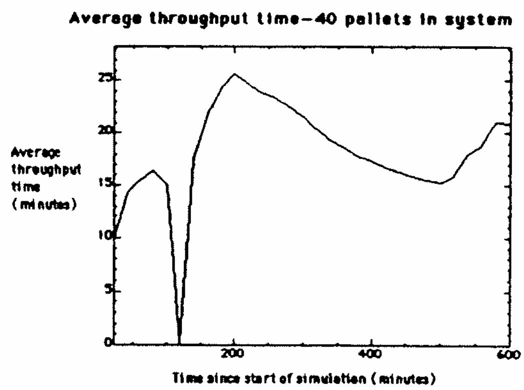
- Throughput stayed the same (2 parts output per minute) in all cases because task A1 (the entry and exit point, according to our assumption) acts as a bottleneck. Task A1 takes 15 seconds, so 4 parts can go through A1 every minute. Because a new part comes in through A1 for every part that leaves through A1, 2 of the 4 parts are coming in and 2 are going out.
- Average throughput time per part between the 120th and 600th minute increases when more parts are added to the system, as follows: 10.05 minutes for 20 parts in the system; 20.97 minutes for 40 parts; and 30.38 minutes for 60 parts.

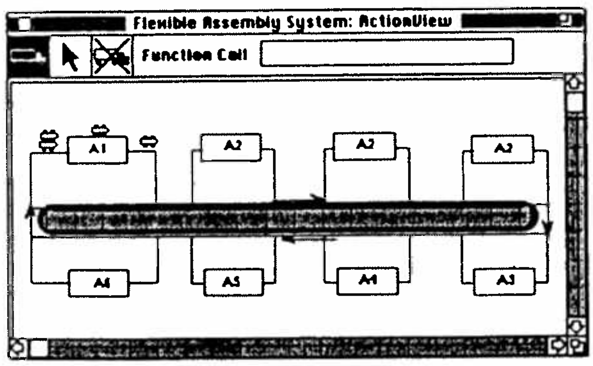
The graph in Figure 2, generated in Micro Saint, shows how average throughput time changed over the course of the simulation with 40 pallets in the system. The dip at time 120 occurs because the values used to calculate the average were zeroed at that point.

Development and execution times

- The model required 14 hours to design and develop and 11 hours to debug, generate graphs, and analyze data. We also spent 8 hours developing an iconic animation of the model for demonstration purposes (shown in Figure 3), but this animation was not necessary for data gathering or analysis.
- The model execution time varied depending upon the number of parts in the system. With 20 parts in the system, the model executed in 6 minutes on an i486 IBM PC compatible operating at 33 Mhz. With 60 parts in the system the model executed in 19 minutes on the same computer.







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Flexible Assembly System Model Comparison—Micro Saint

Micro Saint is a full-featured, discrete event simulation software tool that includes iconic animation. It is designed to simulate any type of process that consists primarily of discrete activities, although it includes features for limited continuous modeling. Micro Saint has been successfully used to analyze a variety of processes including manufacturing systems, service systems (e.g., hospitals, banks), and human-machine systems.

Micro Saint has a built-in compiler that allows users to create complex code without the need for any external language. Instead, users interact with menus or graphical user interface (GUI) elements such as windows and dialog boxes, and compilation occurs automatically during model execution. Within this easy-to-use interface, users can develop activity networks, define how activities and queues operate, define and manipulate variables that represent system characteristics, develop optional iconic animations, run models, and generate statistical summaries and graphs from collected data. While running a model, users can select from menus or open multiple windows to view and manipulate different aspects of the model as it runs. They can also watch the activities illuminate on the network diagram as they occur or watch a graphical, iconic animation of the process if one was developed (see Figure 4).

The activity network for the FAS model includes 51 activities—27 in the main network (of which 8 are subnetworks, representing the processing stations), and 24 in the subnetworks (3 per subnetwork). Figure 1 shows the Micro Saint user interface and diagrams for the main network and the A1 subnetwork. The queues at the reentry points in the main network are sorted to ensure that reentering parts have priority, while the queues in the subnetworks (where parts wait to be processed by each station) are designated as First In, First Out (FIFO).

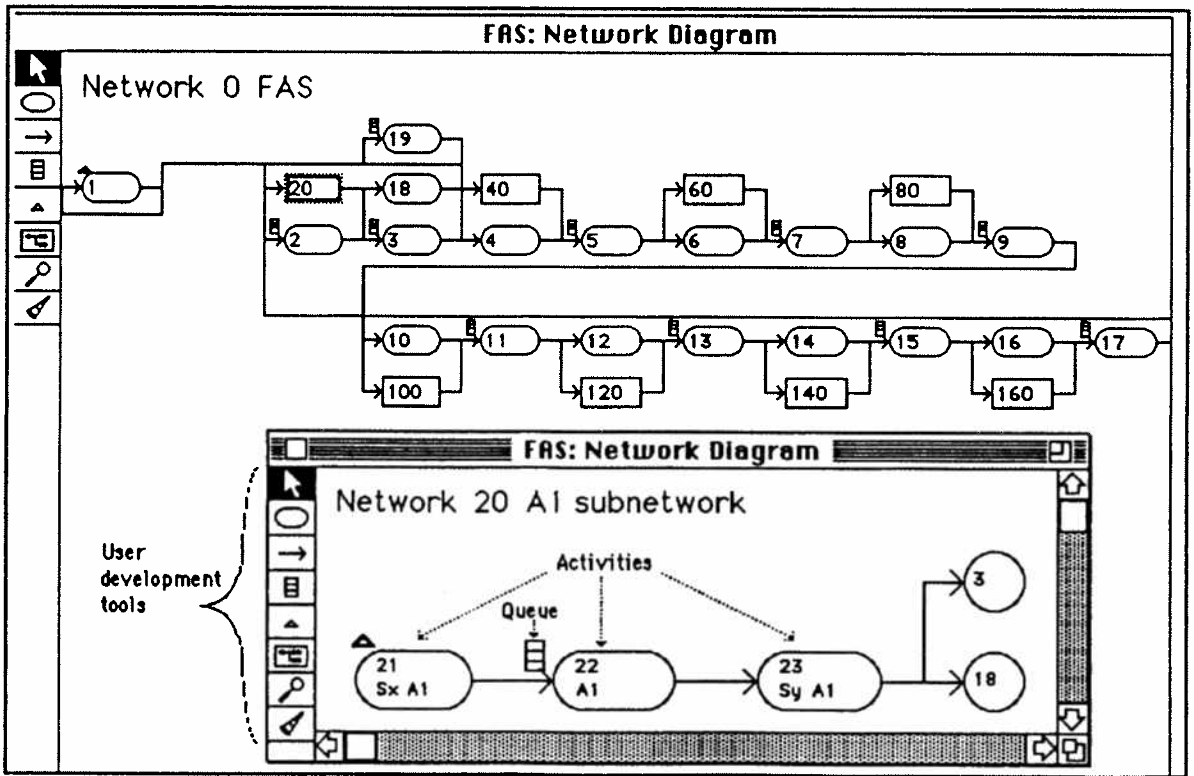

Figure 1

The constraints, timing, effects, and routing logic for each activity (or "task") are defined by expressions and menu choices, as shown in Figure 2 for task #11. This task represents movement along the section of conveyer belt B1 between stations A3 and A4. Because of the release condition for this task, no part can enter until enough time has elapsed to make space available on the conveyer belt. Note how the "Tactical" decision type and subsequent expressions determine whether a part should go into the A4 subnetwork or bypass it; the part will go to A4 only if it has not yet been processed at A4 and there is room for it in the queue in front of A4. Tag values and an array called "A4done" are used to identify the different parts and keep track of whether they have been processed by A4.

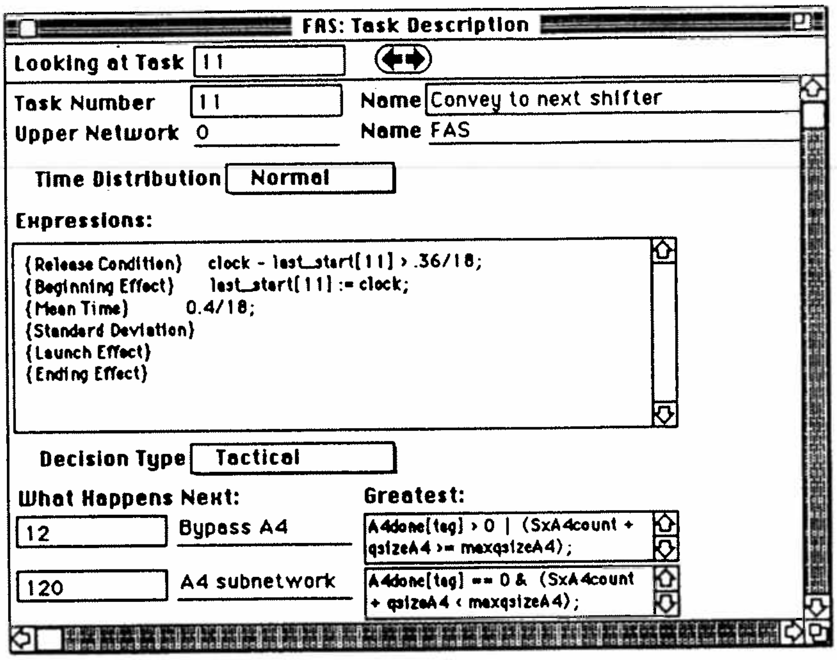

Figure 2

The sections that follow describe the assumptions we made in building our FAS model, the results of running the model with 20, 40, and 60 pallets, and the development and execution times for the model.

Assumptions made in building the model

- The buffers in front of each station function as FIFO queues, with the buffer length limiting the queue size according to the following formula:

  (length of buffer)/(length of pallet) = maximum queue size

  For example, .8/.36 = 2.2, so the queues in front of A2, A3, A4, and A5 can contain only two pallets at a time.

- A pallet moving along conveyer belt B1 can be paused momentarily if it reaches an Sy station at the same time as a pallet switching over from a B2 belt, since parts shifting back to B1 are supposed to have priority.

- Station A6 takes in parts that have not been processed at one or more of the following stations: A3, A4, A5. Since A6 can be a substitute for any of these stations, we needed an algorithm to determine which station A6 emulates for any given part. We arbitrarily made A3 be the first choice, A4 the second, and A5 the third; that is, station A6 performs A3 if A3 is needed, otherwise A4 if A4 is needed, otherwise A5.

- The operation performed at station A1 is either loading or unloading, each of which takes 15 seconds.

The last assumption in the preceding list is not one we felt entirely comfortable with, since it makes A1 into a bottleneck station, but it seemed the most reasonable interpretation of the information provided (i.e., "Unprocessed parts are put on pallets in A1," "Finished parts are unloaded in A1," and the 15-second operation time for A1).

Results of running the model with 20, 40, and 60 pallets

- Throughput stayed the same (2 parts output every minute) in all cases because of task A1 (the entry and exit point, according to our assumption) acting as a bottleneck. Because task A1 takes 15 seconds, 4 parts can go through A1 every minute. Because a new part comes in through A1 for every part that leaves through A1, 2 of the 4 parts are coming in and 2 are going out. Increasing the number of parts in the system from 20 to 40 or 60 can't increase the throughput, because the maximum output rate has already been achieved when there are 20 parts in the system.

- Average throughput time per part between the 120th and 600th minute increases when more parts are added to the system, as shown below:

  Average throughput time for 20 parts in the system: 10.05 minutes
  Average throughput time for 40 parts in the system: 20.97 minutes
  Average throughput time for 60 parts in the system: 30.38 minutes

The graph in Figure 3, generated in Micro Saint, shows how average throughput time changed over the course of the simulation with 40 pallets in the system. The dip at time 120 occurs because the values used to calculate the average were zeroed at that point, so that the overall average would cover only throughput times collected between time 120 and time 600.

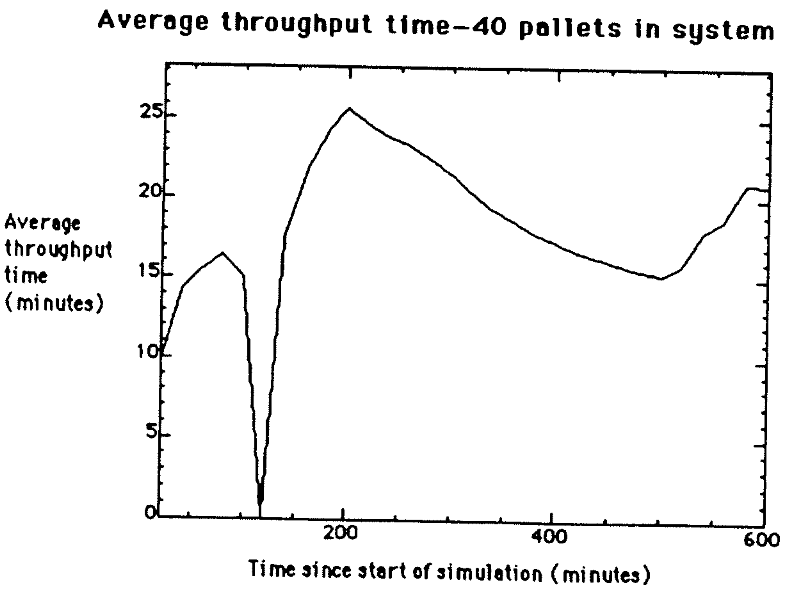

Figure 3

Development and execution times

- The model required 14 hours to design and develop and 11 hours to debug, generate graphs, and analyze data. We also spent 8 hours developing an iconic animation of the model for demonstration purposes (shown in Figure 4), but this animation was not necessary for data gathering or analysis.

- The model execution time varied depending upon the number of parts in the system. With 20 parts in the system, the model executed in 6 minutes on an i486 IBM PC compatible operating at 33 Mhz. With 60 parts in the system the model executed in 19 minutes on the same computer.

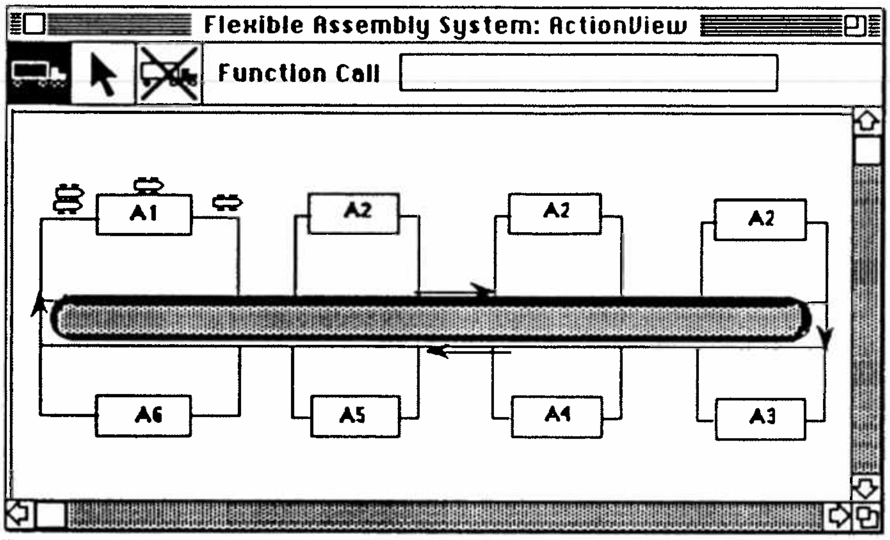

Figure 4

For information or comments, please phone or fax or write to:

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Comparison 2 - SIMUL_R

1. The Language

SIMUL_R is a compiling simulation language for continuous and discrete systems, the discrete part is called PROSIMUL_R. The system offers graphical and textual modelling, using one or more models in one simulation program. Examinations are done by using menus and/or a strong runtime interpreter.

The interpreter allows the usage of loops, command files (recursive, too) and arbitrary expressions with assignments and displaying. A special feature are user defined functions which enable the user to add new commands to the system (commands for steady state, zero search, continuous and discrete optimization, statistical evaluations are available as well).

A huge graphical library supports among others moving plots, 3D-plots, niveau lines, cross plots, animation for both, continuous and discrete systems.

SIMUL_R is an open system as it allows data input and output from and to other systems, including user input during simulation (by keys or graphical) as well as hardware in the loop.

PROSIMUL_R only knows one resource: the station. Everything else, like conveyors, is implemented as macros (so it is easy to add new functional objects to the system by writing new macros).

2. The Model

The model consists of one macro for the submodels and the DYNAMIC-section, which contains eight callings of this macro, with different parameters. The conveyors of this example, which are used as buffers, too, are implemented by PROSIMUL_R's TCONVEYOR_BUFFER macro.

Pallets are put into the system at the loading place for parts (Ax of A1). Old pallets coming to unload parts have priority over new pallets.

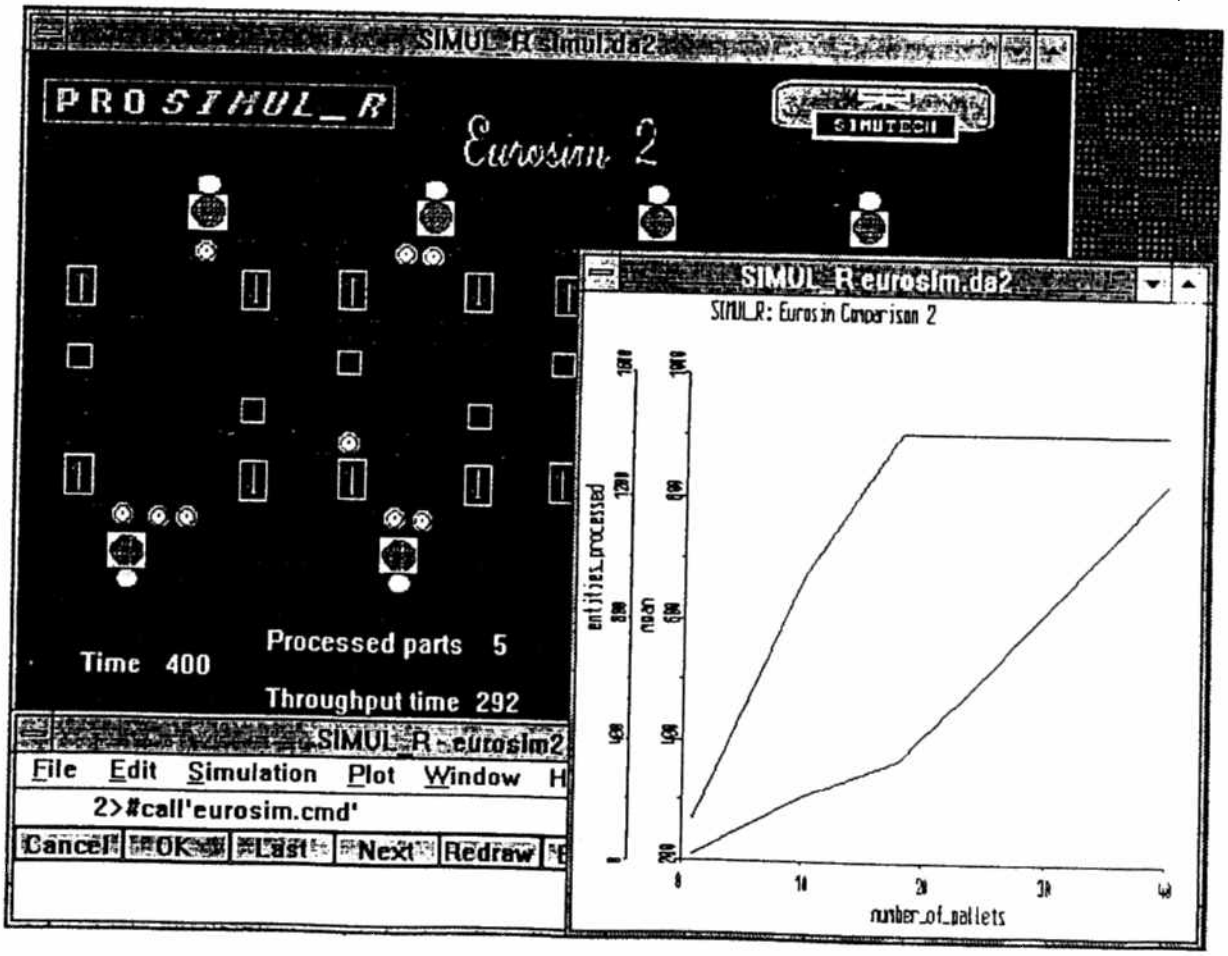
3. The Results

The table shows the results. SIMUL_R's discrete optimization command DOPTCONPAR computes 21 as optimum number of pallets. With 60 pallets and more the system blocks, because pallets cannot enter the circulation conveyor and the pallets on this conveyor move on it endlessly.

number of pallets	processed entities	mean of throughput time
1	138	208.3
10	939	306.7
20	1405	409.5
21	1409	429.5
22	1409	450.3
30	1405	614.2
40	1403	825.0

The figure shows the animation screen and the plot using the MS-Windows version of PROSIMUL_R.

For information and comments, please phone, fax or write to *R. Ruzicka, SIMUTECH, Hadikgasse 150, A-1140 Vienna, Austria. Tel: +43-(0)222-82 03 87 (new: 894 75 08); Fax: +43-(0)222-82 93 91 (new: 894 78 04).*



Comparison 2 - GPSS/H

1. Description of GPSS/H

GPSS/H is described in an article on page 5. Please refer to it for an overview of GPSS/H.

2. Observations about the FAS System

The following aspects of the Flexible Assembly System (FAS) being modeled are worth noting:

1. The maximum production rate is about 1409 units every 8 hours. The A2 stations are the bottleneck. (Each A2 station takes 61-1/3rd seconds to process one unit: 1-1/3rd seconds to move the unit onto the A2 station, then 60 seconds of operating time.)

2. The minimum time needed to assemble a unit is 229-2/3rd seconds (about 3.8 minutes). This time consists of 135 seconds of operation time, 20 seconds of shifting time, and 74-2/3rds seconds to travel 22.4 meters in one system lap in which one Station A2 and Stations A3, A4 and A5 are used, with two A2 Stations and the A6 Station being bypassed.

3. Model Description

The Comparison 2 problem checks two features of discrete event simulation languages:

- the possibility to define and combine submodels;
- the method to describe complex control strategies.

GPSS/H *macros* and *subroutines* provide tools for defining and combining submodels; and such things as *Boolean expressions* combined with *TEST blocks; GATE/Logic-Switch* combinations; and the ease of implementing *table-driven routings* thanks to *file I/O* and *matrices*, give GPSS/H the ability to handle complex control strategies easily. (Those who want to obtain the GPSS/H comparison model(s) should see Section 5.)

4. Model Verification

The model(s) were verified using the interactive monitoring feature of GPSS/H. This was done by setting traps on transactions (pallets) and tracing their movement through the system. Pallet movement was consistent with the rules described in the problem statement. For example, it was verified that the minimum time required by the model to assemble a unit is 229-2/3rds seconds.

5. Model Size and CPU-Time Requirements

Two GPSS/H models were built. The larger model, using no macros or subroutines, consists of 264 Blocks. The smaller model, using macros and subroutines, consists of less than 100 Blocks (and so can be executed under Student DOS GPSS/H!). Both models are included on the free animation disk (see Section 6). Also included on this disk is a GPSS/H model instrumented to produce the trace output file on which the animation is based.

Using the 264-block model, the 18-pallet simulation of Table 1 was run on a 33 MHz 80386 computer with a math co-processor and using GPSS/H 386 under MS-DOS 5.0. It took 20.4 CPU seconds to compile and execute the model. There were 263,507 block executions.

The same 18-pallet model was also run on the same hardware platform using Personal GPSS/H. Compilation and execution required 34.3 CPU seconds in this case. (GPSS/H 386 uses DOS extender technology not only to circumvent the 640K DOS barrier but also to process information in 32-bit chunks, whereas Personal GPSS/H works with information in 16-bit chunks. As a result, GPSS/H 386 is much faster than Personal GPSS/H.)

6. Animation of the Model

A GPSS/H comparison model has been animated using Wolverine's animation software, Proof Animation. The animation can be run on DOS 286 (or better) machines equipped with a math co-processor and DOS 3.0 or better. To obtain this animation on a disk at no cost, contact Wolverine Software Corporation, 4115 Annandale Road, Annandale, Virginia 22003-2500 USA; Tel: +1.703.750.3910; Fax: +1.703.642.9634. (The animation is self-contained in the sense that except for DOS, no other software is needed to view it.)

7. Experimental Results

Selected experimental results for the Comparison 2 are given in Table 1. These results were obtained by simulating for 2 hours, then reinitializing statistical aspects of the simulation, then simulating for another 8 hours. It was assumed that all pallets were empty initially and were positioned to be loaded at Station A1. Because all timings are dterministic, all correct models built under the same initial conditions and assumptions as the GPSS/H model(s) should produce the results in Table 1 (assuming the GPSS/H model(s) are correct), independent of the simulation software being used.

As shown in Table 1, the optimal feasible production rate (about 1409 units every 8 hours) is achieved (for all practical purposes) with 18 pallets.

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Number of Pallets	Jobs Completed in Final 8 Hours	Job Completion Time (Minutes) Mean	Std. Dev.	Number of Jobs Needing 1 or 2 or 3 or More Laps to Finish 1	2	3	>3	Number of Uses of Station A6
15	1350	5.33	0.89	1350	0	0	0	0
16	1350	5.69	0.89	1350	0	0	0	0
17	1371	5.96	0.82	1371	0	0	0	88
18	1408	6.13	0.79	1408	0	0	0	293
19	1409	6.47	0.53	1409	0	0	0	118
20	1409	6.82	0.50	1289	115	5	0	116
25	1408	8.52	2.75	682	300	180	246	252

Table 1: Selected Experimental Results

```
******************** Comparison 2: FAS Model ************************
*      (Reference:  EUROSIM Simulation News Europe, July 1991)
*                  Modeling Language: GPSS/H
*                  Modelers: Dan Brunner / Doug Smith
*         Wolverine Software Corporation, Annandale, VA 22003
***********************************************************************
        SIMULATE
TRUE    SYN             1
FALSE   SYN             0
*
B1      EQU             1(8),S
B2      EQU             9(8),S
B3      EQU             17(8),S
B4      EQU             25(8),S
SOURCE      EQU         33,S
AX      EQU             1(8),F
SX      EQU             9(8),F
SY      EQU             17(8),F
JUNCTION EQU            25(8),F
DONE1 EQU         1,PH
DONE2 EQU         2,PH
DONE3   EQU             3,PH
DONE4   EQU             4,PH
DONE5 EQU         5,PH
*
      STORAGE     S1,5/S2-S7,4/S8,5
        STORAGE         S9,3/S10-S15,2/S16,3
      STORAGE     S17-S24,1
      STORAGE     S25-S32,2
        STORAGE         S(SOURCE),60
WHICHOP FUNCTION        PH(STN),D8
0,1/1,2/2,2/3,2/4,3/5,4/6,5/7,6
B1DIST  FUNCTION        PH(OPNUM),D6
1,2/2,1.6/3,1.6/4,1.6/5,1.6/6,2
B2DIST  FUNCTION        PH(OPNUM),D6
1,1.2/2,0.8/3,0.8/4,0.8/5,0.8/6,1.2
OPTIME  FUNCTION        PH(OPNUM),D6
1,15/2,60/3,20/4,20/5,20/6,30
*     Variable Declarations
      INTEGER     &NPALLETS
      REAL        &SPEED
        LET             &SPEED=0.3
*     Boolean Variables used to test for completed op'ns
1     BVARIABLE   (PH(DONE1)=FALSE)OR_
                        ((V(DONE345)=3)AND(PH(DONE2)=TRUE))
2     BVARIABLE   (PH(DONE2)=FALSE)AND(BV(IN345)=FALSE)
3     BVARIABLE   (PH(DONE3)=FALSE)
4     BVARIABLE   (PH(DONE4)=FALSE)
5     BVARIABLE   (PH(DONE5)=FALSE)
6     BVARIABLE   (V(DONE345)<3)
IN345 BVARIABLE   (V(DONE345)>0)AND(V(DONE345)<3)
DONE345 VARIABLE        PH(DONE3)+PH(DONE4)+PH(DONE5)
*
*     Primary Macro to process parts through Stations
*
ASTAT   STARTMACRO
        ASSIGN          STN,#A,PH
        ASSIGN          OPNUM,FN(WHICHOP),PH    Op Num is func of Station Num
      TEST E            BV(PH(OPNUM)),TRUE,BYPASS#A    Need Processing Here?
      GATE SNF     B2+PH(STN),BYPASS#A     Is Buffer Free?
```

```
      TEST E            PH(OPNUM),1,NO1#A Yes&Yes; Is this Operation 1?
*
      ASSIGN            DONE1,TRUE,PH          Operation 1 => Mark 1 as done
        ASSIGN          DONE2,FALSE,PH          New pallet => 2 not done yet
        ASSIGN          DONE3,FALSE,PH          New pallet => 3 not done yet
        ASSIGN          DONE4,FALSE,PH          New pallet => 4 not done yet
        ASSIGN          DONE5,FALSE,PH          New pallet => 5 not done yet
        TRANSFER        ,BEGIN#A
*
NO1#A TEST NE     PH(OPNUM),6,BEGIN#A         Is this Operation 6?
      ASSIGN            (DONE1-1)+PH(OPNUM),TRUE,PH  Not 1 or 6; mark done
*
BEGIN#A SEIZE           SX+PH(STN)  Seize the input switch
      ENTER       B2+PH(STN)  Movement into station begins here
        LEAVE           PH(PREVIOUS)    Leave previous conveyor
      ADVANCE     2.0         Transfer Switch time
      RELEASE     SX+PH(STN)  Release the input switch
      GATE SF     B2+PH(STN),NOBLK#A
NOBLK#A ADVANCE   FN(B2DIST)/&SPEED   Convey down input buffer
      GATE FNU    AX+PH(STN)  Wait for machine to be available
        SEIZE           AX+PH(STN)      Officially seize the machine
      LEAVE       B2+PH(STN)  Relinquish space on input buffer
      ADVANCE     0.4/&SPEED          Move into machine
      TEST E            PH(OPNUM),6,NO6A#A        If this is Operation 6...
LOOP6#A SELECT E  (OP)PH,DONE3,DONE5,FALSE,PH   Choose Op 3, 4, or 5
      TEST G            PH(OP),0,NO1A#A      Done if no op'ns left
      ASSIGN            PH(OP),TRUE,PH            Mark as done
      ADVANCE     FN(OPTIME)  Use Operation 6
      TRANSFER    ,LOOP6#A    Loop back for next op
*
NO6A#A      ADVANCE
      ADVANCE     FN(OPTIME)  Use the machine (other than 6)
      TEST E            PH(OPNUM),1,NO1A#A Branch unless this is Operation 1
        DEPART          SYSTEM          Operation 1 => old job ends
      QUEUE       SYSTEM          Operation 1 => new job begins
NO1A#A      ENTER       B3+PH(STN)  Move into output buffer
        PRIO            PR+1
      SEIZE       JUNCTION+PH(STN)    Junction must be clear
        PRIO            PR-1
      SEIZE       SY+PH(STN)  Seize the output switch
        RELEASE         AX+PH(STN)      Relinquish machine
      ADVANCE     0.4/&SPEED  Remove part from machine
        LEAVE           B3+PH(STN)      Relinquish space on output buffer
      ADVANCE     2.0-(0.4/&SPEED)    Switching time less machine unload
        ENTER           B4+PH(STN)      Move onto output conveyor
        RELEASE         SY+PH(STN)      Release the output switch
MERGE#A ASSIGN          PREVIOUS,B4+PH(STN),PH  Record current storage
      TEST NE     PH(STN),3,SHFT3#A       Branch if Station 3
      TEST NE     PH(STN),7,SHFT7#A       Branch if Station 7
      RELEASE     JUNCTION+PH(STN)        Relinquish the junction
      ADVANCE     0.8/&SPEED          Move down connector
        TRANSFER        ,FIN#A                    End of processing
*
BYPASS#A ENTER          B1+PH(STN)  Move onto bypass conveyor
        LEAVE           PH(PREVIOUS)    Relinquish previous storage
      ADVANCE     (FN(B1DIST)/&SPEED)         Move down bypass
      SEIZE       JUNCTION+PH(STN)    Seize the junction
        LEAVE           B1+PH(STN)      Move off of bypass conveyor
      ADVANCE     0.4/&SPEED  Move to junction
      ENTER       B4+PH(STN)  Enter output conveyor
```

```
        TRANSFER          ,MERGE#A         Continue with logic above
*
SHFT3#A SEIZE          SWITCH3      Seize Transfer Switch
      ADVANCE      0.33             Clear the junction
      RELEASE      JUNCTION+PH(STN)  Release the junction
      ADVANCE      1.34        Clear transfer switch
      RELEASE      SWITCH3     Release Transfer Switch
      ADVANCE      0.33        End of transfer path
      TRANSFER     ,FIN#A
SHFT7#A SEIZE          SWITCH7      Seize Transfer Switch
      ADVANCE      0.33             Clear the junction
      RELEASE      JUNCTION+PH(STN)  Release the junction
      ADVANCE      1.34        Clear transfer switch
      RELEASE      SWITCH7     Release Transfer Switch
      ADVANCE      0.33        End of transfer path
*
FIN#A ADVANCE
      ENDMACRO
*
* The actual model begins here
*
      GENERATE     1,,,&NPALLETS,,10PH,1PL     Initialize the system
      ASSIGN            DONE1,TRUE,PH             Initialize pallet type
*
        QUEUE           SYSTEM                   Track entries
        ENTER           SOURCE                   Dummy storage
      ASSIGN            PREVIOUS,SOURCE,PH       Initialize previous storage
RECIRC  ADVANCE
ASTAT   MACRO           0                        Visit Station 0
ASTAT   MACRO           1                        Visit Station 1
ASTAT   MACRO           2                        Visit Station 2
ASTAT   MACRO           3                        Visit Station 3
ASTAT   MACRO           4                        Visit Station 4
ASTAT   MACRO           5                        Visit Station 5
ASTAT   MACRO           6                        Visit Station 6
ASTAT   MACRO           7                        Visit Station 7
        TRANSFER        ,RECIRC                  Loop continuously
*
      GENERATE     60     Timer Transaction, 1 per minute
        TERMINATE       1
*
      DO           &NPALLETS=20,60,20
      START        120    120 Minutes warm-up time
      RESET
      START        480    8 Hours simulated time
        PUTPIC          LINES=4,(&NPALLETS,QC(SYSTEM)-&NPALLETS,QT(SYSTEM))
WITH * PALLETS...
NUMBER OF PARTS PROCESSED: *
AVERAGE TIME IN SYSTEM: *** SECONDS
=====================================
        PUTPIC          LINES=4,FILE=SYSPRINT,_
                        (&NPALLETS,QC(SYSTEM)-&NPALLETS,QT(SYSTEM))
WITH * PALLETS...
NUMBER OF PARTS PROCESSED: *
AVERAGE TIME IN SYSTEM: *** SECONDS
=====================================
        CLEAR
        ENDDO
*
        END
```

Comparison 2 - CASSANDRA

The Simulator

CASSANDRA (Cognizant Adaptive Simulation System for Applications in Numerous Different Relevant Areas) 2.1 - developed in the Institute for Measurement and Computing Techniques of the Hungarian Academy of Sciences - is a universal kernel system based internally on an object oriented structure utilizing primarily numerical Petri Net elements for its model representation. This approach ensures a realistic structural and non-procedural view of the systems investigated.

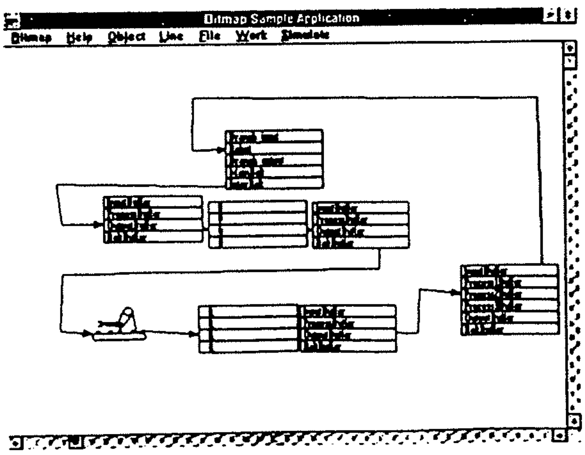
CASSANDRA 2.1 enhances the effectivity of simulation by automating the control of simulation experiments as well as the goal oriented reconstruction of the model structures using AI attributed *demons*.

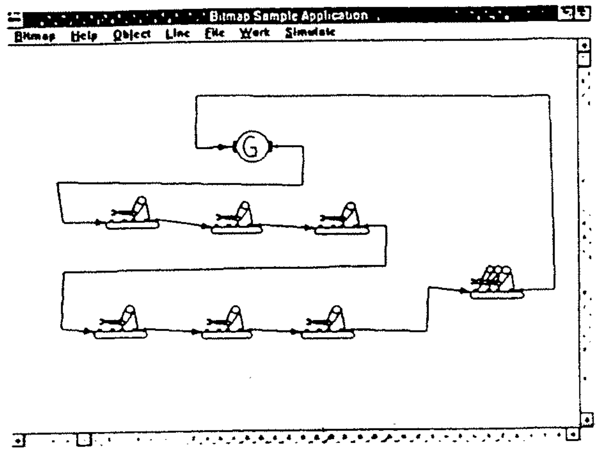
The simulator provides for an easy extension into problem oriented, specialized and user friendly tools for various fields by means of extending it with application field specific higher level building elements and I/O communication layers.

In our case CASSANDRA 2.1 was extended with a set of macro elements (as robots, conveyor belts etc.) based on the internal PN elements for simulating FMS models. Beyond that an experimental user interface layer for the given field has been developed by TU Wien and the Simulation Project Center in Wiener Neustadt under the supervision of Prof. Dr. Felix Breitenecker. The extension of the kernel system by this specific I/O layer was given the codename IGENJA.

Model Description

The model was run on a 80386/387 AT type system under MICROSOFT WINDOWS 3.0. The model building blocks consisted of various robots with their respective conveyor belt segments and shifting parts according to the example that had to be modelled. The resources could examine the constraints corresponding to the order of operations to be performed on the workpieces which were checked. The figure illustrates the graphic description of the model in the IGENJA system. The models in the system could be assembled graphically from user level model elements of the system library that were transformed automatically into the internal PN representation.





Results

The final results of the simulation experiments are give in table 1.

Number of pallets	total throughput	average throughput time [s]
10	1039	277.9
15	1374	313.3
20	1415	410.7
25	1417	517.9
30	1417	629.1
35	1416	691.6
40	1415	838.5
45	1418	866.8
50	1379	1029.3
55	deadlock	
60	deadlock	

Remark: data collected from the 120th to the 600t minute.

Beyond the above results the IGENJA system provide the animation of the changes in the state of the model durin simulation run enabling thereby a good overview of th operation of the system investigated.

For information and comments, please phone or fax c write to:

Prof. Dr. A. Jávor, KFKI Research Institute for Mea surement and Computing Techniques of the Hungaria Academy of Sciences, H-1525 Budapest, P.O.Box 49, Hun gary, Tel: +36-1 1699499, Fax: +36-1 1553894

Comparison 2 - DESMO

1. The DESMO Software

Background:

The simulation package DESMO, developed at the informatics department of Hamburg University, was inspired by the process style DEMOS system in Simula (G.M. Birtwistle) adopting the entity approach for simulation objects. The DESMO user can import a wide range of simulation functions into his model program, which is written in the base language Modula-2. Modula-2 with its comprehensive language kernel allows for well structured and readable, safe and efficient simulation programs on PCs offering features such as strong typing, modularization with separate compilation and interface checking, information hiding and access protection, respectively.

Package Functionality:

DESMO offers, next to event scheduling and process interaction functions, contructs for modelling on a higher level of abstraction (above processes) allowing for a more problem oriented and therefore more convenient implementation of simulation models. These synchronization mechanisms are: *Resource competition* with mutual exclusion (i.e. entity resource requests), *producer/consumer relations* of entities, *direct co-operation* of entities (master/slave relations), and *conditional waiting* of entities.

Semi automatic statistics, collection and graphical display of simulation time series data, trace and debug facilities, consistency and deadlock checks as well as extensive reporting are available.

Technical Data:

Implemented in LOGITECH Modula/TopSpeed Modula on IBM PC (2/50 and 2/80 with 80287 coprocessor). 25 modules with 19000 lines of source code (430 kB) / 380 kB object code.

2. Model Implementation

The sample model is implemented in the process interaction style using also higher modelling constructs of DESMO. The model consists of three components: the subsystems, the conveyors linking these subsystems and the pallets as dynamic elements. The pallets are defined as processes. Each subsystem and each conveyor is realized as a Modula-2 record with the related elements as record components. If feasible the elements are represented by higher modelling constructs; i.e. the station, one buffer behind the station and the conveyors between the systems are *resources*. The conveyors B1 and B2 are simply implemented as (free capacity) counter variables. To enter a system a pallet has to go through a *conditional waiting* object. There it is checked if the pallet can enter and on which way it will pass through the system. The pallet operation sequence is realized as a Modula set with station numbers as elements. The set contents and a limiting condition (A2 being the first or last station) determine the station selection of a pallet. System control follows the pallet process description and the automatical synchronization mechanisms.

The simulation program has 400 lines of code (14 kB) and the run time on the PS 2/80 is 80 sec for the sample system (15 pallets).

3. Simulation Results

As starting condition pallets are not permitted on conveyor B2. Therefore the maximum number of pallets in the system is 40 (capacities of all B1 and the conveyors between the systems). The simulation experiments were executed with 10 pallets in the system up to 40 by steps of 5. The results show that 20 is a favourable number of pallets (see Tab.1). The throughput is too small if there are less pallets in the system. On the other hand more pallets are not increasing the throughput of the system because of congestion effects whereas the average throughput time of one pallet increases significantly.

Nr. of pallets	througput (pallets)	avg.through-put-time (min)
10	939	5.1
15	1351	5.3
20	1408	6.8
25	1407	8.5
30	1409	10.2
35	1408	12.0
40	1409	13.7

Tab. 1: Results
(data collection from 120th to 600th minute)

Documentation:

B. Page: Discrete Event Simulation and Modula-2. Syst. Anal. Model. Simul. 7 (1990) 5, 339-358

B. Page et. al.: Diskrete Simulation. Eine Einführung mit Modula-2. Springer 1991 (see also review, page 25)

Contact:

Prof. Dr.-Ing. Bernd Page, Dipl.-Inform. Andreas Häuslein, cand.inform. Dirk Martinssen, FB Informatik, Universität Hamburg, Vogt-Kölln-Str.30, W-2000 Hamburg 54, Germany

Comparison 2 - TOMAS

Simulation System TOMAS/16

1. Description of the Language

The simulation system TOMAS (Technology Oriented Modelling And Simulation) supports simulation in the field of discrete technological processes. At the end of the 70ies it was designed by the Faculty of Informatics of the Technical University Dresden and realised for the first time in the beginning of the 80ies. In 1990 TOMAS/16 was implemented by DVZ Neubrandenburg GmbH for MS-DOS PCs. Since then it has been offered on the software market.

TOMAS is mainly used in two areas:

- during designing of manufacturing processes
- during planning and controlling of manufacturings

TOMAS - being a building element system - consists of 12 modules, by means of which the user - supported by the computer - can build models. As TOMAS is a simulation system oriented at special fields, the modules present universal manufacturing subprocesses, that means, they imitate typical processes of manufacturing.

These modules - operators and generators - will be passed by operands during simulation. Operands may be for example manufacturing jobs, lots, vehicles, parts.

Behaviour of the single operators and generators is specified by parametrization of the elements. Then the model is able to be processed.

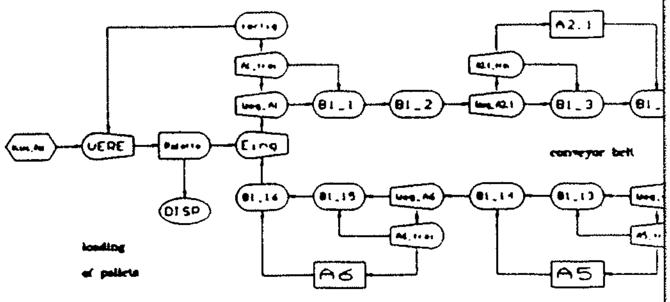
The management of the simulation system TOMAS/16 is easy for the user, because it is menu-driven and many helps will be available in on-line status.

2. Model Description

To solve the problem 7 of the 12 modules were used, realising the following functions:

Num.	Module	Function
1	GENO generator of operand	creates first pallets
1	GENA passive generator	terminates completely processed parts, put unprocessed parts on pallets (Al)
2	VERE joining operator	subelement to connect pallets
1	DISP disposition operator	sink of model, statistics of pallets
7	BEMM processing operator	manipulate parts of pallets (A2-A6)
16	VERZ branching operator	branching of pallets
17	SPEI storing operator	sections of conveyor belts B1 and B2

The following picture shows how pallets will be controlled in the model and a part of the conveyor belt.



3. Experimentation Results

In contrast to other solutions published in "Eurosim" in our model the pallets are created step by step. They are put on the conveyor belts if there is a place available (see model picture above). So we can show that never more than 40 pallets are on the belt. If more than 40 are created then a part of the pallets is waiting in front of the belt. If there were more pallets on the belt a deadlock would be determinated.

The optimum number of pallets may be seen in the following table:

Number of Pallets	Total Throughput 120th to 600th minute	Average Throughput Time
10	848	5.655
13	964	6.461
14	1018	6.590
15	1014	7.091
16	**1031**	**7.431**
17	857	9.290
18	867	9.679
20	884	10.394
30	951	14.754
40	1005	18.832

The biggest throughput will be reached by a number of 16 pallets. If there are more pallets on the belt the average throughput time will be greater, that means some pallets must circulate over and over, before being processed.

Further increasing the number of pallets doesn't yield the same numbers as with 16 pallets, because the third A2-station's and the A6-station's capacity aren't fully used if 16 pallets are in the system.

For information and comments, please phone, fax or write to:

Beate Steinke, DVZ Neubrandenburg GmbH, Bereich Softwareentwicklung und Systemberatung, Woldegker Straße 12, 0-2000 Neubrandenburg, Germany, Tel: +37-90-587 443 Fax: +37-90-587 302

Comparison 2 - SIMPLE-mac

1. A description of SIMPLE-mac

The starting point for this object oriented simulator is a limited supply of parameterizable elements (modules) which allow a complete representation of any discrete system. Controller modules provide a flexible representation (in the form of decision tables) of the complete data flow. The individual modules can be grouped together to form macros, which can in turn serve as modules for the model development process. The creation of an animation layout results from the model development process and therefore requires no additional effort.

Because of SIMPLE's modular concept it is not necessary to create the simulation model via a programming language. Instead, the individual modules are arranged on the screen and connected to one another through material and data flow. In the event the fundamental attributes of a given element are insufficient, its attributes can be extended through the addition of local and/or global controllers.

An additional advantage of SIMPLE-mac is the possibility to view and modify all model parameters without having to leave the simulator.

SIMPLE-mac is operated via a menu driven, window oriented graphic interface. It also provides its own editor for the arrangement of modules and the creation of decision tables. The graphic interface was designed in the MAC-OS style.

2. Model description

The time elapsed for positioning a pallet in the work station Ax (moving from the end of the buffer zone to the work station - 1.33 seconds) is included as a part of the operation time. This method results in an optimal value for the total throughput of 1440 parts (see EUROSIM-91/2, page 28).

The basic submodule consists of seven "RUTSCHE" (Chute) elements and a local controller. This module was used to represent the work stations A2, A3, A4, A5 and A6. To model the first work station (A1) the basic submodule was extended with a controller for the creation and destruction of entities. Further, it was attempted to improve the throughput and throughput time by using a smaller number of pallets with the help of a supervisory controller.

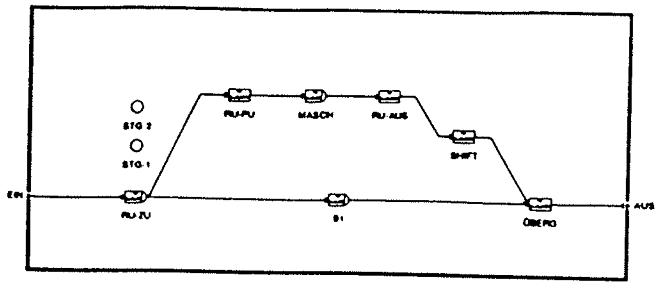
3. Results of the simulation

The diagram shows the results of the individual simulation runs. By using the SIMPLE-mac features to create superimposed, complex controllers an improved strategy for small numbers of pallets could be found.

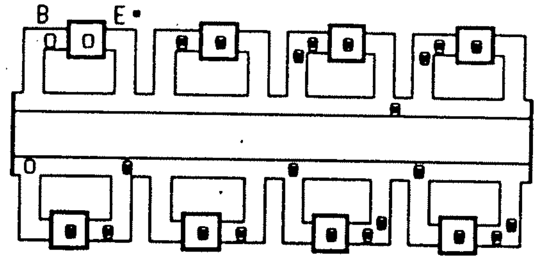
With the use of 50 pallets and more the system blocked due to the exhaustion of the capacity of the conveyor belt.

For information or comments, please phone, fax or write :

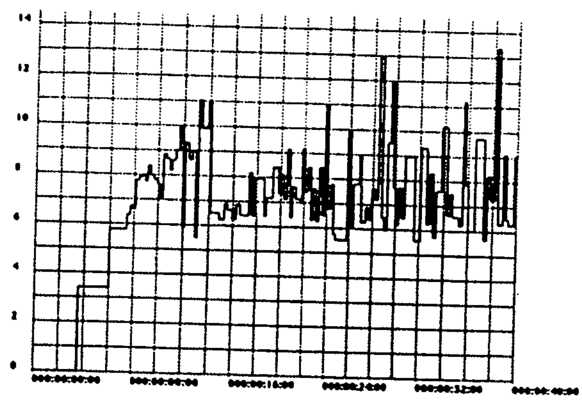
Gernot Kronreif, Fa. UNSELD & PARTNER, Lerchenfelderstraße 44/V, A-1080 Vienna, Austria. Tel: +43-(0)222-4030371; Fax: +43-(0)3332-65149.



basic sub-module



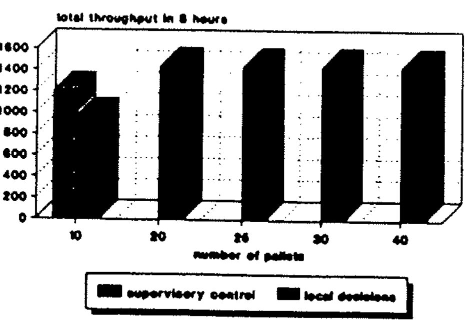
animation layout



throughput time (20 pallets)

no. of pallets in system	total troughput	avg. trough-put time [s]	min. trough-put time [s]	max. trough-put time [s]
10	960	300,0	254,6	318,3
10 (with supervisory control)	1200	240,2	220,1	260,9
20	1439	400,2	270,3	748,0
25	1440	500,4	311,4	1839,5
30	1440	580,7	389,2	2339,0
40	1438	803,7	320,7	3525,1

Flexible Assembly System
Total Throughput



Comparison 2 - WITNESS

1. Description of WITNESS

The simulating system WITNESS used to simulate the given problem offers global elements to build the model. Elements can describe discrete and continuous events. In this case only the discrete elements were needed. The elements are defined by name and displayed on the screen. Any display can be used by creating icons with an editor. The third step of describing the model is detailing the elements. Every element has got a parameter mask which has to be filled by the user. Parameters are cycle-time, capacity or breakdown details as well as material flow or information flow links between the elements and control strategies to run the model. Simulating the model produces an online animation. Results can be given by standard statistics or self-made functions and values.

The used WITNESS version runs on PC 386 with OS/2.

2. Building the model

To build a model that simulates the given problem, the following WITNESS standard elements have been used: machines for every Ax; conveyor for every Sx, Sy, B2, B3 (conveyor between Ax and Sy) and C (conveyor between the subsystems); buffer for every B1; part to define the pallet; attributes (of parts) to give every pallet its individual state of work; variables to define dynamic cycle-times.

Two assumptions were made to complete the model:

- empty pallets (and pallets with completely processed parts) that cannot get to station A1 because the buffer in front of A1 is full move on through the system

- the operation time in A6 is 30 sec for every execution of the work that should be done in A3, A4 or A5. A6 does all the remaining work of A3, A4, A5 as one complete operation.

Using WITNESS, it is at last impossible to build the model out of submodels. The given problem consists of eight slightly different areas but WITNESS does only give the opportunity to define slightly different elements. There is, as well, the possibility to build a system out of subsystems by creating a subsystem as an individual model and integrating these models into a new system. For this it is necessary for the user to make use of a text editor and to rename and control the identifier of all elements.

3. Results

To find the optimal number of pallets to run the system, various simulation runs were made. The results we are interested in were given by the standard statistic output of WITNESS by collecting data from the 120th to the 600th minute.

a.) the optimum number of pallets in the system is 17. By looking at the results it is interesting to see that it is possible to get an output of 1441 parts although there should be a maximum value of 1440 parts, given by the simulated time (8 hours) divided by the longest operation time (20 sec).

b.) the average throughput time by using 17 pallets is 350.6 sec.

c.) the system will get a deadlock situation by using 62 pallets.

d.) the optimum efficiencies of stations in the system will be given by using 17 pallets. In this case, station A6 won't be used at all (only perhaps at the reason of randomly chosen start positions of empty parts). The efficiencies of all other 'normal' stations is 100 %.

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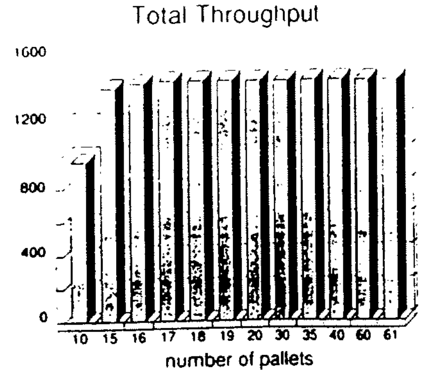
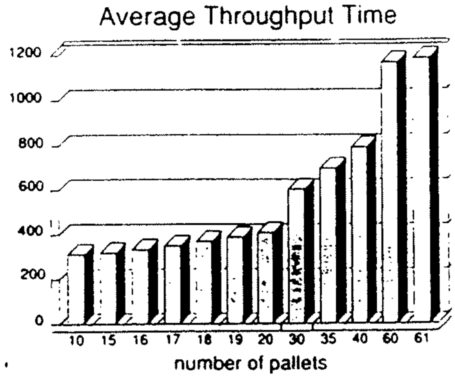
			efficiencies (%)							
number of pallets	total throughput	average throughput time	A1	A2 (1)	A2 (2)	A2 (3)	A3	A4	A5	A6
10	959	311,75	49,99	100,00	99,97	0,00	66,66	66,65	66,67	0,00
15	1398	320,35	72,81	100,00	100,00	91,26	97,08	97,08	97,09	0,00
16	1426	334,38	74,25	100,00	100,00	97,00	98,01	99,00	99,00	1,46
17	1440	350,62	75,00	100,00	100,00	100,00	100,00	100,00	100,00	0,00
18	1440	370,11	47,98	100,00	100,00	99,76	84,58	99,10	99,76	24,20
19	1441	389,33	75,04	100,00	100,00	99,84	94,58	98,27	99,23	11,25
20	1439	409,30	74,94	100,00	99,99	99,67	89,94	94,91	97,64	25,73
30	1438	602,85	74,93	100,00	100,00	100,00	87,76	92,20	95,34	37,38
35	1441	697,10	75,05	100,00	100,00	100,00	89,02	93,84	96,18	31,98
40	1441	791,92	75,06	100,00	100,00	100,00	91,57	95,36	96,69	24,76
60	1439	1166,40	74,94	100,00	100,00	100,00	90,84	94,80	96,52	26,15
61	1440	1183,70	75,02	100,00	100,00	100,00	93,55	96,30	97,27	18,62

Total Throughput



Average Throughput Time



Comparison 2 - SIMFLEX/2

Description of SIMFLEX/2

SIMFLEX/2 has been developed by the section Production Systems of the Department for Mechanical Engineering at the University of Kassel. It is an element orientated simulator for material flow systems. Out of a given set of standardized elements material flow systems are constructed via a menue oriented, graphic user interface. The elements' graphic depiction can be taken from existing plant layouts with a CAD-interface. The elements' function is influenced by means of technical (e.g. speed, capacity) and logistic parameters (e.g. strategies). When required the user can modify the steering programs of the elements. In this way even plants with complex logistics can be modelled. Having started the model a graphic animation and a statistic registration system can be added. Thus the user is enabled to intervene in a running simulation. A special feature of SIMFLEX/2 is its real time interface for communication with Programmable Logic Controllers (PLC). Through this it is possible to use the simulator for controlling real plants.

Description of the model

The type of problem allows several sequences of operations. Therefore each pallet is assigned with a note which states the jobs already done. A pallet's note and the number of pallets waiting to be worked on by a specific submodule decide whether a pallet is accepted for processing by some submodule or whether it passes by. The decision is made by a controller at a submodule's entrance. Figure 1 shows the complete structure of a submodule. At the construction of the model the CAD-interface has been used for the plant's scale depiction (figure 2).

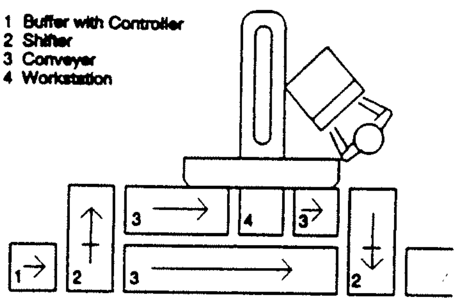


Figure 1: Submodule

SIMFLEX/2

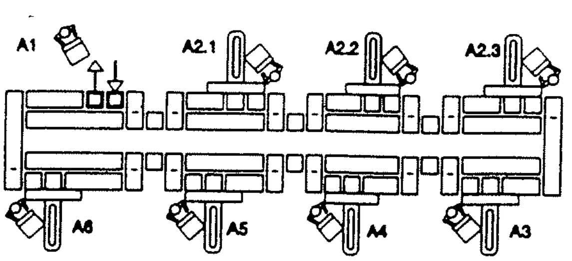


Figure 2: Plant Layout

SIMFLEX/2

Results

In order to find out the optimal number of pallets, 10 experiments were run. We started with 5 pallets and increased their number up to 50 by steps of 5. We measured the pallets' average throughput time, the total throughput within 8 hours and the stations' efficiencies.

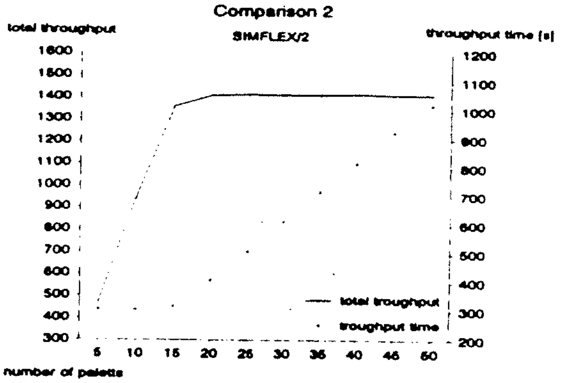


Figure 3

The optimal number of pallets in the system was found to be between 15 and 24, since then the throughput is already high while the throughput time is still low (figure 3). With fewer pallets the throughput is considerably and the throughput time only slightly reduced. An increase of pallets to more than 20 leads to only little more throughput but considerably prolongs throughput time. In addition, the jobs of station A3, A4 and A5 shift to the substitute station A6.

number of pallets	total troughput	average throughput time
5	470	306,0
10	941	306,0
15	1359	318,0
20	1409	408,6
25	1412	509,4
30	1410	612,6
35	1410	715.8
40	1414	816.0
45	1412	924,0
50	1412	1020,6

no. of pa.	efficiencies [%]							
	A1	A2.1	A2.2	A2.3	A3	A4	A6	A7
5	24,48	100,00	0,00	0,00	34,60	34,61	34,61	0,00
10	49,01	100,00	100,00	0,00	69,25	69,19	69,25	0,00
15	70,82	100,00	100,00	88,95	100,00	100,00	100,00	0,00
20	73,38	100,00	100,00	99,88	93,47	97,70	99,55	29,57
25	73,54	100,00	100,00	100,00	92,30	97,02	99,18	33,79
30	73,44	100,00	100,00	100,00	89,88	94,09	97,30	44,36
35	73,45	100,00	100,00	100,00	92,50	96,13	98,29	35,64
40	73,65	100,00	100,00	100,00	94,12	97,41	99,14	29,87
45	73,56	100,00	100,00	100,00	96,27	99,09	99,73	23,67
50	73,53	100,00	100,00	100,00	97,82	99,74	99,97	19,78
operation time and pallet changing time are taken into account								

For more information and comments please contact:
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Comparison 2 - EXTEND

Description of EXTEND

EXTEND is a general purpose simulation system supporting both continuous and next event modeling. It is library-based and uses a block diagram approach to modelling. You can use libraries of pre-built blocks to set up models with no programming (for example Manufacturing) or you can use MODL, a built-in modeling language, to modify existing blocks or create new ones. The Manufacturing library allows you to create complex factory simulations.

Since version 2.0 EXTEND supports hierarchical modeling. We worked with version 1.1.

EXTEND runs on Macintosh computer. EXTEND™ is a product of Imagine That Inc., 151 Bernal Road, Suite 5, San Jose, CA 95119 USA.

Model Description

Figure 1 shows a model description by default blocks of EXTEND's Sample Manufacturing Library (a freeware child of the Manufacturing library) and the general Discrete Event Library. The times to change the conveyors are added to the conveyor working times. It is difficult to describe flexible control strategies by the default blocks.

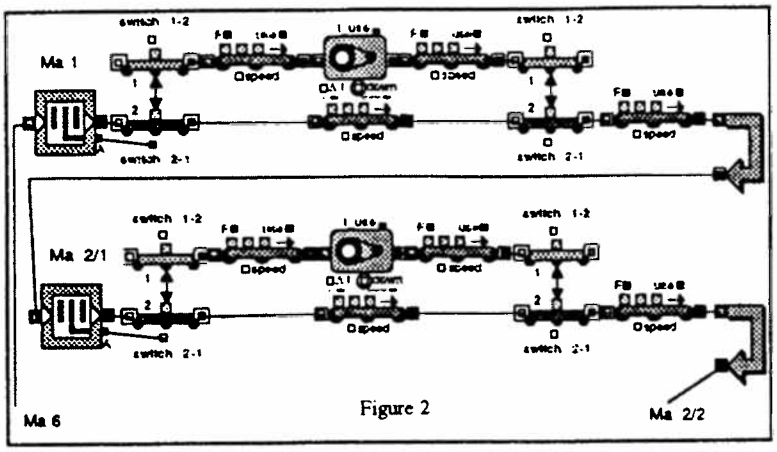

Figure 2

We developed a second model with modified and new created blocks (machine, conveyor switcher, control) to handle flexible control strategies. Figure 2 shows the general model layout for two machines. The "machine" block modifies item attributes, which are evaluated by the "control" block. The control strategies are described for each "control" block by a decision table (figure 3). The new features of version 2.0 allow a control description by logical equations and to model in hierarchical levels.

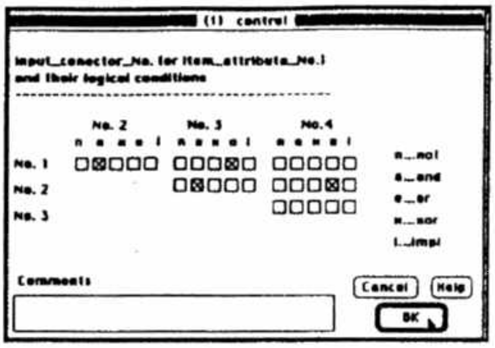

Figure 3

Simulation Results

The simulation experiments were executed with 10 pallets in the system up to 30 by steps of 5. The experiments showed that 20 is the favourable number of pallets. The simulation results are summarized for 20 pallets in table 1.

20 pallets machine No	finished items (throughput) 0...2 hours	 0...10 hours	 2...10 hou
2/1	120	600	480
2/2	120	600	480
2/3	118	598	480
3	347	1787	1440
4	345	1785	1440
5	344	1784	1440
6	5	5	0
finished items	346	1786	1440
circulations of pallets (with 1 item)	11	11	0

Table 1

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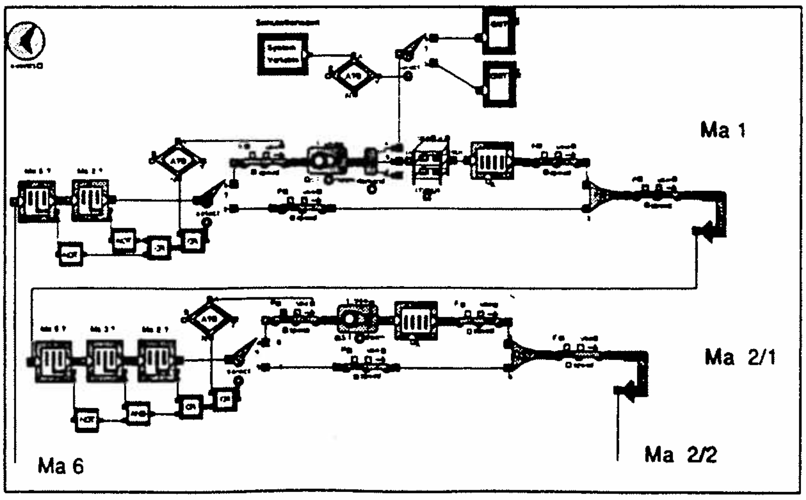


Figure 1

Comparison 2 - POSES

hort description of POSES V4.3

The simulation system POSES (*Prädikat-Transition-netz-Orientiertes-Simulations und Entwurfs-System*) de-eloped by the Technical University Chemnitz and nplemented in version 4.3 by GPC mbH Chemnitz allows ıodelling and simulation based on extended predicate tran-ition nets. Extensions to predicate transition nets are (fix or tochastic value dependent) time consumpting transitions, ree matching expressions on arcs, additional boolean con-itions for transition concession, special access mechanisms or predicates (ram, lifo, fifo, fiforam, liforam), logical token enerating interrupts and so on.

The models have to be specified by using the POSES-lan-uage. In this language the user has to define data structures or tokens and predicate types like in the programming anguage PASCAL. Also the net structure with all necessary rc expressions has to be defined in this language.

The POSES-Editor, Compiler, Linker and Generator are n a POSES-development shell including tools to create ndependent executable simulation programs. Nearly all a-rameters (consumption time, capacities, priorities, okens, states, lifeness, trace parameters, ..) of the modelled et elements can be defined or changed by the user during xperiment sessions.

By using high level Petri nets the abstraction level for nodelling and simulation depends only on the user's selec-ion. Global and detailed aspects are possible in the same nodel. Moduls of ready-made net substructures are also seful.

POSES offers the inclusion of user-defined PASCAL or C routines. In this way POSES is also a simulation environ-ment to develop a test control software on a level chosen by the user. POSES applications are simulation services for plant and warehouse logistics, organisation, computer com-munication and control software development problems.

Model description

The full net model is segmented into 8 equally structured net modules. Buffer components like B1, B2, the rest buffer behind work station B2', input shift Sx and output shift Sy are modelled by predicates. All work stations Ax, all trans-portation flows into B1, B2, B2' are modelled by time consumpting transitions. The pallets flowing through the system are represented by data tokens containing a record structure like a work order paper. Depending on the data state of these records the control mechanism is implemented as conditions and matching masks in arc expressions.

Experimentation Results

The results of the simulation are given in the table:

Number of pallets	total throughput	average throughput time [s]
15	1454	282
16	1455	302
17	1454	322
18	1457	341
19	1459	360
20	1462	380
21	1457	420
22	1460	424
23	1462	438
24	1440	465
25	1439	485
40	1440	785

Dipl.Ing. Bert Oehmke, Gesellschaft für Prozeßautomation & Consulting mbH, Senefelder Str. 38, D-O-9022 Chemnitz, Tel: +49-(0)371 50593, Fax: +49-(0)371 50594.

Comparison 2 - EXAM

1. A description of EXAM

The general purpose system EXAM is intended to support all stages of simulation process: the model description, the experiment description and the simulation itself. In accordance with this EXAM contains two separate frames: Model Description Frame (MDF) and Experiment Description Frame (EDF). In order to apply EXAM to a definite area, one needs to put necessary modules (reflecting the main features of the process) to a special library. Because of the modular concept, the simulation model can be represented as a hierarchy of elements linked to each other. MDF makes it possible to view and modify both structure of the model and any parameters of elements (including procedural ones) without any reprogramming. EDF enables to include any standard or non-standard methods and combine them to design complex experiments which can be carried out even with several models.

The base language for EXAM is object-oriented Turbo Pascal. EXAM has an interactive shell, working under MS-Windows 3.0 or its higher versions, which is intended to give the user the possibility to describe models and experiments without knowledge of any programming and mathematics.

2. Model description

In order to illustrate the possibilities of EXAM, we used two representations of the model. The general scheme of these models is the same in both cases and is shown in Figure 1, which is actually a representation appearing on the screen during the work in MDF. In both cases EXAM was extended with a set of necessary modules, based on the internal mathematical model (aggregative one). In the first representation each element shown in Figure 1 was built from a single module describing the dynamics of the station as a whole. Different elements are obtained from the module by specifying its parameters. In the second representation each element from Figure 1 is actually a subsystem consisting of several other elements, describing the dynamic of the station, see Figure 2. The links between the elements in both cases reflect both pallets flow and artificial information signals related to possible blocking of the belts.

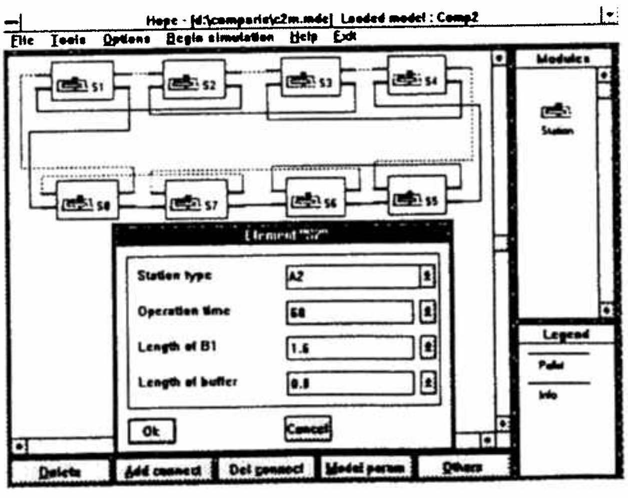


Figure 1

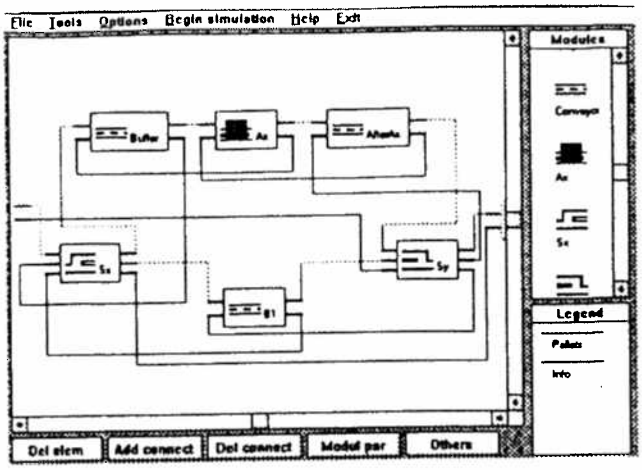


Figure 2

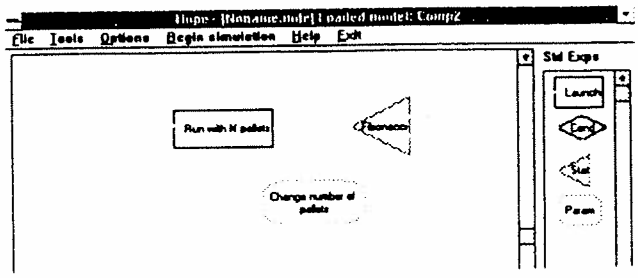


Figure 3

3. Results

In order to illustrate the work of EDF, we organized an optimization of the system by Fibonacci's method, using the objective function $Q = c_1T_1 + c_2T_2$, where $c_1 = 1$, $c_2 = -1/400$ (actually, they have been taken arbitrarily), T_1= total throughput, T_2= average throughput time. A general scheme of the experiment is shown in Figure 3. The steps of the optimization for the first model are collected in the table:

Number of pallets	T_1	T_2
34	1411	693.756
21	1409	429.674
13	1155	323.922
26	1410	532.318
18	1396	371.190
23	1411	470.103
20	1404	409.519
22	1410	449.886
21	1409	429.674

The optimal number of pallets is 21. The results for the second model are very close to those for the fist one (the differences are only due to the randomness of the initial states). So, we omit them.

4. Technical Data

The above model was run on an IBM AT 386/387 compatible computer operating at 20 MHz. The total run time at each step of optimization took from 0.5 to 3 min (depending on the number of pallets and, therefore, on the number of events).

For information and comments, please contact Prof. Dr. Vladimir Kalashnikov, Institute of System Analysis, Russian Academy of Sci., 9, Prospect 60 let Oktjabrja, 117312 Moscow, Russia; Fax: +7-095-9382209; Telex: 411237 POISK, E-mail: person@vniisi.uucp.free.msk.su

Comparison 2 - Taylor II

1. Description of Taylor II

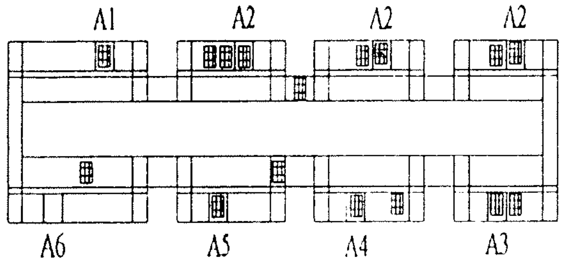
Taylor is a Dutch product developed by F&H Logistics and Automation B.V. in Tilburg, the Netherlands, since 1986. In mid 1992 the package, now called Taylor II, received a complete new structure. Taylor II is developed for all kinds of discrete event simulation and offers a wide range of special functions for processes in production and logistics.

Modeling in Taylor II starts with building a layout of different element types like machine, buffer, conveyor, etc. The second step is to create one or more routings. Now the model runs immediately with the standard 2d-animation. This offers the possibility of a visual debug. The third step, detailing the model, is done by filling out parameter masks. Typical parameters are capacities, breakdown behaviour, cycle-times, etc. At strategic points you often have to make complex decisions regarding where products are sent to. For this purpose the fixed addresses in the routings can be replaced by TLI-statements. TLI (Taylor Language Interface) is an easy to use macro language that enables you to define rules for order picking, assembly, complex guiding and receiving strategies. Furthermore, the package includes many features for pre- and user-defined analysis, animation and presentation. Taylor II runs on PC with MS-DOS or compatible. An MS-Windows version will appear in 1993.

2. Model Description

For the given problem only two types of elements were necessary: machines for every Sx, Sy and Ax; conveyors for every (part of) Bx and the connection of the subsystems. The pallets (products in Taylor) were given attributes for individual information and user-defined variables for calculating the processing time at A6 and measuring the throughput time. The attribute values of the pallets were stored in a matrix which has been used as a decision table. At every Sx there is a query in the routing and depending on the table values (0 or 1) the pallet is sent to B2 or B1. B1 is always possible just in case that there is not enough empty space on a B2.

Taylor II does not offer the possibility to build a model out of submodels. But, you only have to specify the parameters you need. This in combination with the easy creation of layout and routings, accounts for very fast modeling. The following figure shows the model in standard 2d-representation with an additional background drawing.

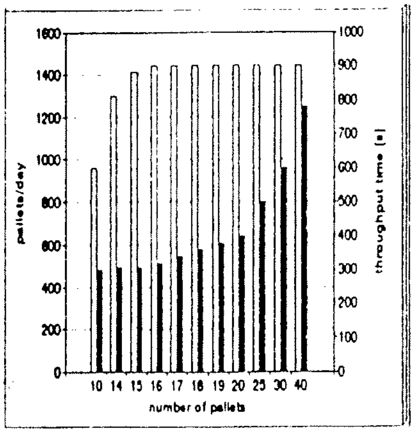


3. Results

When looking at the results given in the table below you find an optimum of 16 pallets with an average throughput time of 320 s. The maximum throughput varies between 1440 and 1441. In the model, the unloading and loading at A1 is seen as one operation. Pallets are counted when the operation starts. When collecting data from the 120th to the 600th minute it happens that a pallet is counted but not finished when the simulation stops. The only way to avoid this is to build a more detailed model.

For comments, questions or info please contact *Dirk Werner, F&H Simulationssoftware GmbH, Neubrückstraße 4, D-40213 Düsseldorf 1, Tel: +49-211-322151, Fax: +49-211-322897.*

number of pallets	production per day	throughput time [s]	utilization Ax [%]					
			A1	A2 (avg)	A3	A4	A5	A6
10	960	299.9	50.0	66.7	66.7	66.7	66.7	0.0
14	1299	310.4	67.7	90.2	90.2	90.2	90.2	0.0
15	1411	306.0	73.5	98.0	98.0	98.0	98.0	0.0
16	1440	320.0	75.0	100.0	100.0	100.0	100.0	0.0
17	1440	340.0	75.0	100.0	100.0	100.0	100.0	0.0
18	1441	360.0	75.0	100.0	95.2	100.0	100.0	7.1
19	1440	379.9	75.0	100.0	93.4	97.4	100.0	13.9
20	1441	400.0	75.0	100.0	87.8	94.3	97.8	29.9
25	1408	498.4	75.0	100.0	92.0	97.0	99.0	18.2
30	1440	598.1	75.0	100.0	90.3	94.6	97.6	26.2
40	1440	776.8	75.0	100.0	93.0	96.2	98.2	19.7



Comparison 2 - PCModel

PCModel is a full-function simulation language and graphic animation system with an interactive session control facility providing extremly responsive interaction with the simulation as it executes.

The object-based language allows to define 6 integer and 2 time variables for each object, in the simulation equal to a pallet. While the location dimensions of all A2 and the A3, A4, A5 stations are the same, it is easy to create submodels for each of the four subsystem types with relative locations. The conveyor B1 represents the main-path in the model. At each Sx-location in front of a submodel, the pallet is asked if the process of the station ahead is done or not, and if not, if the buffer in front of the operation location is able to absorb the pallet. After being processed in the subsystem, the appropriate object variable is decremented. If a desired location is blocked the pallet waits at place until the location is free again. With this PCModel- feature it is not necessary to create a FIFO-buffer in front of the process locations.

Results of running the model with 20, 40 and 60 pallets: The number of throughputs stayed nearly the same with 20, 40 or 60 pallets in the system. During the animation the system seemed to be well balanced with 20 parts. Every station was well occupied, even A6 sometimes (1.7 hours of 8), this shows the result of processed pallets in A6. More parts in the system seem to make the subsystem A2 to a bottleneck. A change of logical control of A6 to a fourth station A2 shows that the throughput did not rise up, because of the new bottleneck stations A3, A4 and A5, but A6 was as well frequent with a full buffer in front of it, as the 'original' stations A2. This is a sign that the processing times of the system are not optimally synchronised. A partition of the processes shows that A6 substituted to 56% station A3, to 30% A4 and only to 14% A5 with 20 parts in system. The other runs show an equal substitution of A3, A4 and A5, (figure 1).

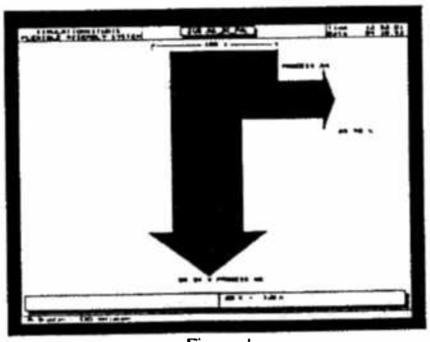


Figure 1

The more pallets are in the system the higher the average and maximum throughput time rises up. The longest throughput time of a pallet with 20 parts in the system was 21 minutes, with 60 pallets instead nearly 2 hours. The average throughput time stayed, except at the beginning, constant and variation was only little but on different levels: 6.6 minutes for 20 pallets, 13.3 minutes for 40 pallets and 20 minutes for 60 pallets in the system, (figure 2 and 3).

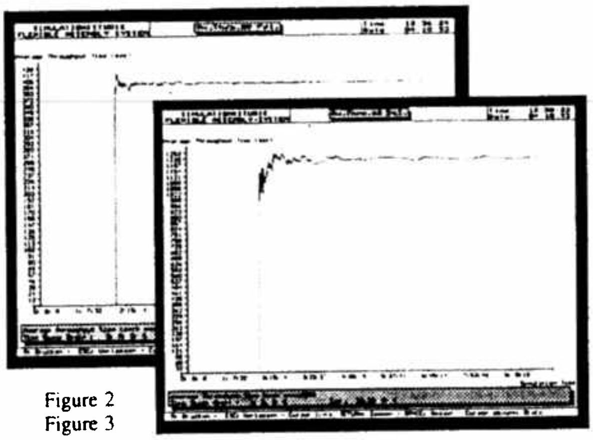


Figure 2
Figure 3

Development and execution times: The model required 8 hours to design and debug the logic and 3 hours for the overlay (figure 4). The DIPLAN Corp. developed analyzing software tools for PCModel report files for different needs. For this simulation the tools needed just a configuration file. This took about half an hour.

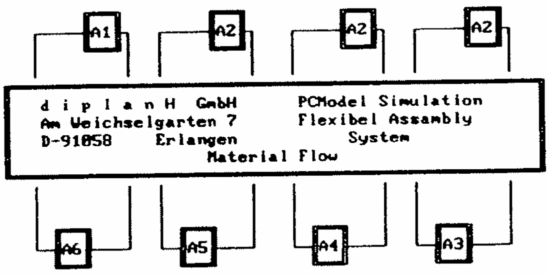


Figure 4

The model execution time varied depending upon the number of parts in the system. With 20 parts in the system, the model executed in 5 minutes on an i386 IBM PC compatible operating at 40 MHz. With 60 parts in the system the model executed in less than 15 minutes on the same computer.

For more information and comments please contact: *Dr. K. Schlüter, M. Stichert, DIPLAN GmbH, Am Weichselgarten 7, D-91058 Erlangen, Germany, Tel: +49-9131-691-235, FAX: +49-9131-691-111.*

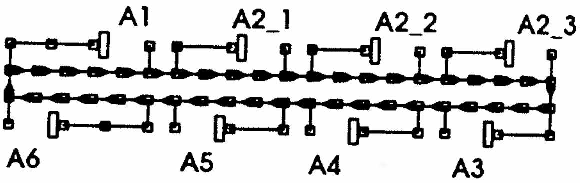
Comparison 2 - MOSYS

Description of MOSYS

MOSYS is a complex modularly structured simulation tool developed by the Fraunhofer Institute for Production Systems and Design Technology (IPK) Berlin. The tool enables the user to create and evaluate models of any discrete system with the desired degree of detail. The basic philosophy of the simulation tool is that any system can be generated by using five different types of elementary building blocks which can be composed in subsystems of the considered model on an arbitrary number of hierarchical levels. Thus the user is enabled to create models following either a top down or a bottom up strategy what makes the work essentially easier. The software runs on different platforms as IBM/370, VAX-stations and Unix-PCs.

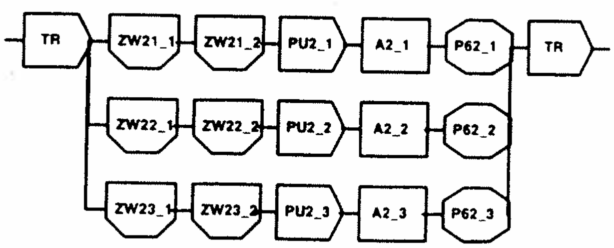
Model Description

The system's model was generated in a quite detailed way. The topological model shown below reflects the real distances and speeds of the transportation facilities of the system.



Topological layout of the system

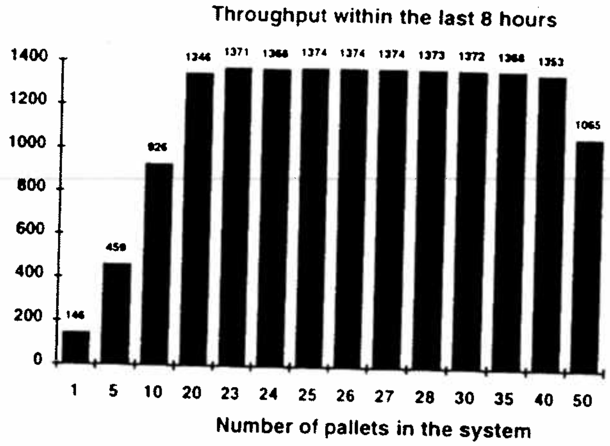
Behind each assembly station Ax in the functional model there is a number of test elements determining the further route of parts through the system depending on their status (for instance in the picture below the three stations A2 are shown with the logical flow for a part which has already passed station A6 before it was processed on A2_x (x=1,2,3).



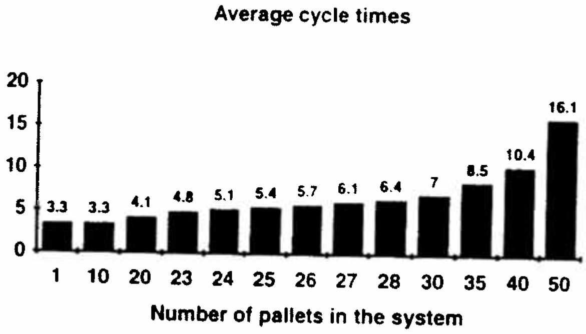
Section of the functional operation plan

Simulation Results

The main goal of the simulation was to find out the optimal number of pallets in the system and to determine the cycle time of the pallets (i.e. the time passing between fixing a part on a pallet and taking it apart). The results are given in the following diagram.



The system has its maximum throughput for 25 - 27 pallets. The respective cycle times are given in the following diagram:



Comparing the simulation runs and taking into account the pallet cycle times, too, it turns out that the optimum number of pallets in the system is about 25-26. Here the throughput is at the maximum and the pallet cycle times are not essentially larger than the overall processing time, i.e. waiting times in front of the stations and the time for additional turns around on the belt are very small. For a higher number of pallets in the system the throughput remains relatively stable up to 40, while the cycle time increases. For more than 40 pallets the throughput strongly declines due to blocking effects and, finally for 60 pallets in the system deadlocks occur.

For further information please contact: *Markus Rabe or Norbert Deul: IPK Berlin, Pascalstraße 8-9, D-10587 Berlin, Tel: +49-(0)30 39006248, Fax: +49-(0)30 3911037.*

Comparison 2 - CASSANDRA 3.0

Introduction

In SNE 4, March 1992, we already have reported the solution of the problem using an earlier version CASSANDRA 2.1. Here a qualitatively higher level solution using the entirely new version is presented. Beyond the new graphic I/O interface and animation two basic aspects should be mentioned. 1) The experiments can be controlled by intelligent demons finding the optimum determined by the user automatically [1] (see Fig. 1) 2) The models are represented internally by Knowledge Attributed Petri Nets (KAPN) [2] enabling the individual workpieces to carry the technological prescriptions and state of manufacturing with them in a naturally and easily describable way.

The experiment

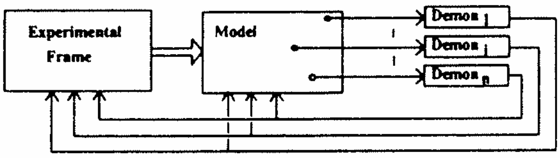


Figure 1

The graphic representation of model is shown in Fig. 2. together with the demon supervising the experiment. (Internally the models are represented by KAPN subnetworks.)

Two versions of the demon controlled experiment are presented. In the first experiment the demon was

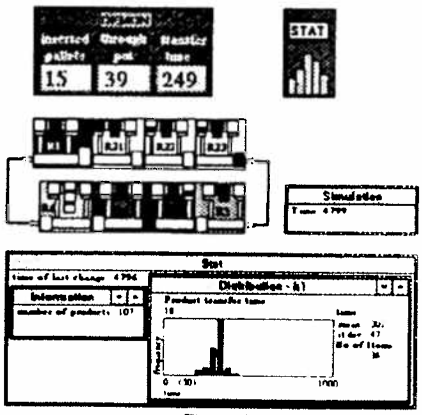


Figure 2

instructed to increase the number of pallets step by step and the throughput, transfer time, as well as the standard deviation of the product transfer time were recorded. The results can be seen in Fig. 3.

In the next experiment the starting point was that we have no knowledge in advance about the system para-

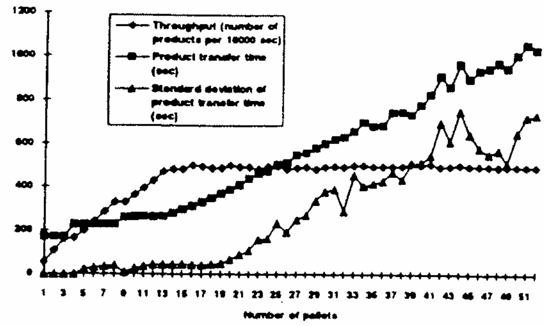


Figure 3

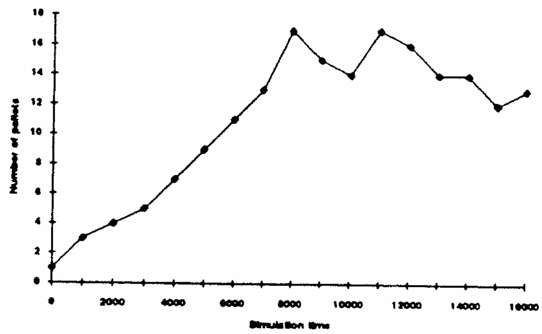


Figure 4

meters which can be obtained. The demon was instructed to find a complex measure regarded as an optimum as follows: "Find the maximum throughput and decrease it until the value of 90 % in order to reduce the product transfer time!" In case we regard this as an optimum the value of 13 pallets has been obtained as can be seen from the results of the search procedure shown in Fig. 4. Obviously the demon(s) in the system can be instructed the obtain various optimums of the weighted values of different system parameters.

References

[1] Jávor, A., Benkő, M., Leitereg, A., Moré, G., AI Controlled Simulation of Complex Systems. Computing & Control Engineering Journal (in publication)

[2] Jávor, A., Knowledge Attributed Petri Nets. Systems Analysis, Modelling, Simulation, 13(1993)1/2, 5-12.

For information and comments, please phone or fax or write to: *Prof. Dr. A. Jávor, KFKI Research Institute for Measurement and Computing Techniques of the Hungarian Academy of Sciences, H-1525 Budapest, P.O.Box 49, Hungary, Tel: +36 1 1699499, Fax: +36 1 1553894, E-mail: h7023jav@ella.hu*

Comparison 2 - DSIM

The simulation system DSIM has been developed at the Dept. Simulation Techiques at Technical University Vienna, supported by a grant of the "Bundesministerium für Wissenschaft und Forschung" of Austria.

DSIM is a discrete simulation system working in an windows environment (PC) and consists of the three modules SIMSHELL, SIMPAINT, and SIMSTAT.

The module SIMSHELL offers graphical modelling of a process flow and menu-driven control of experiments and the storage of results. Icons represent subprocesses, connections between the icons show the flow of entities (workpieces, information, etc., fig. 2). The description of the subprocesses is stored in one or more model libraries; these submodels are defined in terms of coloured, time dependent Petri nets. An expert user may modify or define subprocesses and libraries within the module SIMPAINT. Control or routing strategies may be defined either by means of Work Tables at runtime in SIMSHELL (centralized control) or by means of decisions in the Petri net description in SIMPAINT.

The simulator itself scans the Petri net description and schedules immediately an action, if necessary (time event); two versons are available: one with and one without deadlock detection and deadlock handling. Analysis of the stored data may be performed within the module SIMSTAT, which offers basic display features and interfaces for postprocessing (e.g. EXCEL).

DSIM is free software and available from the server `simserv.tuwien.ac.at`. Further developments will include e.g. optimization with genetic algorithms.

Model description

In modelling the investigated process for the stations Ai submodels of a predefined library were modified slightly, for the load/unload station a new subprocess was defined. Fig.1 shows the representing icon and parts of the Petri net description developed in SIMPAINT.

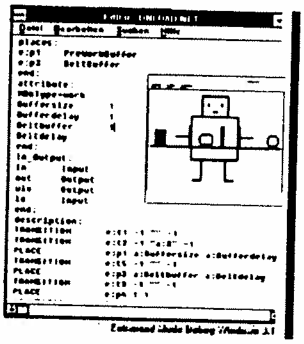


Figure 1

Within SIMSHELL the model was build up by subprocesses of the model library (fig.2, six simple stations, one intelligent station, and the load/unload station with a delay element). When opening the icons, specific parameters for the subprocesses and initial values, e. g. the number of pallets, can be chosen. During a simulation run (menu Simulate) relevant selected data are stored, additionally a simple animation is offerred; bar charts with absolute values or average values show the status of the stations.

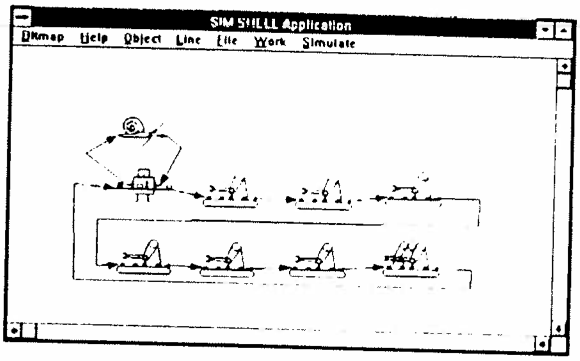


Figure 2

The table shows the results for different number of pallets:

pallets	throughput [pallets]	av. cycletime [s]	av. time in system [s]
15	1344	21,43	278,58
20	1425	20,20	409,06
30	1416	20,34	549,36
40	1370	21,02	706,55

Postprocessing of the stored data can be performed within SIMSTAT by displaying the data (fig.3) or interfacing to programs like EXCEL.

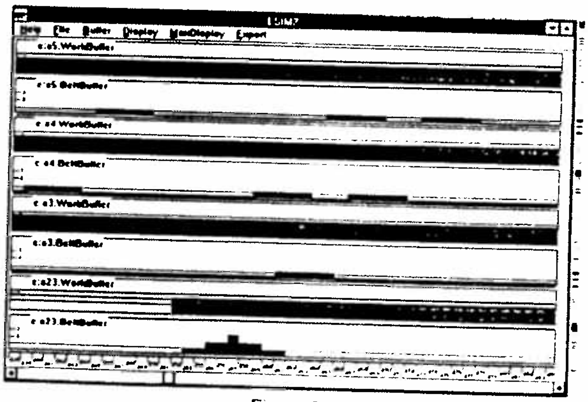


Figure 3

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Solution DESMO

Full Version

Lösung DESMO

Studie

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1. Einleitung

Für den Vergleich von Simulationssoftware wurde in der Zeitschrift EuroSim - Simulation News Europe die Aufgabe gestellt, ein flexibles Fertigungssystem zu modellieren.

Die Aufgabenstellung befindet sich in der Ausgabe Number 1, March 91, p. 28. Weitere Spezifikationen sind in der Ausgabe Number 2, July 91, p. 26 gegeben.

Realisiert wurde das Modell mit DESMO, einem Simulationspaket auf Basis von Modula - 2, welches am Fachbereich Informatik der Universität Hamburg im Rahmen einer Diplomarbeit entwickelt wurde.[1]

Da im Modell viele parallele Handlungen abgebildet werden, wurde zur Realisierung der prozeßorientierte Ansatz gewählt. Zusätzlich werden noch höhere Synchronisationsmechanismen aus DESMO verwendet (Ressourcenwettbewerb, bedingtes Warten), die die Ablaufsteuerung in einigen Teilen wesentlich vereinfachen.

2. Modellbestandteile

Im folgenden werden die Modellbestandteile beschrieben, die sich nach der Interpretation der Aufgabenstellung ergaben.

Subsystem:

Die gesamte Fertigungsanlage besteht aus acht Subsystemen, im folgenden kurz System genannt, die von den Paletten entsprechend ihrer Bearbeitungsvorschrift durchlaufen werden müssen (s. Abb. 1, S. 12). Ein solches System besteht aus der Arbeitsstation, den Förderbändern vor und hinter der Station, die gleichzeitig als Puffer dienen, dem Hauptband auf dem Paletten an der Station vorbei können, sowie jeweils einem Schieber am Anfang und Ende des Systems, in dem Paletten vom Hauptband zur Station gelangen können und umgekehrt.

Die Bestandteile sind in einem Record zusammengefaßt, welcher im einzelnen folgende Komponenten besitzt:

```
system_structure = RECORD
                      shift_place      : CondQ.Object;
                      blocked          : BOOLEAN;
                      buffer_cap,
                      buffer_fill      : CARDINAL;
                      station          : Res.Object;
                      typ              : [1..6];
```

1 vgl. R. Bölckow, A. Heymann, R. Kandler, H. Liebert:
Entwurf und Implementation eines Simulators für die zeitdiskrete Simulation in Modula-2
Diplomarbeit, Fachbereich Informatik, Universität Hamburg, 1989

```
        operation_time   : SimTime;
        rear_buffer      : Res.Object;
        conveyor_cap,
        conveyor_fill    : CARDINAL;
    END;
```

Jedes System verfügt im Modell über eine Eingangsstelle (*shift_place*), an der geprüft wird, ob eine Palette das System betreten kann und auf welchem Weg sie durch das System geleitet wird. Für diese Prüfung ist auch die boole'sche Variable *blocked* notwendig. Hiermit werden evt. auftretende Zeitgleichheiten beim Übergang von System 4 nach System 5 bzw. von System 8 nach System 1 abgefangen. Gegebenenfalls wird die Palette hier blockiert, falls die Eingangsbedingung noch nicht erfüllt ist (s. Ablaufsteuerung).

Der Puffer vor der Arbeitsstation sowie das Hauptband sind als einfache Zähler realisiert, die die aktuelle Füllung beinhalten. Daneben gibt es je einen Zähler für die maximal mögliche Füllung, die sich als Quotient aus der Länge des Bandes und der Palettenlänge ergibt, wobei nur ganzzahlige Lösungen erlaubt sind.

Die Arbeitsstation sowie der Puffer hinter der Station sind durch Ressourcen modelliert, wodurch sich hier die Ablaufsteuerung vereinfacht. Durch die interne Warteschlange einer Ressource kann ein möglicher Stau im Puffer einfach abgebildet werden. Die Palette wartet die Zeit ab, die sie für einen reibungslosen Durchlauf durch den Puffer benötigen würde und fordert dann die Ressource der Station an. In DESMO wird sie nun automatisch an das Ende der Warteschlange der Ressource eingereiht. Sollten sich noch andere Paletten vor ihr befinden, so stehen diese ebenfalls noch in der Warteschlange. Die Zeit, die eine Palette in der Warteschlange verbringt, ist somit identisch mit der Zeit, die sie im Puffer stehen würde, ohne sich fortzubewegen. Verläßt eine Palette die Station und gibt die Ressource frei, so wird von DESMO automatisch die erste wartende Palette in der Warteschlange (falls vorhanden) aktiviert. Sie setzt dann selbstständig ihre Handlungen fort. Ebenso kann eine Palette eine Arbeitsstation erst verlassen, wenn der Puffer hinter der Station frei ist. Falls dieser Puffer noch durch eine andere Palette besetzt ist, kann diejenige aus der Station nicht weiter und wird blockiert. Die Reaktivierung erfolgt auch hier automatisch in dem Moment, wo der hintere Puffer freigegeben wird.

Der zuerst eingeschlagene Weg, sowohl den Puffer als auch das Hauptband als Ressource zu modellieren, brachte ein Problem für die Ablaufsteuerung mit sich. Wenn eine Palette in einem System ankommt, in dem sie beide Wege durch das System nehmen kann, ist es möglich, daß die Kapazitäten des Puffers und des Förderbandes erschöpft sind und sie vorerst blockiert wird. Erst wenn eine Kapazität frei wird, kann sie ihren Weg durch das System fortsetzen. Bei der Modellierung mit Ressourcen und einer einstweiligen Blockierung müsste die Palette im voraus wissen, welche Ressource (Puffer oder Hauptband) als nächstes freigegeben wird, damit sie die "richtige" anfordert und bei

Freigabe derselben sofort weiterlaufen kann. Liegt dieses Wissen nicht vor, so kann es passieren, daß die Palette Ressource A anfordert, Ressource B aber zuerst freigegeben wird. Dadurch würde die Palette unnötig blockiert werden, da sie in der internen Warteschlange der Ressource A solange blockiert wird und dort erst freikommt, wenn ihr eine Ressource A zugeteilt wird.
Es wurde daher der Weg gewählt, die Eingangsstelle durch ein Objekt für bedingtes Warten zu modellieren. Hier wird bei Ankunft der Palette überprüft, ob sie das System betreten kann. Ist dies nicht der Fall, wird sie vorerst blockiert. Bei einer für die Eintrittsbedingung relevanten Zustandsänderung, muß eine erneute Überprüfung dann explizit eingeleitet werden.

Die letzten Komponenten sind die Bearbeitungszeit einer Palette in einer Station und der Stationstyp. Letzterer beschreibt die Station des Systems, da es mehrere Systeme gibt, in denen derselbe Stationstyp realisiert ist.

Zwischentransportbänder:

Mit den Zwischentransportbändern sind die Verbindungen zwischen den einzelnen Systemen gemeint, wobei diese Verbindung zwischen den Systeme 4 und 5 sowie 8 und 1 entfällt. Falls keine Blokkierung vorliegt, können Paletten direkt von einem System in das nächste überwechseln.
Eine solche Verbindung besteht aus einem Transportband sowie der entsprechenden Transportzeit. Auch diese beiden Komponenten sind in einem RECORD zusammengefaßt:

```
connection_structure = RECORD
                          c_belt            : Res.Object;
                          transport_time    : SimTime;
                       END;
```

Durch die Modellierung der Zwischentransportbänder als Ressourcen ergeben sich zwei Vorteile. Zum einen dient die interne Warteschlange ebenso wie bei einer Arbeitsstation dazu, bei einem evt. auftretenden Stau die Paletten aufzunehmen. Die Paletten stehen in der Reihenfolge in der Warteschlange, in der sie auf dem Hauptband stehen. Zum anderen muß die Ausgangsstelle aus einem System nicht extra modelliert werden. Eine Palette, die in einer Station fertig bearbeitet wurde und durch den hinteren Puffer gelaufen ist, bekommt eine höhere Priorität und fordert ebenfalls das nächste Zwischentransportband an. Aufgrund der höheren Priorität steht sie an erster Position in der Warteschlange der Ressource und wird bei deren Freigabe vor den Paletten weiterbefördert, die über das Hauptband kommen.
Bedingt durch das Fehlen dieser Transportbänder zwischen den Systemen 4 und 5 sowie 1 und 8 ergibt sich dort eine etwas andere Modellierung. Die Regelung wird hier von der Eingangsstelle des nächsten Systems übernommen (s. Ablaufsteuerung).
Die Zwischentransportbänder sind dem jeweiligen vorhergehenden System zugeordnet.

Paletten:

Mit den Paletten wird der wichtigste Bestandteil der Fertigungsanlage beschrieben. Da es die Paletten sind, die sich aktiv durch die Fertigungsanlage bewegen, erfolgt die Modellierung als Prozeß, d. h. jede Palette ist als eigenständiger Prozeß mit eigener Ablaufsteuerung realisiert. Für jede Palette wird ein solcher Prozeß erzeugt, der während der gesamten Simulationsdauer existiert, da sich die Paletten permanent im System befinden.

Für die Steuerung durch das System werden für jede Palette Attribute benötigt, auf die sie während der Simulation zugreifen kann. In DESMO wird ein jeweiliger Prozeß (hier: eine Palette) durch ein Entity repräsentiert, für welches Attribute in einem Record zusammengefaßt werden können. Bei der Erzeugung eines neuen Entity wird diesem ein Zeiger auf einen solchen Record mitgegeben, über den das Entity auf seine Attribute zugreifen kann. Im einzelnen hat der RECORD für die Paletten folgende Komponenten:

```
pallet_structure = RECORD
                      load_time          : SimTime;
                      old_system,
                      new_system         : [1..8];
                      stations           : BITSET;
                      station_elements   : [0..4];
                      in_station,
                      from_station       : BOOLEAN;
                   END;
```

Wenn die Palette in System 1 durch die Arbeitsstation A1 beladen wird, wird der Zeitpunkt dieser Aktion in der Variablen *load_time* festgehalten, der für die spätere Auswertung der Ergebnisse notwendig ist. Mit den beiden Variablen *old_system* und *new_system* kann sich die Palette im Gesamtsystem orientieren. Der Variablen *stations* wird beim Beladen der Palette eine Menge zugewiesen, die die Arbeitsstationen enthält, in denen die Palette bearbeitet werden muß. Nach einer Bearbeitung wird die Menge genau um das Element reduziert, welches die aktuelle Arbeitsstation repräsentiert. Die Variable *station_elements* enthält die Anzahl der Elemente von *stations*. Dieser Zähler wird gebraucht, da in Modula-2 keine Funktion zur Ermittlung der Anzahl von Elementen einer Menge existiert. Der Zähler ist u. a. notwendig zur Entscheidung, ob eine Palette in einem System bearbeitet werden soll (s. Ablaufsteuerung). Ebenso für die Steuerung notwendig sind die boole'schen Variablen.

3. Modellannahmen und Modelldaten

Aus der Aufgabenstellung wurden die folgenden Annahmen abgeleitet:

- Als Zeitbasis wurden Minuten gewählt. Alle zeitbehafteten Variablen im Modell beziehen sich auf diese Zeitbasis.
- Die Länge einer Palette wird mit 0.36m angegeben. Da die Länge der Puffer, der Hauptbänder und der Zwischentransportbänder jeweils ein Vielfaches von 0.4m ist, wird angenommen, daß eine Palette den Platz von 0.4m beansprucht, d. h. es können sich auf einem Transportmittel immer nur eine ganze Anzahl von Paletten befinden.
- Als Zeiteinheit (*time_unit*) wird die Zeit bezeichnet, die eine Palette benötigt, um 0.4m zurückzulegen. Sie berechnet sich aus der Geschwindigkeit der Förderbänder, die für jedes Band 18 m/min beträgt. (*time_unit* = 1/45 min.)
- Biegt eine Palette in den Puffer einer Arbeitsstation ab, so sind dazu 2 s = 1/30 min (*shift_time*) notwendig. Nachfolgende Paletten werden in ihrem Ablauf durch den Bandwechsel nicht beeinflußt und können, soweit keine Blockierung vorliegt, ihren Weg fortsetzen. Dies bedeutet z. B., daß auch zwei Paletten direkt hintereinander in den Puffer einer Station eintreten können, obwohl die erste Palette den Schieber noch nicht verlassen hat.
- Die Simulation soll mit der betrachteten Anzahl leerer Paletten im System beginnen, wobei sich die Paletten wahlweise auf den Hauptbändern befinden dürfen, jedoch nicht in den Puffern oder Arbeitsstationen. Letztere Annahme begrenzt die maximale Anzahl der Paletten im System auf 40. (Summe der Kapazitäten der Hauptbänder und Zwischentransportbänder.)
  Der Anfangszustand wird in diesem Modell erreicht, indem die Paletten über das Zwischentransportband hinter System 1 eingeschleust werden und sich gemäß ihrer Handlungsbeschreibung durch das Gesamtsystem bewegen. Die Simulation wird von dem Zeitpunkt an gerechnet, zu dem die letzte leere Palette das Gesamtsystem betritt.
- Auf Grund der Annahme, daß leere Paletten zu Anfang nicht in Puffern und Arbeitsstationen stehen dürfen, wird davon ausgegangen, das leere Paletten auch während der Simulation nicht in die Stationen abbiegen dürfen. Hiervon ausgenommen ist Station 1, in der leere Paletten beladen werden. Diese Annahme ist nur für die Steuerung in der Anfangsphase relevant, da sich danach keine leeren Paletten mehr im Gesamtsystem befinden.
- Eine Palette wird in A1 beladen und muß danach die Stationen A2, A3, A4 und A5 durchlaufen, ehe sie wieder in A1 entladen werden kann. Dabei kann sie erst in A2 und anschließend in A3, A4, A5 bearbeitet werden, wobei es nicht auf die Reihenfolge bei den drei letztgenannten Stationen ankommt.

Ebenso ist die umgekehrte Reihenfolge möglich, d. h. A2 wird als letzte Station durchlaufen.
Zusätzlich gibt es die flexible Station A6, die die Aufgaben von A3, A4 oder A5 übernehmen kann, wobei bei jedem Durchlauf einer Palette immer nur eine Maschine nachgebildet werden kann.

- Wird eine Palette durch Station A6 bearbeitet, so ist die Auswahl, ob Station A3, A4 oder A5 nachgebildet wurde, nicht festgelegt. Hier wird die erste der Stationen A3, A4, A5 als bearbeitet angesehen, die in der Menge der noch zu bearbeitenden Stationen gefunden wird.
- In Station A1 wird eine Palette ent- und beladen (jeweils 7.5 Sec). Als vereinfachende Annahme wird in der Anfangsphase eine leere Palette in A1 ebenfalls "entladen". Für die Ergebnisse ist dieses nicht relevant, da sich zum Reset-Zeitpunkt der Statistik (120. Min.) keine leeren Paletten mehr im System befinden.

4. Ablaufsteuerung

Im Hauptprogramm wird als erstes die Initialisierungsroutine aufgerufen, die die Systeme und Zwischentransportbänder einrichtet sowie den Filenamen für die Ausgabedateien und die Anzahl der Paletten im System (1..40) einliest.
Danach wird der Puffer von Station 1 als voll gekennzeichnet, damit keine Palette zu dieser Station abbiegen kann, bevor nicht alle Paletten im Gesamtsystem sind. Die Paletten werden nun erzeugt und angestoßen, wobei das Hauptprogramm selbst das Zwischentransportband 1 anfordert, nachdem die vorletzte Palette erzeugt wurde. Bekommt das Hauptprogramm das Zwischentransportband zugewiesen, so sind alle bislang erzeugten Paletten im Gesamtsystem. Das Hauptprogramm gibt das Zwischentransportband sofort wieder frei, erzeugt die letzte Palette und stößt diese an. Sie kann sofort das freie Zwischentransportband belegen und ist damit im System. Dadurch kann bei einer unterschiedlichen Anzahl von Paletten der Zeitpunkt bestimmt werden, ab dem die Simulationszeit genommen werden kann.
Die Simulation beginnt dadurch, daß sich das Hauptprogramm für den Zeitraum der Simulation passiviert. Es wird zwischendurch nur noch einmal aktiv, um nach der vorgegebenen Anlaufphase von 120 min die statistischen Zähler zurückzusetzen. Nach Ablauf der Simulationszeit wird vom Hauptprogramm aus die Ergebnisausgabe veranlaßt.
Die Steuerung der Paletten ist in ihrer Prozeßbeschreibung enthalten.

Paletten-Prozeß:

Der Programmteil bis zur LOOP-Schleife dient zur Initialisierung der Palette und zum Einschleusen derselben in das System. Der eigentliche Ablauf wird innerhalb der LOOP-Schleife beschrieben.

Wenn eine Palette ein neues System erreicht, wird zuerst überprüft, ob sie in dieses System eintreten kann und ggf. zur Arbeitsstation abbiegt. Dieses wird über ein *Condq.Object* realisiert, welches von jeder Palette durchlaufen wird. Es wird hier die Eintrittsbedingung überprüft, die in der boole'schen Funktionsprozedur *Entry* zusammengefaßt ist. Liefert die Funktion FALSE, d. h. die Palette kann im Moment nicht weiter, wird sie automatisch blockiert. Bei einer für die Bedingung relevanten Zustandsänderung, die explizit mit *CondQ.Signal* angezeigt werden muß, erfolgt eine erneute Überprüfung der Bedingung und die Palette wird ggf. aus der Warteschlange entfernt und aktiviert. Bei der Überprüfung kommt die Variable *blocked* eines Systems zum tragen, die jedoch nur beim Übergang von System 4 nach System 5 bzw. von System 8 nach System 1 benötigt wird. Es ist theoretisch möglich, daß gleichzeitig vor dem hinteren Schieber von System 4 (System 8) eine Palette vom Puffer hinter der Station und eine vom Hauptband ankommt. Die von der Station kommende Palette hat im Moment Priorität, jedoch muß ausgeschlossen werden, daß sich die Palette vom Hauptband über die andere schiebt.

Dies soll anhand einer möglichen Konstellation verdeutlicht werden: Beide Paletten kommen gleichzeitig am hinteren Schieber an und wollen über das Hauptband des nächsten Systems weiter. Die vom Hauptband kommende Palette muß in ihrem Ablauf jetzt solange blockiert werden, bis die von der Station kommende Palette den Schieber durchquert hat. Erst danach kann sich die vom Hauptband kommende Palette weiterbewegen, die nun unmittelbar an die andere Palette anstößt. Unterbleibt diese Blockierung, würde sich die Palette vom Hauptband auf die andere schieben, was ausgeschlossen sein soll.

Gesagtes gilt in gleicher Form für Konstellationen, bei denen Paletten innerhalb solcher kurzer Zeitabstände den Schieber erreichen, in denen eine Palette diesen noch nicht vollständig durchquert hat. Hier wird ebenfalls die später ankommende Palette bis zu dem Zeitpunkt blockiert, bis die erste das Ende des Schiebers erreicht hat.

Die Lösung dieses Problems erfolgt durch die Variable *blocked*, die bei dem Wunsch einer Palette ein System zu betreten u. a. abgefragt wird. Sie wird auf TRUE gesetzt, wenn eine Palette den Schieber betritt. Wenn sie das Ende des Schiebers erreicht hat, wird *blocked* wieder auf FALSE gesetzt und eine nachfolgende Palette kann ihren Weg fortsetzen, sofern auch die anderen Bedingungen erfüllt sind.

Für die Übergänge zwischen den anderen Systemen braucht diese Variable nicht verändert zu werden (Default = FALSE). Um hier ein System zu verlassen, wird die Ressource des nachfolgenden Zwischentransportbandes angefordert. Die Paletten werden automatisch in die Warteschlange der Ressource eingereiht und gemäß dieser Reihenfolge wird jeweils der ersten Wartenden die Ressource zugeteilt, d. h. es kann immer nur eine Palette weiter, während die anderen durch die nicht vorhandene Ressource automatisch blockiert werden.

Bei einer evt. auftretenden Zeitgleichheit von Paletten steht die Palette von der Station aufgrund ihrer Priorität an erster Stelle der Warteschlange und bekommt die Ressource zuerst zugeteilt. Die Ressource wird erst freigegeben, wenn die Palette, der sie zugeteilt wurde, über das Zwischentransportband gelaufen ist und in das nächste System eintreten kann. Eine nachfolgende Palette kann somit nicht mehr mit der ersten in Konflikt kommen.

Falls eine Palette nicht blockiert wurde, gibt es für sie zwei Wege durch ein System. Entweder biegt sie zur Station ab oder sie läuft geradeaus über das Hauptband. In beiden Fällen wird zuerst geprüft, welches System betreten wurde. Für die Systeme 5 und 1 ist weiterhin entscheidend, ob die Palette von der Station oder vom Hauptband des vorherigen Systems kommt. Im ersten Fall muß der Puffer hinter der Station freigegeben werden. Durch die Modellierung als Ressource erfolgt eine Aktivierung einer wartenden Palette automatisch. Wenn dagegen ein Platz auf dem Hauptband frei wird, muß dieses der Eingangsstelle explizit mitgeteilt werden, da eine evt. blockierte Palette ihren Weg fortsetzen könnte.

Nach Eintritt der Palette in ein System besteht der Durchlauf im Wesentlichen aus dem Warten der Zeiteinheiten für den Durchlauf der Förderbänder sowie dem Belegen und Freigeben der Station und dem Puffer hinter der Station. Dabei wird angenommen, daß der Übergang vom Puffer zur Station ebenfalls eine Zeiteinheit benötigt. In System 1 mit Station A1 kommt noch zusätzlich nach Durchlauf der Palette durch die Station hinzu, daß die Statistik fortgeschrieben wird und die Attribute der Paletten für einen neuen Systemdurchlauf entsprechend gesetzt werden.

Beim Verlassen des Systems ist noch darauf zu achten, welches System als nächstes betreten werden soll. Bei System 5 oder 1 reiht sich die Palette gleich in die Eingangsstelle ein. Bei den anderen Systemen muß die Palette zuerst das Zwischentransportband anfordern und die Transportzeit warten, ehe sie die Eingangsstelle des nächsten Systems betreten kann.

Es stellte sich noch die Frage, wie die Bearbeitungsreihenfolge gelöst werden sollte. Die hier realisierte Lösung faßt alle zu durchlaufende Stationen A2, A3, A4, A5 in einer Menge zusammen. Nach Bearbeitung durch eine Station wird das entsprechende Element entfernt. Die Elemente der Menge sowie die Anzahl der Elemente (*station_elements*) sind bestimmen, ob eine Palette in eine Station abbiegen möchte. In A1 kann sie nur abbiegen, wenn keine Elemente mehr in der Menge vorhanden sind, d. h. die Palette wurde von allen Stationen bearbeitet. Zu einer Station A2 kann sie abbiegen, wenn noch alle Elemente vorhanden sind (die Palette wird durch A2 als erstes bearbeitet) oder A2 nur noch als letztes Element vorhanden ist. Zu A3, A4, A5 kann sie abbiegen, wenn die Station als Element vorhanden ist. Die Prüfung, ob eine Station A2 zuerst oder zuletzt durchlaufen wird, erfolgt bei Prüfung an den entsprechenden Systemen mit Stationstyp A2. Zu A6 kann sie abbiegen, wenn eine der Stationen A3, A4, A5 in der Menge enthalten ist.

Diese Regelungen gelten nur für volle Paletten, da leere Paletten ein System immer über das Hauptband durchlaufen. Ausnahme ist Station A1, in die leere Paletten zum Beladen abbiegen dürfen.

5. Simulationsergebnisse

Simulationsläufe wurden mit 10 bis 40 Paletten im System bei einer Schrittweite von 5 Paletten durchgeführt. Der vorgegebene Lauf mit 60 Paletten konnte aus genannten Gründen nicht durchgeführt werden. Simuliert wurde jeweils über eine Zeit von 10 Stunden, wobei nach 2 Stunden ein Reset der statistischen Größen durchgeführt wurde. Die für die Aufgabenstellung relevanten Daten wurden mit Hilfe eines *Count*- und eines *Tally*-Objektes aus DESMO ermittelt. Ersteres realisiert eine einfache Zählfunktion mit der die Anzahl der bearbeiteten Paletten ermittelt wurde. Ein *Tally*-Objekt unterstützt die Ermittlung von Mittelwerten ohne zeitliche Gewichtung und wurde zur Berechnung der durchschnittl. Zeit einer Palette im System verwendet. Die Ausgabe erfolgt über die jeweiligen Standard-Reports von DESMO (vgl. Anhang C).

Beide Reports zeigen neben ihrem Titel, der bei der Initialisierung zugewiesen wird, den Zeitpunkt an, zu dem ein Reset durchgeführt wurde. Die Größe *Obs* stellt bei einem Count-Report die Summe der Beobachtungsgrößen dar, wogegen sie im Tally-Report die Anzahl der Aktualisierungen angibt. Im Tally-Report wird dann der Mittelwert und die Standardabweichung aufgelistet sowie der kleinste und größte Wert der Beobachtungsgrößen.

Die aufgelisteten Reports werden von DESMO jeweils zu unterschiedlichen Zeiten ausgegeben. Diese sind jedoch abhängig von der Anzahl der betrachteten Paletten, da es unterschiedlich lange dauert, bis 10 oder 40 Paletten im System sind und die Simulationszeit erst ab dem Zeitpunkt gerechnet wird, an dem die letzte leere Palette das System betreten hat.

Die wichtigsten Ergebnisse der durchgeführten Simulationsläufe sind in Tabelle 1 zusammengefaßt. Aus ihnen geht hervor, daß 20 eine akzeptable Anzahl von Paletten darstellt. Eine geringere Anzahl vermindert den Durchsatz, jedoch nicht die mittlere Zeit, die eine Palette im System zubringt. Andererseits erhöht sich der Durchsatz nicht, wenn sich mehr Paletten im System befinden. Dagegen steigt die mittlere Zeit einer Palette im System beträchtlich an.

Anzahl Paletten	Durchsatz (Paletten)	mittl. Zeit einer Palette im System (min)
10	939	5.1
15	1351	5.3
20	1408	6.8
25	1407	8.5
30	1409	10.2
35	1408	12.0
40	1409	13.7

Tab. 1: Ergebnisse

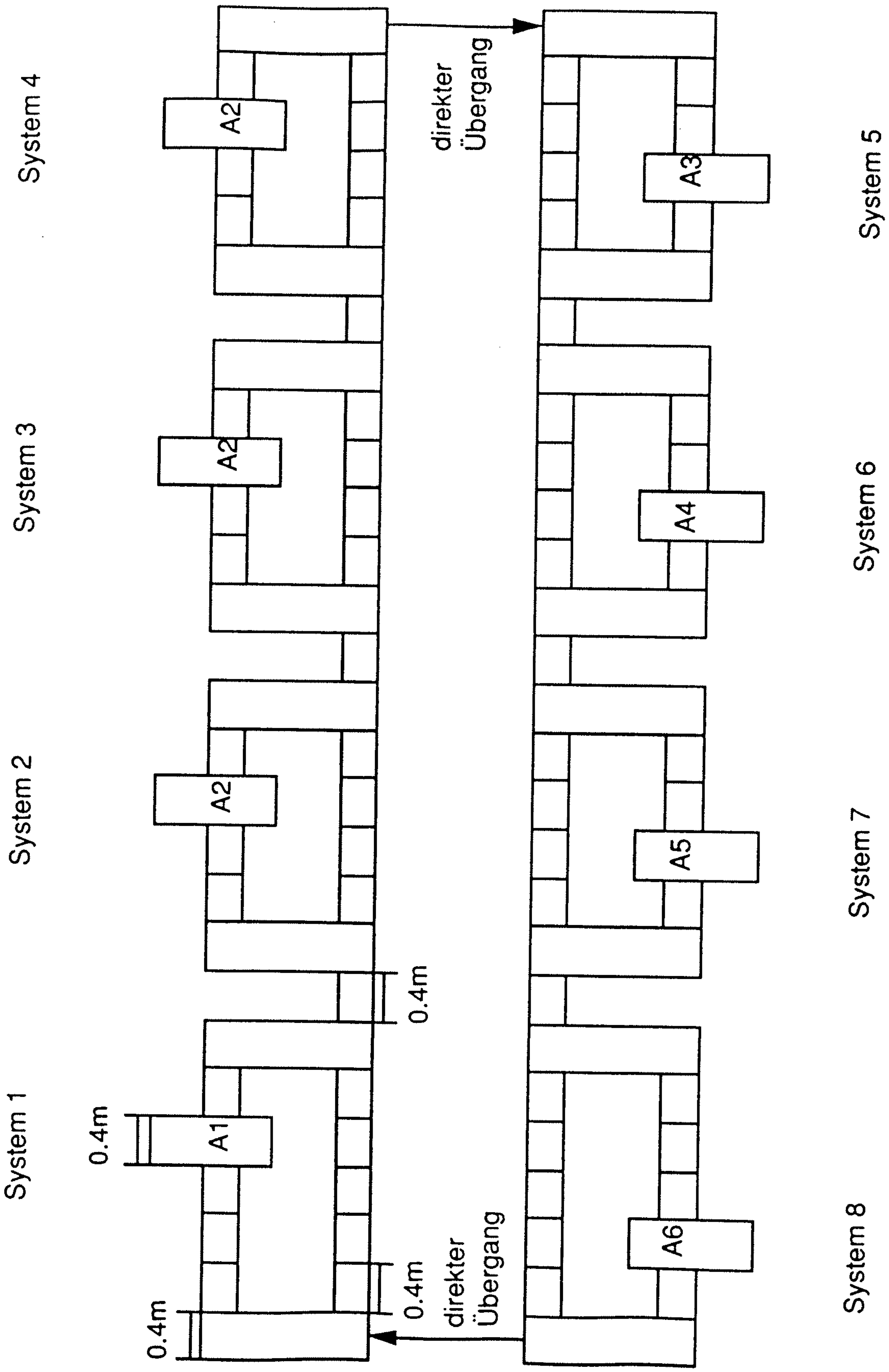


Abbildung 1: Aufbau der Fertigungsanlage

Anhang B: Programmlisting

```
(* Flexible Assembly System *)
(* see EUROSIM - Simulation News Europe, Number 1, Mar 1991, p. 28 *)
(* and EUROSIM - Simulation News Europe, Number 2, Jul 1991, p. 26 *)
(* Programmer  : Dirk Martinssen *)
(* last change : 23.01.91        *)

MODULE EuroSim;

(* procedures of DESMO *)
FROM ProcessSimulation IMPORT Entity, New, Schedule, SetPriority,
                              Attributes, Current, Hold, SimTime,
                              Time, NOW, Reset, SetReportFile,
                              SetErrorFile, CloseFiles;
FROM StringHdl IMPORT Copy, CardToString, Trim, Concat;
IMPORT Res, CondQ, Count, Tally;
FROM CondQ IMPORT WaitUntil, Signal;
FROM ReportIO IMPORT WriteString, WriteCard, WriteReal, WriteLn;

(* procedures of Modula-2 *)
FROM IO IMPORT RdStr, WrStr, WrLn, RdCard, WrCard, WrReal;
FROM Storage IMPORT ALLOCATE, DEALLOCATE;

CONST shift_time = 1.0 / 30.0;  (* time to shift from B1 to B2 or back *)
      time_unit = 1.0 / 45.0;   (* transport time for 0.4m on conveyor *)

TYPE  (* attributes of a conveyor between two systems *)
      connection_structure = RECORD
                               c_belt         : Res.Object;
                               transport_time : SimTime;
                             END;

      (* attributes of a system *)
      system_structure = RECORD
                           shift_place        : CondQ.Object;
                           buffer_cap,
                           buffer_fill        : CARDINAL;
                           station            : Res.Object;
                           typ                : [1..6];
                           operation_time     : SimTime;
                           rear_buffer        : Res.Object;
                           conveyor_cap,
                           conveyor_fill      : CARDINAL;
                           blocked            : BOOLEAN;
                         END;

      (* attributes of a pallet *)
      pallet_structure = RECORD
                           load_time        : SimTime;
                           old_system,
                           new_system       : [1..8];
                           stations         : BITSET;
                           station_elements : [0..4];
```

```
                              in_station,
                              from_station      : BOOLEAN;
                            END;

      pallet_attributes = POINTER TO pallet_structure;

VAR   system     : ARRAY [1..8] OF system_structure;
      connection : ARRAY [1..8] OF connection_structure;

      nr_of_tasks, i       : CARDINAL;
      pallet_attr          : pallet_attributes;
      throughput           : Count.Object;
      avg_throughput_time  : Tally.Object;

PROCEDURE time_in_system () : REAL;
(* procedure for statistics             *)
(* result: time of a pallet in the system *)
VAR attr : pallet_attributes;
BEGIN
  attr := Attributes (Current ());
  RETURN (Time () - attr^.load_time);
END time_in_system;

PROCEDURE Init;

VAR c_cap                                  : ARRAY [1..8] OF CARDINAL;
    b_cap, kind                            : ARRAY [1..8] OF CARDINAL;
    o_time                                 : ARRAY [1..8] OF SimTime;
    operation_time1, operation_time2,
    operation_time3, operation_time4       : SimTime;
    name, nr, name_with_nr,
    name2, name2_with_nr,
    name3, name3_with_nr                   : ARRAY [1..12] OF CHAR;
    FileName                               : ARRAY [1..8] OF CHAR;
    Extension                              : ARRAY [1..4] OF CHAR;
    RF, EF,                                : ARRAY [1..12] OF CHAR;
    i                                      : CARDINAL;

BEGIN

operation_time1 := 0.25;                (* operation time of A1         *)
operation_time2 := 1.0 / 3.0;           (* operation time of A3, A4, A5 *)
operation_time3 := 0.5;                 (* operation time of A6         *)
operation_time4 := 1.0;                 (* operation time of A2         *)

c_cap  [1] := 5;    b_cap [1] := 3;        (* capacities of B1 (c_cap) *)
c_cap  [2] := 4;    b_cap [2] := 2;        (* capacities of B2 (b_cap) *)
c_cap  [3] := 4;    b_cap [3] := 2;
c_cap  [4] := 4;    b_cap [4] := 2;
c_cap  [5] := 4;    b_cap [5] := 2;
c_cap  [6] := 4;    b_cap [6] := 2;
c_cap  [7] := 4;    b_cap [7] := 2;
c_cap  [8] := 5;    b_cap [8] := 3;
```

```
o_time [1] := operation_time1;   kind [1] := 1;   (* kind = stationtyp *)
o_time [2] := operation_time4;   kind [2] := 2;
o_time [3] := operation_time4;   kind [3] := 2;
o_time [4] := operation_time4;   kind [4] := 2;
o_time [5] := operation_time2;   kind [5] := 3;
o_time [6] := operation_time2;   kind [6] := 4;
o_time [7] := operation_time2;   kind [7] := 5;
o_time [8] := operation_time3;   kind [8] := 6;

Copy ("station_", name);
Trim (name);
Copy ("shifting_", name2);
Trim (name2);
Copy ("r_buffer_", name3);
Trim (name3);
(* initialization of the systems *)
FOR i := 1 TO 8 DO
   CardToString (i, 2, nr);
   Concat (name, nr, name_with_nr);
   Concat (name2, nr, name2_with_nr);
   Concat (name3, nr, name3_with_nr);
   WITH system [i] DO
     shift_place := CondQ.New (name2_with_nr, FALSE);
     buffer_cap := b_cap [i];
     buffer_fill := 0;
     station := Res.New (name_with_nr, 1);
     typ := kind [i];
     operation_time := o_time [i];
     rear_buffer := Res.New (name3_with_nr, 1);
     conveyor_cap := c_cap [i];
     conveyor_fill := 0;
     blocked := FALSE;
   END; (* WITH *)
END; (* FOR *)

Copy ("connect_", name);
Trim (name);
(* initialization of the conveyors between the systems *)
FOR i := 1 TO 8 DO
   CardToString (i, 2, nr);
   Concat (name, nr, name_with_nr);
   WITH connection [i] DO
     c_belt := Res.New (name_with_nr, 1);
     transport_time := time_unit;
   END; (* WITH *)
END;

(* initialization of statistic objects *)
throughput := Count.New ("throughput");
avg_throughput_time := Tally.New ("avg through", time_in_system);

WrStr ("Please enter filename for output ( <=8 characters) : ");
RdStr (FileName); WrLn;
```

```
Copy (FileName, RF);
Trim (RF);
Extension := ".RPT";
Concat (RF, Extension, RF);
Copy (FileName, EF);
Trim (EF);
Extension := ".ERR";
Concat (EF, Extension, EF);
SetReportFile (RF);
SetErrorFile (EF);

REPEAT
   WrStr ("Please enter the maximal number of simultaneous pallets");
   WrLn;
   WrStr ("in the system (1 <= x <= 40)  -> ");
   nr_of_tasks := RdCard ();
UNTIL (1 <= nr_of_tasks) AND (nr_of_tasks <= 40);

END Init;

PROCEDURE Entry (pallet : Entity) : BOOLEAN;
(* procedure to check if a pallet can enter a system and if it        *)
(* will enter the station of the system. Used in combination          *)
(* with the object for conditional waiting of a system (shift_place) *)
VAR full_conveyor,
    full_buffer,
    work_in_station,
    turn_to_station : BOOLEAN;
    attr            : pallet_attributes;

BEGIN
  attr := Attributes (pallet);
  WITH system [attr^.new_system] DO
    full_conveyor  := (conveyor_cap = conveyor_fill);
    full_buffer    := (buffer_cap = buffer_fill);

    CASE attr^.new_system OF
    1       : work_in_station := (attr^.station_elements = 0); |
    2, 3, 4 : work_in_station := ((attr^.station_elements = 4)
                                  OR
                                  ((2 IN attr^.stations)
                                    AND
                                    (attr^.station_elements = 1))); |
    5       : work_in_station := (3 IN attr^.stations); |
    6       : work_in_station := (4 IN attr^.stations); |
    7       : work_in_station := (5 IN attr^.stations); |
    8       : work_in_station := NOT (((2 IN attr^.stations)
                                      AND (attr^.station_elements = 1))
                                    OR (attr^.station_elements = 0));
    END; (* CASE *)
```

```
    turn_to_station := (NOT full_buffer
                            AND work_in_station AND NOT blocked);
    IF turn_to_station OR (NOT full_conveyor AND NOT blocked)
       THEN IF turn_to_station
               THEN attr^.in_station := TRUE;
               ELSE attr^.in_station := FALSE;
            END;
            RETURN TRUE;
       ELSE attr^.in_station := FALSE;
            RETURN FALSE;
    END;
  END; (* WITH *)
END Entry;

PROCEDURE PalletProcess (pallet : Entity);
(* process description of a pallet *)

VAR attr         : pallet_attributes;
    j            : CARDINAL;

   PROCEDURE TickOffStation;
   (* local procedure to remove a station *)
   (* from the set of unmachined stations *)
   VAR station_typ : CARDINAL;
     BEGIN
       WITH attr^ DO
          CASE system [new_system].typ OF
            2, 3, 4, 5 : EXCL (stations, system [new_system].typ);
                     6 : station_typ := 3;
                         WHILE (NOT (station_typ IN stations))
                            DO INC (station_typ);
                         END;
                         EXCL (stations, station_typ);
          END; (* CASE *)
          DEC (station_elements);
       END; (* WITH *)
     END TickOffStation;

BEGIN

(* initialization of the pallet *)
attr := Attributes (pallet);
WITH attr^ DO
   load_time := Time ();
   old_system := 1;
   new_system := 2;
   stations := {};
   station_elements := 0;
   in_station := FALSE;
   from_station := FALSE;
END;
```

```
(* assignments to put a pallet in the system *)
SetPriority (pallet, 1);
Res.Acquire (connection [attr^.old_system].c_belt, 1);
SetPriority (pallet, 0);
Hold (connection [attr^.old_system].transport_time);

(* process description *)
LOOP
WITH attr^ DO
  (* test to enter a system *)
  WaitUntil (system [new_system].shift_place, Entry);
  IF in_station
     (* enter a station *)
     THEN IF (new_system = 1) OR (new_system = 5)
             THEN IF from_station
                     THEN (* come from buffer behind station *)
                          Res.Release (system [old_system].rear_buffer, 1);
                          SetPriority (pallet, 0);
                          system [new_system].blocked := TRUE;
                          INC (system [new_system].buffer_fill);
                          Hold (shift_time);
                     ELSE (* come from B1 *)
                          DEC (system [old_system].conveyor_fill);
                          Signal (system [old_system].shift_place);
                          system [new_system].blocked := TRUE;
                          INC (system [new_system].buffer_fill);
                          Hold (time_unit);
                  END;
                  system [new_system].blocked := FALSE;
                  Signal (system [new_system].shift_place);
             ELSE Res.Release (connection [old_system].c_belt, 1);
                  INC (system [new_system].buffer_fill);
          END;
          (* wait time to change from B1 to B2 *)
          Hold (shift_time);
          (* wait time to go through the buffer *)
          FOR j := 1 TO (system [new_system].buffer_cap)
             DO Hold (time_unit);
          END;
          (* acquire station *)
          Res.Acquire (system [new_system].station, 1);
          DEC (system [new_system].buffer_fill);
          Signal (system [new_system].shift_place);
          (* wait time to go in station *)
          Hold (time_unit);
          from_station := TRUE;
          IF (new_system = 1)
             THEN (* wait time to unload palett *)
                  Hold (system [new_system].operation_time / 2.0);
                  (* statistics *)
                  Count.Update (throughput, 1);
                  Tally.Update (avg_throughput_time);
```

```
          (* new initialization of the pallet *)
          stations := {2, 3, 4, 5};
          station_elements := 4;
          load_time := Time ();
          (* wait time to load palett *)
          Hold (system [new_system].operation_time / 2.0);
     ELSE (* wait operation time *)
          Hold (system [new_system].operation_time);
          TickOffStation;
  END;
  (* acquire buffer behind station *)
  Res.Acquire (system [new_system].rear_buffer, 1);
  (* release station *)
  Res.Release (system [new_system].station, 1);
  Hold (time_unit);
  new_system := (new_system MOD 8) + 1;
  old_system := (old_system MOD 8) + 1;
  SetPriority (pallet, 1);
  IF NOT ((new_system = 1) OR (new_system = 5))
     THEN (* leave system over conveyor between two systems *)
          Res.Acquire (connection [old_system].c_belt, 1);
          Res.Release (system [old_system].rear_buffer, 1);
          SetPriority (pallet, 0);
          Hold (shift_time);
          Hold (connection [old_system].transport_time);
  END;
ELSE (* enter B1 *)
  IF (new_system = 1) OR (new_system = 5)
    THEN IF from_station
           THEN (* come from buffer behind station *)
                Res.Release (system [old_system].rear_buffer, 1);
                SetPriority (pallet, 0);
                system [new_system].blocked := TRUE;
                INC (system [new_system].conveyor_fill);
                Hold (shift_time);
           ELSE (* come from B1 *)
                DEC (system [old_system].conveyor_fill);
                Signal (system [old_system].shift_place);
                system [new_system].blocked := TRUE;
                INC (system [new_system].conveyor_fill);
                Hold (time_unit);
         END;
         system [new_system].blocked := FALSE;
         Signal (system [new_system].shift_place);
    ELSE Res.Release (connection [old_system].c_belt, 1);
         INC (system [new_system].conveyor_fill);
  END;
  (* wait time to go through B1 + shiftplace *)
  FOR j := 1 TO (system [new_system].conveyor_cap) + 1
     DO Hold (time_unit);
  END;
  from_station := FALSE;
  new_system := (new_system MOD 8) + 1;
  old_system := (old_system MOD 8) + 1;
```

```
          IF NOT ((new_system = 1) OR (new_system = 5))
             THEN (* leave system over conveyor between two systems *)
                  Res.Acquire (connection [old_system].c_belt, 1);
                  DEC (system [old_system].conveyor_fill);
                  Signal (system [old_system].shift_place);
                  Hold (time_unit);
                  Hold (connection [old_system].transport_time);
          END;
  END;
END; (* WITH *)
END; (* LOOP *)
END PalletProcess;

PROCEDURE SelfReport;
(* report procedure for the results *)
BEGIN
   WriteString ("Flexible Assembly System");
   WriteLn;
   WriteString ("------------------------");
   WriteLn; WriteLn;
   WriteString ("Number of pallets in the system : ");
   WriteCard (nr_of_tasks, 2);
   WriteLn; WriteLn; WriteLn;
   WriteString ("                            Clock Time = ");
   WriteReal (Time (), 3);
   WriteLn;
   WriteString
("************************************************************************
********");
   WriteLn;
   WriteString
("*
    *");
   WriteLn;
   WriteString
("*                            R E P O R T
    *");
   WriteLn;
   WriteString
("*
    *");
   WriteLn;
   WriteString
("************************************************************************
********");
   WriteLn; WriteLn;

   Count.ReportAll;
   Tally.ReportAll;
END SelfReport;
```

```
BEGIN (* Main *)

  Init;

  (* mark buffer in front of A1 as full                              *)
  (* => no pallet can enter A1 until all pallets are in the system *)
  system [1].buffer_fill := system [1].buffer_cap;

  (* generate and start pallet processes *)
  FOR i := 1 TO (nr_of_tasks - 1) DO
     NEW (pallet_attr);
     Schedule (New ("Pallet ", PalletProcess, pallet_attr), NOW ());
  END;

  Res.Acquire (connection [1].c_belt, 1);
  Res.Release (connection [1].c_belt, 1);

  (* last pallet *)
  NEW (pallet_attr);
  Schedule (New ("Pallet ", PalletProcess, pallet_attr), NOW ());

  (* clear buffer in front of station A1 => start simulation *)
  system [1].buffer_fill := 0;
  Signal (system [1].shift_place);

  (* reset statistic after 120 min *)
  Hold (120.0);
  Reset;

  (* wait simulation time (8 h = 480 min) *)
  Hold(480.0);
  SelfReport;

  CloseFiles;
END EuroSim.
```

Anhang C: Report - Ausgaben

Flexible Assembly System

Number of pallets in the system : 10

Clock Time = 600.311

```
**************************************************************************
*                                                                        *
*                              R E P O R T                               *
*                                                                        *
**************************************************************************
```

C O U N T S

Title	(Re)set	Obs
throughput	120.311	939

T A L L I E S

Title	(Re)set	Obs	Mean	Std.Dev	Min	Max
avg through	120.311	939	5.111	0.357	4.755	5.467

Flexible Assembly System

Number of pallets in the system : 15

Clock Time = 600.533

```
**************************************************************************
*                                                                        *
*                              R E P O R T                               *
*                                                                        *
**************************************************************************
```

C O U N T S

Title	(Re)set	Obs
throughput	120.533	1351

T A L L I E S

Title	(Re)set	Obs	Mean	Std.Dev	Min	Max
avg through	120.533	1351	5.333	0.827	3.722	6.589

Flexible Assembly System

Number of pallets in the system : 20

Clock Time = 600.756

R E P O R T

C O U N T S

Title	(Re)set	Obs
throughput	120.756	1408

T A L L I E S

Title	(Re)set	Obs	Mean	Std.Dev	Min	Max
avg through	120.756	1408	6.819	0.971	4.591	13.066

```
Flexible Assembly System
------------------------

Number of pallets in the system : 25


                         Clock Time = 600.978
***********************************************************************
*                                                                     *
*                           R E P O R T                               *
*                                                                     *
***********************************************************************

                            C O U N T S
                            -----------

Title             (Re)set     Obs
------------------------------------
throughput        120.978    1407


                          T A L L I E S
                          -------------

Title             (Re)set     Obs       Mean      Std.Dev      Min       Max
------------------------------------------------------------------------------
avg through       120.978    1407      8.518       2.655      5.363    28.840



Flexible Assembly System
------------------------

Number of pallets in the system : 30


                         Clock Time = 601.200
***********************************************************************
*                                                                     *
*                           R E P O R T                               *
*                                                                     *
***********************************************************************

                            C O U N T S
                            -----------

Title             (Re)set     Obs
------------------------------------
throughput        121.200    1409
```

T A L L I E S

Title	(Re)set	Obs	Mean	Std.Dev	Min	Max
avg through	121.200	1409	10.231	4.636	5.422	42.605

Flexible Assembly System

Number of pallets in the system : 35

Clock Time = 601.422

```
*******************************************************************************
*                                                                             *
*                              R E P O R T                                    *
*                                                                             *
*******************************************************************************
```

C O U N T S

Title	(Re)set	Obs
throughput	121.422	1408

T A L L I E S

Title	(Re)set	Obs	Mean	Std.Dev	Min	Max
avg through	121.422	1408	11.953	5.839	5.847	60.510

```
Flexible Assembly System
------------------------

Number of pallets in the system : 40


                              Clock Time = 601.644
****************************************************************************
*                                                                          *
*                                 R E P O R T                              *
*                                                                          *
****************************************************************************

                                  C O U N T S
                                  -----------

Title            (Re)set     Obs
-------------------------------
throughput       121.644     1409


                                 T A L L I E S
                                 -------------

Title            (Re)set     Obs      Mean      Std.Dev      Min      Max
--------------------------------------------------------------------------
avg through      121.644     1409     13.653      7.558     5.906   70.534
```

Studie

„Leistungsfähigkeit und Verfügbarkeit diskreter Simulationsssoftware"

G. Pflug, Universität Wien

F. Breitenecker, Technische Universität Wien

3.2.1. GPSS/H

3.2.1.1. Allgemeines

GPSS/H ist der Klassiker unter den ereignisorientierten *(discrete-event)* Simulationssprachen. Basierend auf dem von IBM entwickelten Ur-GPSS (General Purpose Simulation System) brachte die Wolverine Software Corporation 1977 Version1 und 1988 Version 2 der kompilierenden Version GPSS/H auf den Markt.

3.2.1.2. Produktdaten

3.2.1.2.1. Hersteller:
Wolverine Software Corporation
4115 Annadale Road, Annadale VA 22003-2500
Tel: 703-750-3910 Fax: 703-642-9634

3.2.1.2.2. Distributor:
Scientific COMPUTERS GmbH
Franzstraße 107, Postfach 1865
D-5100 Aachen
Tel: (0241)26041/42 Fax: (0241)44983

3.2.1.2.3. Plattformen, Systemerfordernisse:
Es existieren GPSS/H-Versionen für PCs , Unix Workstations (Sun-3, SPARC, Hewlett-Packard oder Silicon Graphics9, für VAXes unter VMS und für IBM Mainframe Computer.

3.2.1.2.4. Preis:
auf Anfrage, je nach Version (PC-Version etwa DM 5000.-)

3.2.1.2.5. Verfügbarkeit:
GPSS/H 2.0 Versionen,die unter DOS laufen: Student GPSS/H bietet alle Eigenschaften des kommerziellen GPSS/H und ist nur in der Modellgröße (höchstens 100 Blocks bzw. 200 Statements) begrenzt. Personal GPSS/H läuft auf 286er PCs , die Modellgröße ist auf 640K RAM begrenzt. GPSS/H Professional läuft auf 386er PCs, benützt den "DOS Extender" und macht es möglich mit 2 oder 4 Megabyte RAM große Modelle zu simulieren.

3.2.1.3. Evaluierungsresultate

3.2.1.3.1. User Interface
GPSS/H stelllt keine eigene Editierumgebung zur Verfügung, jeder Texteditor, der Files in ASCII-Format speichert, kann verwendet werden.

3.2.1.3.2. Dokumentation
Schreiber T.J.: "An Indroduction to Simulation Using GPSS/H." John Wiley & Sons, New York, 1991 (Inhalt: Studentenversion; eignet sich als Lehrbuch und zum Selbststudium)
Banks J., Carson J.S.: "Getting Started with GPSS/H". Wolverine Software Corporation, Annadale, USA, 1989 (wird mit der Vollversion mitgeliefert, gutes Lehrbuch)
Henriksen, J.O.: "GPSS/H Reference Manual". Wolverine Software Corporation

3.2.1.3.3. Grundprinzipien
GPSS/H arbeitet mit blockorientierter Beschreibung, die Abarbeitung erfolgt ereignisorientiert. Grundlage der Modellbildung sind *Transactions* , auch *units of traffic* genannt, die von Block

zu Block durch das System wandern. GPSS/H Model Files können in Batch Mode oder Test Mode (Simulation kann Schritt für Schritt verfolgt werden) ausgeführt werden. Basissprache ist Fortran.

3.2.1.3.4. Granularität
GPSS/H ist durch bis zu 80 verschiedene Blöcke (je nach Version) sehr fein strukturiert.

3.2.1.3.5. Grenzen
Da GPSS/H einfach strukturiert ist, besitzt es keine Softwaregrenzen.

3.2.1.3.6. Modellbeschreibung
In einem GPSS/H Modell sind Compiler-Direktiven, gefolgt von der Modellbeschreibung (in Blöcken), und abgeschlossen von Runtime-Befehlen in einer Datei zusammengefaßt.
Bei entsprechender Programmierung,mit Hilfe von Macros, indirekter Adressierung und Zerlegung in Segmente mit unterschiedlichen Aufgaben können GPSS/H Programme aber auch modularen Aufbau erhalten.

3.2.1.3.7. Experimentbeschreibung
Da GPSS/H Modell-, und Experimentbeschreibung nicht trennt: siehe 3.2.1.3.6..

3.2.1.3.8. Output-Analysen
Der im Batchmode standardmäßig erzeugte Postsimulation Report enthält umfangreiche statistische Informationen (aktuelle, durchschnittliche, maximale,.. Werte) über Clocks, Transactions, Blöcke und Randomnumbers. Zusätzlich können Werte von interessanten Variablen gesammelt und dem Report angefügt werden. Auch dokument-ierender Text kann eingebunden werden. Graphische Ausgabemöglichkeiten gibt es nur beschränkt (Histogramme).

3.2.1.3.9. Import/Export von Datenformaten
ASCII Daten können von einem File oder vom Keyboard eingelesen werden, ebenso können Daten auf ein File oder auf den Bildschirm ausgegeben werden.

3.2.1.3.10. Animation
PROOF von Wolverine bietet eine unabhängige, objektorientierte und leicht erlernbare Postanimation. Das GPSS/H Programm wird um Animationsblöcke oder -macros erweitert. PROOF liest dann ein vom Anwender gestaltetes Layout File (graphischer Aufbau: Farben, Objekte,...) ein und arbeitet das vom Simulator erzeugte Trace File zeitsynchronisiert ab.

3.2.1.4. Allgemeine Vorteile

Für GPSS/H spricht das weite Anwendungsfeld, langjährige Erprobung, hohe Verfügbarkeit, Kompatibilität und viele Implementationen.

3.2.1.5. Allgemeine Nachteile

GPSS/H bietet (noch) keine graphische Modellbildung. Bei komplexeren Aufgaben muß eine relativ lange Einarbeitungszeit in Kauf genommen werden.

3.2.1.6. Schlußfolgerung

GPSS/H ist eine klassische, stabile "Allround"-Software; und stellt einen Quasistandard bei den klassischen Sprachen dar. GPSS/H ist allgemein einsetzbar, erfordert aber Einarbeitungszeit.

Beispiele für Modell- und Ergebnisbeschreibung:

```
*****************************************************
*       MODELLTEIL                                  *
*****************************************************
*
*       1. T I S C H E
*
1             GENERATE   ,,,6,110,5PH   TISCHGENERATOR
2             SAVEVALUE  TISCH+,1,XH
3             ASSIGN     1,ERSTTISCH,,PH
4      TISCHA ASSIGN     3,FIRSTISCH,,PH   ABSOLUTE ELEMENTNUMMER
5             ASSIGN     5,PHANPLTZ,,PH    ANZAHL DER PLÄTZE
6      FTISCH LINK       FTISCH,5PH        FREIE TISCHE
7      BTISCH JOIN       BTISCH            BESETZTE TISCHE
8             LINK       BTISCH,5PH
*
```

STORAGE	—AVG-UTIL-DURING— TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS	MAXIMUM CONTENTS
TISCH1	0.424			24	424.152	AVAIL	100.0	4	1.697	2	4
TISCH2	0.283			17	400.071	AVAIL	100.0	4	1.134	0	4
TISCH3	0.345			23	360.071	AVAIL	100.0	4	1.380	4	4
TISCH4	0.465			23	485.424	AVAIL	100.0	4	1.861	4	4
TISCH5	0.314			34	443.025	AVAIL	100.0	8	2.510	0	6
TISCH6	0.369			38	466.635	AVAIL	100.0	8	2.955	4	6

3.2.2. PS SIMDIS

3.2.2.1. Allgemeines

PS SIMDIS ist eine diskrete Simulationssprache, die zur GPSS-Familie gehört.
PS SIMDIS kann als "bequemere" Umgebung von GPSS gesehen werden.

3.2.2.2. Produktdaten

3.2.2.2.1. Hersteller:
Institut für Graphik und Simulation, TU Magdeburg
Postfach 4120
O- 3010 Magdeburg
Tel.: +49-(0)391 5592

3.2.2.2.2. Distributor:
(wie oben)

3.2.2.2.3. Plattformen, Systemerfordernisse:
PS SIMDIS OS/ES : OS Version für PS-Systeme
SIM-PC: allgemeine PC Version.

3.2.2.2.4. Preis:
auf Anfrage

3.2.2.2.5. Verfügbarkeit:
PS SIMDIS: Version für OS/ES, SIM-PC: Version für PC

3.2.2.3. Evaluierungsresultate

3.2.2.3.1. User Interface
Das Programm wird mit Hilfe eines Texteditors eingegeben.

3.2.2.3.2. Dokumentation
Manual

3.2.2.3.3. Grundprinzipien
PS SIMDIS ist eine blockorientierte Simulationssprache. Die Modellbildung erfolgt GPSS-ähnlich: Es gibt statische (storages, facilities,chains,...) und dynamische (transactions) Elemente. Transactions können im Laufe der Simulation erzeugt und vernichtet werden.

3.2.2.3.4. Granularität
Wie GPSS/H ist PS SIMDIS fein strukturiert, entsprechend der GPSSH-Blockstruktur.

3.2.2.3.5. Grenzen
Durch die Hardware beschränkt, auf PC durch DOS begrenzt.

3.2.2.3.6. Modellbeschreibung
wie bei GPSS/H

3.2.2.3.7. Experimentbeschreibung
wie bei GPSS/H

3.2.2.3.8. Output-Analysen
Daten können in Form von Tabellen, Graphiken (Histogrammen, Balkendiagrammen, Graphen,...) ausgegeben werden.

3.2.2.3.9. Import/Export von Datenformaten
Daten können mit ASCII-Files im-, und exportiert werden.

3.2.2.3.10. Animation
Nur SIM-PC , die PC-Version von PS SIMDIS verfügt über eine Animationsmöglichkeit auf einfacher direkter Basis.

3.2.2.4. Allgemeine Vorteile

Da PS SIMDIS im wesentlichen eine Erweiterung von GPSS/H darstellt, gelten auch diesselben Vorteile.

3.2.2.5. Allgemeine Nachteile

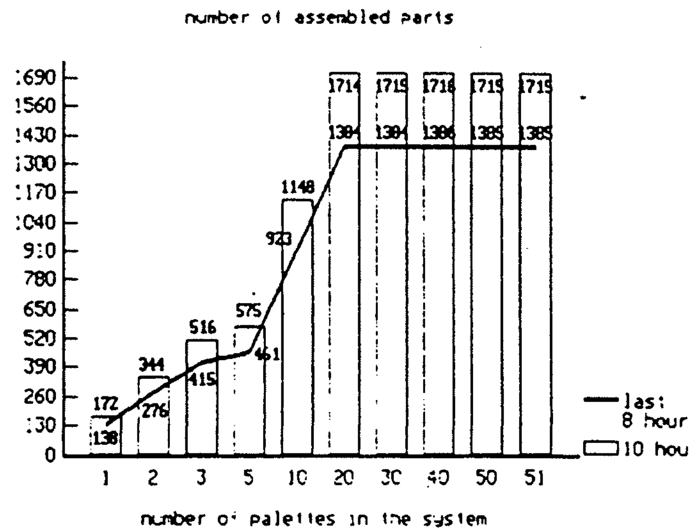
wie bei GPSS/H

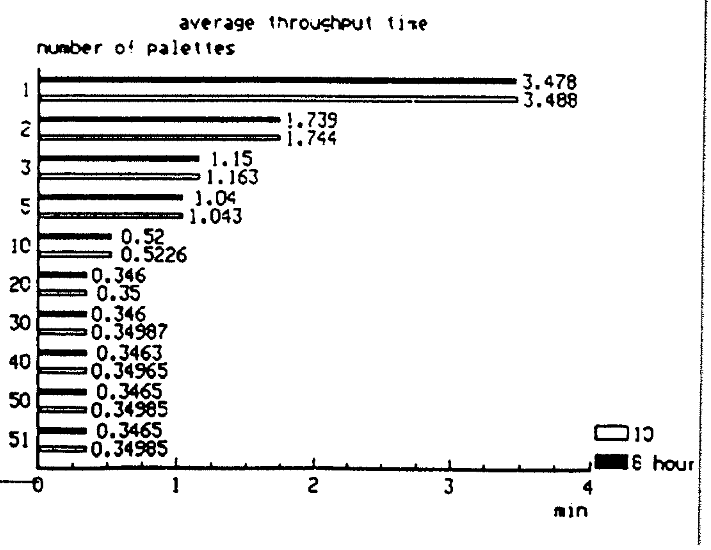
3.2.2.6. Schlußfolgerung

PS SIMDIS ist eine Hochschulweiterentwicklung von GPSS, dementsprechend ist es für den Lehreinsatz geeignet.

Beispiele für Modell- und Ergebnisbeschreibung:

```
SYB   ADVANCE    AV#SHI_T          shifting the palette
-------------------------------------------------------------
      SEIZE      WAYB
      LOGIC R    TORB              open second way
      TRANSFER   ,BBBB
* Here begins the belt B1.
-------------------------------------------------------------
BBA1  ENTER      SBB1,AV#PAL_L     OK, entering this belt B1
      RELEASE    WAYA
      ADVANCE    SK#SBB1
      GATE LR    TORB
      SEIZE      WAYB

BBE1  LEAVE      SBB1,AV#PAL_L     leaving the belt
* This is the end of this belt.
-------------------------------------------------------------
BBBB  ADVANCE    AV#WAY_L          between two subsystems
-------------------------------------------------------------
* This is subsystem C
-------------------------------------------------------------
MMC3  TEST E     PB1,1,BCA1        we have to skip - no part loaded

      TEST E     PB2,0,BCA1        we can skip - nothing to do
* OK. We have something to do.

      TEST E     AV#SBQU,0,BCA1  sorry, not allowed to do anything
* OK. Let's do it.

      TEST GE    SP#SCB2,AV#PAL_L,BCA1
      RELEASE    WAYB
* The buffer in front of station C is not full.

SKC   ADVANCE    AV#SHI_T          shifting palette to belt B2
* Here begins the buffer in front of station C.
-------------------------------------------------------------
BCA2  ENTER      SCB2,AV#PAL_L     OK, palette enters the buffer
      ADVANCE    SK#SCB2           move palette to the station
* Station C is empty.

      SEIZE      STC               entering the station C
      ADVANCE    AV#PAL_L
BCE2  LEAVE      SCB2,AV#PAL_L     leaving the buffer
* Here is the end of the buffer in front of station C.
-------------------------------------------------------------
```





3.2.4. SIMAN

3.2.4.1. Allgemeines

Das 1983 eingeführte SIMAN ist ein "general purpose SIMulation ANalysis"- Programm zum Modellieren von diskreten und kontinuierlichen Systemen, wobei als Vorbild für die diskret/ kontinuierlich kombinierten Elemente die Simulationssprache SLAM diente.

3.2.4.2. Produktdaten

3.2.4.2.1. Hersteller:
Systems Modeling Corporation
504 Beaver Street
Sewickley, Pennsylvania 15143
Tel: (412) 741-3727 Fax: (412) 741-5635

3.2.4.2.2. Distributor:
The CIMulation Centre Limited
Avon House, P.O. Box 46
Chippenham, Wiltshire
England, SN15 1JH
Tel: (0249) 650316 Fax: (0249) 443413

3.2.4.2.3. Plattformen, Systemerfordernisse:
Mainframes und PC's unter DOS oder OS/2

3.2.4.2.4. Preis:
je nach Version; Grundpreis für PC etwa DM 5000.-

3.2.4.2.5. Verfügbarkeit:
neueste Version: SIMAN/CINEMA IV Version 4.0

3.2.4.3. Evaluierungsresultate

3.2.4.3.1. User Interface
Das Programm wird mit einem Texteditor eingegeben. Ein interaktives, graphisches Interface, BLOCKS genannt, wird als separates Unterstützungssystem angeboten.

3.2.4.3.2. Dokumentation
C. Dennis Pegden: "Introduction to SIMAN" , Systems Modeling Corporation
Handbücher: "SIMAN IV Reference Guide" , SMC, 1989, und "CINEMA IV Reference Guide" , SMC, 1990.
Horst Tempelmeier: "Simulation mit SIMAN" , Physica Verlag, Heidelberg, 1991.

3.2.4.3.3. Grundprinzipien
Der diskrete Teil von SIMAN IV arbeitet primär prozeßorientiert. (Es kann aber auch ein ereignisorientierter Ansatz verwendet werden.) Die 5 Prozessoren *model* (zum Erstellen des Blockdiagramms), *experiment* (beschreibt Experimente), *link* (verbindet *model* und *experiment*) *run* und *output* arbeiten unabhängig voneinander. In der neuesten Version sind sie in einer Shell bequem aufrufbar.
SIMAN IV basiert auf der Programmiersprache FORTRAN.

3.2.3.3.5. Grenzen
Die Modellgröße hängt nur vom verwendeten Betriebssystem ab.

3.2.3.3.6. Modellbeschreibung
Das Modell wird in Form von Blöcken erstellt, die z.B. das Netzwerk repräsentieren (textuell oder graphisch).

3.2.3.3.7. Experimentbeschreibung
Die Experimente werden textuell, bzw. über den graphischen Editor eingegeben und verändert.

3.2.3.3.8. Output-Analysen
Das Darstellen der Simulationsergebnisse unterstützt SLAM II mit statistischen Tabellen und Postprocessing.

3.2.3.3.9. Import/Export von Datenformaten
Mit ASCII-Files können Daten ein-, und ausgegeben werden.

3.2.3.3.10. Animation
SLAM II stellt auch ein Animationssystem (TESS genannt)zur Verfügung, das unter MS-Windows und OS/2 im Modell-Layout integriert werden kann.

3.2.3.4. Allgemeine Vorteile
SLAM II ist eine weitverbreitete, teilweise sehr beliebte Simulationssprache.

3.2.3.5. Allgemeine Nachteile
Die Programmierung gestaltet sich bei textueller Ebenen etwas mühsam.

3.2.3.6. Schlußfolgerung
SLAM II ist eine stabile, allgemein verwendbare Simulationssprache, die allerdings eine lange Einarbeitungszeit erfordert.

Beispiel für eine Modellbeschreibung:

```
;------------------------------------------------------------------------
; CONTROL FILE (VARIABLES EQUIVALENCES AND INITIALIZATIONS)
;------------------------------------------------------------------------
GEN,SIMGROUP,EUROSIM,16/05/1991,1,Y,Y,Y/Y,Y,Y/1,132;
;
;TIMES IN SECONDS, LENGHTS IN CM
;
LIMITS,32,12,100;
;
; DYNAMIC ENTITIES (PALLETS) ATTRIBUTES
EQUIVALENCE/ATRIB(1),MARK;      CYCLE ENTERING TIME
EQUIVALENCE/ATRIB(2),OP2;       FLAG FOR OPER. 2 (1=ALREADY DONE, ELSE 0)
EQUIVALENCE/ATRIB(3),OP3;       FLAG FOR OPER. 3 (1=ALREADY DONE, ELSE 0)
EQUIVALENCE/ATRIB(4),OP4;       FLAG FOR OPER. 4 (1=ALREADY DONE, ELSE 0)
EQUIVALENCE/ATRIB(5),OP5;       FLAG FOR OPER. 5 (1=ALREADY DONE, ELSE 0)
EQUIVALENCE/ATRIB(6),STATION;   NUMBER OF CURRENT STATION (BASIC SUBMODEL)
EQUIVALENCE/ATRIB(7),UP;        TELLS IF IT SHOULD GO THROUGH THE MACHINE
EQUIVALENCE/ATRIB(8),CURR;      CURRENT RESOURCE (CONVEYOR LINE) USED
EQUIVALENCE/ATRIB(9),PREC;      OLD RESOURCE (CONVEYOR LINE) USED
EQUIVALENCE/ATRIB(10),MACHINE;  MACHINE RESOURCE NUMBER (SET ONLY IF UP=1)
EQUIVALENCE/ATRIB(11),BUFFER;   CONVEYOR LINE AFTER MACHINE (SET ONLY IF UP=1)
EQUIVALENCE/ATRIB(12),LAPS;     NUMBER OF CIRCUIT LAPS CURRENTLY DONE
;
; WORK TIMES
ARRAY(1,8)/15,60,60,60,20,20,20,30;
; A-LINES LENGHTS (CONVEYORS BEFORE MACHINES)
ARRAY(2,8)/120,80,80,80,80,80,80,120;
; B-LINES LENGHTS (CONVEYORS THAT DOESN'T PASS THROUGH THE MACHINES)
ARRAY(3,8)/200,160,160,160,160,160,160,200;
; C-LINES LENGHTS (CONVEYORS AFTER MACHINES)
ARRAY(4,8)/80,80,80,80,80,80,80,80;
;SPACES BETWEEN STATIONS
ARRAY(5,8)/0.0,40,40,40,0.0,40,40,40;
;
```

3.2.4. SIMAN

3.2.4.1. Allgemeines

Das 1983 eingeführte SIMAN ist ein "general purpose SIMulation ANalysis"- Programm zum Modellieren von diskreten und kontinuierlichen Systemen, wobei als Vorbild für die diskret/kontinuierlich kombinierten Elemente die Simulationssprache SLAM diente.

3.2.4.2. Produktdaten

3.2.4.2.1. Hersteller:
Systems Modeling Corporation
504 Beaver Street
Sewickley, Pennsylvania 15143
Tel: (412) 741-3727 Fax: (412) 741-5635

3.2.4.2.2. Distributor:
The CIMulation Centre Limited
Avon House, P.O. Box 46
Chippenham, Wiltshire
England, SN15 1JH
Tel: (0249) 650316 Fax: (0249) 443413

3.2.4.2.3. Plattformen, Systemerfordernisse:
Mainframes und PC's unter DOS oder OS/2

3.2.4.2.4. Preis:
je nach Version; Grundpreis für PC etwa DM 5000.-

3.2.4.2.5. Verfügbarkeit:
neueste Version: SIMAN/CINEMA IV Version 4.0

3.2.4.3. Evaluierungsresultate

3.2.4.3.1. User Interface
Das Programm wird mit einem Texteditor eingegeben. Ein interaktives, graphisches Interface, BLOCKS genannt, wird als separates Unterstützungssystem angeboten.

3.2.4.3.2. Dokumentation
C. Dennis Pegden: "Introduction to SIMAN" , Systems Modeling Corporation
Handbücher: "SIMAN IV Reference Guide" , SMC, 1989, und "CINEMA IV Reference Guide" , SMC, 1990.
Horst Tempelmeier: "Simulation mit SIMAN" , Physica Verlag, Heidelberg, 1991.

3.2.4.3.3. Grundprinzipien
Der diskrete Teil von SIMAN IV arbeitet primär prozeßorientiert. (Es kann aber auch ein ereignisorientierter Ansatz verwendet werden.) Die 5 Prozessoren *model* (zum Erstellen des Blockdiagramms), *experiment* (beschreibt Experimente), *link* (verbindet *model* und *experiment*) *run* und *output* arbeiten unabhängig voneinander. In der neuesten Version sind sie in einer Shell bequem aufrufbar.
SIMAN IV basiert auf der Programmiersprache FORTRAN.

3.2.4.3.4. Granularität
Die Struktur des Modells hängt von der verwendeten Ebene ab, da SIMAN Macros zuläßt. (*"stations"*)

3.2.4.3.5. Grenzen
Die maximale Problemgröße ist durch die verwendete Plattform gegeben.

3.2.4.3.6. Modellbeschreibung
SIMAN IV teilt Modellstruktur und experimentiellen Rahmen in zwei getrennte Bereiche. Die statischen und dynamischen Eigenschaften des Modells werden im Prozeß *model* beschrieben.

3.2.4.3.7. Experimentbeschreibung
Um verschiedene Simulationsläufe durchzuführen, muß nur der experimentielle Rahmen (Prozeß *experiment*) geändert werden, die Kontroll-, und Flußlogik im Modellrahmen (Prozeß *model*) bleibt unverändert.

3.2.4.3.8. Output-Analysen
Mit dem SIMAN *output*-Prozessor, der die Daten des *output*-Files bearbeitet, können Graphen, Tabellen, Histogramme, aber auch Konfidenz-, und Korrelationsberechnungen erzeugt werden.

3.2.4.3.9. Import/Export von Datenformaten
Daten können mit ASCII-Files im-, und exportiert werden. Auch LOTUS-kompatible Files können eingebunden werden.

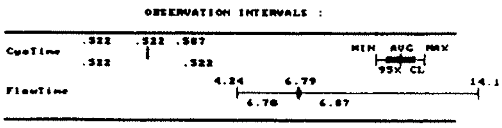
3.2.4.3.10. Animation
SIMAN bietet Animation mit dem CINEMA-System.

3.2.4.4. Allgemeine Vorteile
Daten können mit dem Outputprozessor optimal aufbereitet werden.

3.2.4.5. Allgemeine Nachteile
Für komplexere Entscheidungsmechanismen ist die prozeßorientierte Beschreibung nicht geeignet.

3.2.4.6. Schlußfolgerung
Ähnlich wie ihr Vorbild SLAM ist SIMAN eine stabile, weitverbreitete Software, die auf vielen Plattformen läuft und für verschiedene Anwendungsbereiche geeignet ist. Nach einer soliden Einarbeitung können vor allem prozeßorientierte Modelle einfach gehandhabt werden.

Beispiele für Modell- und Experimentbeschreibung:




```
BEGIN,1,1,YES,test,NO;            | Begin-Statement
                                  |
Initial Settings                  |
      CREATE,8;                   | 8 Entities erzeugen.
      ASSIGN:X(1)=X(1)+1;         | die 8 verschiedenen
      ASSIGN:A(1)=X(1);           | Platinen markieren.
      ASSIGN:A(2)=1;              | Entity erscheine!
REQUEST QUEUE,17;                 | In einen Puffer geben.
      WAIT:A(1);                  | nimm richtige Platine
                                  | wenn ASSEMBLER
      BRANCH:                     | signalisiert.
        ALWAYS,REQUEST:           | Dupliziere sie.
        ALWAYS,PULLKIT;           | gib sie weiter.
```

No.of Pallets in System.	Average Flow Time.	No.of Pallets through System in 8hrs.
10	5.6209	853
12	6.2983	914
13	6.7886	919
14	7.3118	919
15	7.8307	919
20	10.442	919
25	13.054	919
30	15.748	919
40	20.927	920
50	26.047	917
60	0.0	0.0

Fig. 3

3.2.5. DESMO

3.2.5.1. Allgemeines

Das Simulationspaket DESMO (Discrete Event Simulation in Modula-2) unterstützt primär den prozeßorientierten Ansatz, erlaubt aber auch andere Modellierungsstile: transaktionsorientiert (wie GPSS), aktivitätsorientiert (wie ECSL) und ereignisorientiert. Als Vorbild für DESMO diente das von G.M. Birtwistle in Simula implementierte Paket DEMOS.

3.2.5.2. Produktdaten

3.2.5.2.1. Hersteller:
FB Informatik, Universität Hamburg
(Prof. Dr.-Ing. Bernd Page)
Vogt-Kölln-Str. 30
W-2000 Hamburg 54, Germany
Tel: 040/54715-426 Fax: 040/54715-246

3.2.5.2.2. Distributor:
(wie oben)

3.2.5.2.3. Plattformen, Systemerfordernisse:
VAX, PC unter MS-DOS

3.2.5.2.4. Preis:
auf Anfrage

3.2.5.2.5. Verfügbarkeit:

3.2.5.3. Evaluierungsresultate

3.2.5.3.1. User Interface
Das Modellprogramm wird mit Erweiterungen der Programmiersprache Modula-2 implementiert (Texteditor).

3.2.5.3.2. Dokumentation
B.Page: Discrete Event Simulation and Modula-2.Syst.Anal.Model.Simul.7 ,1990, 339-358
B.Page et. al.: Diskrete Simulation. Eine Einführung mit Modula-2. Springer, 1991

3.2.5.3.3. Grundprinzipien
DESMO basiert auf dem prozeßorientierten Ansatz. Das sogenannte *Entitiy* verkörpert die aktive Komponente (Prozeß). Die grundlegenden Synchronisationsmechanismen mit anderen Prozessen werden durch die Module *ProcessSimulation* (zum Manipulieren der Entities) und *Queue* (zum Modellieren von Warteschlangen) ermöglicht. Es stehen aber auch Module für höhere Synchronisationsmechanismen zur Verfügung, wie etwa Ressourcenwettbewerb, Produzenten/Konsumenten-Beziehung, direkte Prozeßkooperation oder bedingtes Warten.

3.2.5.3.4. Granularität
Je nach verwendeter Ebene ist DESMO feiner oder gröber strukturiert.

3.2.5.3.5. Grenzen

Die Problemgröße ist vom verwendeten Rechner abhängig, unter DOS ist die Grenze demnach durch das Betriebssystem gegeben.

3.2.5.3.6. Modellbeschreibung

Das Modell wird in Module gegliedert und Modula-2 ähnlich beschrieben.

3.2.5.3.7. Experimentbeschreibung

Auch die Experimente haben modularen Aufbau, in getrennter Beschreibung.

3.2.5.3.8. Output-Analysen

5 Statistikmodule (*Count, Tally, Accumulate, Histogram* und *Regression*) exportieren für jede Klasse von Simulationsobjekten eine Prozedur *Report* zur Ausgabe der Ergebnisse. Zusätzlich können weitere Datensammlungen und Berechnungen explizit in Auftrag gegeben werden (z. B. Mittelwert, Standardabweichung). Überdies kann der Anwender eigene Report-Routinen definieren und damit Standardeinstellungen (etwa für Überschriften und Datenbeschreibungen) überschreiben (benutzerorientierte Ausgabeprozeduren).

3.2.5.3.9. Import/Export von Datenformaten

Daten lassen sich mit einem Modul (*TimeSeries*) auf eine Datei ausgeben, ein anderes Modul (*DESgraph*) ermöglicht eine graphische Ausgabe während des Simulationslaufes.

3.2.5.3.10. Animation

DESMO bietet keine Animationsmöglichkeiten.

3.2.5.4. Allgemeine Vorteile

Mit DESMO kann man verschiedene Modellierungsstile ("Weltbilder" der Simulation) verwenden und somit diese verschiedenen Ansätze vergleichen.

3.2.5.5. Allgemeine Nachteile

Schwachpunkte von DESMO sind die fehlende graphische Benutzeroberfläche und Animation.

3.2.5.6. Schlußfolgerung

Das Softwarepaket DESMO bietet sich vor allem für Lehrzwecke an, da es unterschiedliche Modellansätze erlaubt und vergleicht.

Beispiel für eine Modellbeschreibung:

```
(* Flexible Assembly System *)
(* see EUROSIM - Simulation News Europe, Number 1, Mar 1991, p. 28 *)
(* and EUROSIM - Simulation News Europe, Number 2, Jul 1991, p. 26 *)
(* Programmer  : Dirk Martinssen *)
(* last change : 23.01.91        *)

MODULE EuroSim;

(* procedures of DESMO *)
FROM ProcessSimulation IMPORT Entity, New, Schedule, SetPriority,
                              Attributes, Current, Hold, SimTime,
                              Time, NOW, Reset, SetReportFile,
                              SetErrorFile, CloseFiles;
FROM StringHdl IMPORT Copy, CardToString, Trim, Concat;
IMPORT Res, CondQ, Count, Tally;
FROM CondQ IMPORT WaitUntil, Signal;
FROM ReportIO IMPORT WriteString, WriteCard, WriteReal, WriteLn;

(* procedures of Modula-2 *)
FROM IO IMPORT RdStr, WrStr, WrLn, RdCard, WrCard, WrReal;
FROM Storage IMPORT ALLOCATE, DEALLOCATE;

CONST shift_time = 1.0 / 30.0;  (* time to shift from B1 to B2 or back *)
      time_unit = 1.0 / 45.0;   (* transport time for 0.4m on conveyor *)

TYPE  (* attributes of a conveyor between two systems *)
      connection_structure = RECORD
                               c_belt          : Res.Object;
                               transport_time  : SimTime;
                             END;

      (* attributes of a system *)
      system_structure = RECORD
                           shift_place          : CondQ.Object;
                           buffer_cap,
                           buffer_fill          : CARDINAL;
                           station              : Res.Object;
                           typ                  : [1..6];
                           operation_time       : SimTime;
                           rear_buffer          : Res.Object;
                           conveyor_cap,
                           conveyor_fill        : CARDINAL;
                           blocked              : BOOLEAN;
                         END;
```

3.2.6. Micro Saint

3.2.6.1. Allgemeines

Micro Saint wurde zum ereignisorientierten Simulieren von diskreten und (in beschränktem Ausmaß) kontinuierlichen Systemen entwickelt, und beinhaltet Animation mit Icons. Das Arbeiten mit Micro Saint erfordert keinerlei Programmierkenntnisse.

3.2.6.2. Produktdaten

3.2.6.2.1. Hersteller:
Micro Analysis and Design
3300 Mitchell Lane, Suite 175, Boulder
CO 80301, USA
Tel: +1(303) 442-6947 Fax: +1(303) 442-8274

3.2.6.2.2. Distributor:
Rapid Data Limited
Crescent House, Crescent Road
Worthing, West Sussex, BN115RW
Tel: +44 903 202819 Fax: +44 903 820762

3.2.6.2.3. Plattformen, Systemerfordernisse:
PC's unter DOS und Windows, UNIX; auch Apple Macintosh

3.2.6.2.4. Preis:
PC-Grundversion etwa DM 6000.- ; günstige Hochschulversion

3.2.6.2.5. Verfügbarkeit:
letzte Version: Micro Saint 3 für Windows

3.2.6.3. Evaluierungsresultate

3.2.6.3.1. User Interface
Das User Interface von Micro Saint arbeitet mit Menüs und graphischen Elementen, wie etwa Fenster und Dialogboxen. Auch für Entscheidungsprozesse wird Menüsteuerung angeboten.

3.2.6.3.2. Dokumentation
"Micro Saint 3.2.. User's Guide". Micro Analysis and Design, 1990.

3.2.6.3.3. Grundprinzipien
Micro Saint arbeitet ereignisorientiert. Das Modell wird mit Blöcken graphisch, interaktiv mit Menüs und Fenstern, erstellt. Das Compilieren erfolgt automatisch während der Modellbildung.

3.2.6.3.4. Granularität
Die Struktur des Modells hängt von der verwendeten Ebene ab, da Teilmodelle gebildet werden können.

3.2.6.3.5. Grenzen
Grenzen werden in DOS durch die DOS-Grenzen gesetzt; unter Windows keine Grenzen.

3.2.6.3.6. Modellbeschreibung
Das Modell wird in verschiedene Aktivitäten ("*tasks*") gegliedert, welche leicht modifiziert

werden können und die wiederum, abhängig von Bedingungen,Entscheidungstabellen,... , andere "tasks" auslösen.

3.2.6.3.7. Experimentbeschreibung
Die Durchführung der Experimente wird durch ein Menü gesteuert.

3.2.6.3.8. Output-Analysen
Um die Resultate einer Simulation effizient auswerten zu können, stellt Micro Saint ein spezielles Analysepaket zur Verfügung, welches die Darstellung von Systemzuständen über die Zeit sowohl in graphischer (Balkendiagramme, Graphen), als auch in tabellarischer Form erlaubt. Durch sogenannte *snapshots* können, abhängig von gewissen Bedingungen, fast alle vorstellbaren Analysen durchgeführt werden.

3.2.6.3.9. Import/Export von Datenformaten
Import/Export von Datenformaten ist über ASCII-Files möglich.

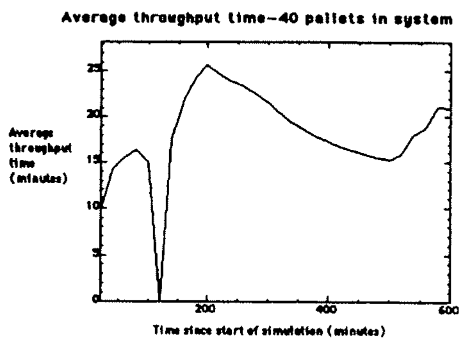
3.2.6.3.10. Animation
Das Modell-Layout kann gleichzeitig als Animations-Layout verwendet werden um einfache Animationen zu erstellen. Die Windows-Version bietet eine echte Animation an, die synchron dem Modell-Layout überlagert wird.

3.2.6.4. Allgemeine Vorteile
Micro Saint erlaubt Simulation in einfacher, anwendungsfreundlicher Form für beliebige Anwendungsbereiche.

3.2.6.5. Allgemeine Nachteile
Bei großen Systemen kann, vor allem wegen der Menütiefe, aufgeblasenen Menüaufbau, die Übersichtlichkeit verloren gehen. Micro Saint ist ein relativ geschlossenes System.

3.2.6.6. Schlußfolgerung
Micro Saint ermöglicht eine rasche Modellerstellung, bei kurzer Einarbeitungszeit, und auch bei keinerlei Programmierkenntnissen seitens des Modellerstellers. Micro Saint ist benutzerfreundlich und besticht vor allem durch die Möglichkeit, komplexe Entscheidungskriterien einfach zu formulieren.

Beispiel für Modell- und Experimentbeschreibung:



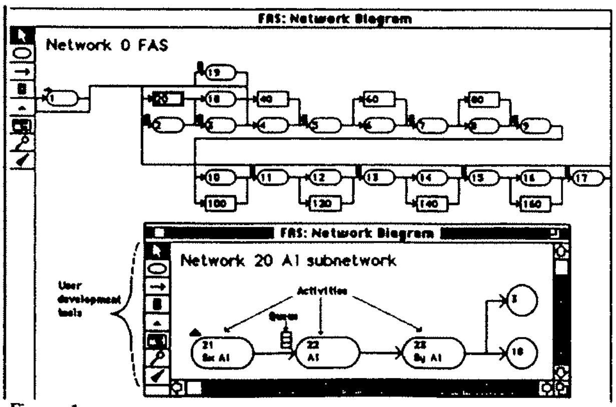


Figure 1

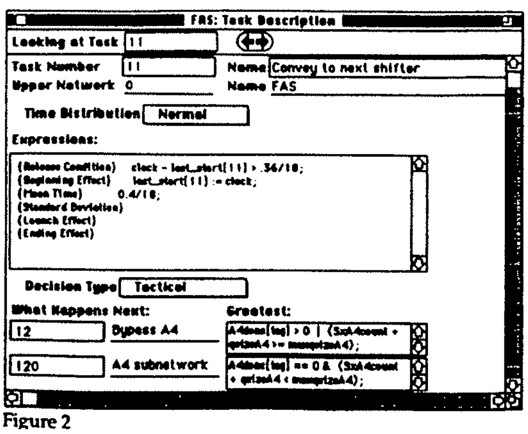


Figure 2

3.2.7. SIMUL_R

3.2.7.1. Allgemeines

SIMUL_R ist eine allgemeine Simulationssprache für diskrete und kontinierliche Systeme; der diskrete Teil wird PROSIMUL_R genannt und u.a. in den Bereichen Fertigungs-, und Verkehrstechnik angewandt. Es wird graphisches und textuelles Modellieren angeboten.

3.2.7.2. Produktdaten

3.2.7.2.1. Hersteller:
SIMUTECH
Hadikgasse 150
A-1140 Wien
Tel: +43-(0)222 894 75 08 Fax: +43-(0)222 894 78 04

3.2.7.2.2. Distributor:
(wie oben)

3.2.7.2.3. Plattformen, Systemerfordernisse:
PROSIMUL-R ist für PC's (MS-Windows), Transputernetze, DEC-Stations (X-Windows, UNIX) verfügbar.

3.2.7.2.4. Preis:
auf Anfrage, je nach Modell; der Grundpreis für PC-Version beläuft sich auf etwa DM 8000.-

3.2.7.2.5. Verfügbarkeit:
aktuelle Version (1992): SIMUL_R 2.3.

3.2.7.3. Evaluierungsresultate

3.2.7.3.1. User Interface
Über ein Menü-, und Mausgesteuertes Interface können Modelle graphisch (SIMDRAW) oder textuell eingegeben werden.

3.2.7.3.2. Dokumentation
R. Ruzicka: "SIMUL_R. A User's Guide". SIMUTECH

3.2.7.3.3. Grundprinzipien
SIMUL_R basiert auf der Computersprache C.
PROSIMUL_R kennt nur eine einzige Ressource, die sogenannte *station* (z.B. Werkzellen) unter deren Verwendung werden Werkzeuge und Transporter dargestellt, die dann von Entities benützt werden können. Alle anderen Elemente werden als Macros implementiert, daher ist es einfach mit neuen Macros neue Objekte zu definieren. Der Anwender kann Funktionen definieren, um dem System neue Befehle (z.B. für Steady State, Optimierung,..) hinzuzufügen.

3.2.7.3.4. Granularität
Verschiedene Ebenen ergeben unterschiedlich fein strukturierten Modellaufbau. Durch Verwendung von Macros kann eine sehr hohe Modularität erreicht werden.

3.2.7.3.5. Grenzen
Grenzen werden nur durch die benützte Plattform gesetzt. Unter DOS wird die Grenze durch DOS selbst festgelegt.

3.2.7.3.6. Modellbeschreibung

SIMUL_R beschreibt Modelle mit einer großen Palette von Makrobefehlen, so können auch komplexe Systeme übersichtlich und leicht kontrollierbar formuliert und verändert werden.

3.2.7.3.7. Experimentbeschreibung

Auch das Experimentieren wird von einer Makrobibliothek unterstützt. Mit Schleifen-, Bedingungs-, und Unterprogrammsbefehlen können komplexere Analyseaufgaben ohne Veränderung des Modells durchgeführt werden. Darüber hinaus bestehen auch Optimierungsmöglichkeiten.

3.2.7.3.8. Output-Analysen

Zur Analyse und Präsentation stellt PROSIMUL_R u.a. Optimierung von diskreten sowie kontinuierlichen Vorgängen, diverse statistische Methoden (z.B. mittlere Bearbeitungszeit, Auslastungzeiten,...) und Darstellung in Zeitkurven und Histogrammen zur Verfügung. Besonderes Augenmerk wurde auf die graphische Darstellung der Daten gelegt: Eine umfangreiche graphische Bibliothek bietet u.a. 3D-Plots, Niveaulinien, selbstwählbare Skalen,..

3.2.7.3.9. Import/Export von Datenformaten

Auf alle Daten kann mit ASCII Files für In-, und Output zugegriffen werden, während der Simulation kann der Anwender mit dem Keyboard oder graphisch Daten einbinden.

3.2.7.3.10. Animation

Die Animation mit SIMDRAW sieht die Verwendung von benutzererstellten Objekten vor, diese können z.B. unter Windows gezeichnet oder von vorhandenen Bildern eingescannt werden.

3.2.7.4. Allgemeine Vorteile

Vorteilhaft ist die Möglichkeit zur kombinierten oder parallelen Verwendung von diskreten und kontinuierlichen Systemen,die zahlreichen Analyse- und graphischen Methoden und die hohe Modularität. Außerdem ist SIMUL_R ein sehr offenes System, beliebige C-Programme können eingebunden werden.

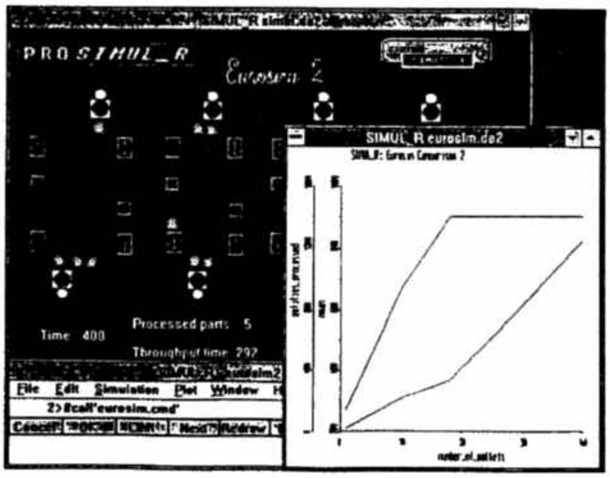
3.2.7.5. Allgemeine Nachteile

Ein Nachteil von SIMUL_R ist die relativ lange Einarbeitungszeit.

3.2.7.6. Schlußfolgerung

PROSIMUL_R und Umgebung (SIMDRAW) ist ein für alle Probleme geeignetes Softwarepaket, das sich an informatischen Grundsätzen orientiert. Es ist eines der wenigen Simulationswerkzeuge, das kontinuierliche und diskrete Prozesse gleichgut unterstützt.

Beispiele für Modell- und Ergebnisbeschreibung:



3.2.8.3.7. Experimentbeschreibung
Die Beschreibung der Experimente erfolgt Menü-gesteuert.

3.2.8.3.8. Output-Analysen
Standardmäßig bietet DOSIMIS3 die Präsentation von Simulationsergebnissen in Form von Tabellen und Graphiken. Reicht dies nicht aus, so können Entscheidungstabellen (über das graphische User Interface einzugeben) verwendet werden, um komplexe Zusammenhänge darzustellen.

3.2.8.3.9. Import/Export von Datenformaten
Daten können mittels ASCII-Files im- und exportiert werden.

3.2.8.3.10. Animation
Die Animation erfolgt im Modell-Layout, synchron zur Simulation.

3.2.8.4. Allgemeine Vorteile

Standardelemente eines Materialflußsystems kann man mit DOSIMIS3 leicht modellieren. DOSIMIS3 ist benutzerfreundlich und erfordert nur eine kurze Einarbeitungszeit.

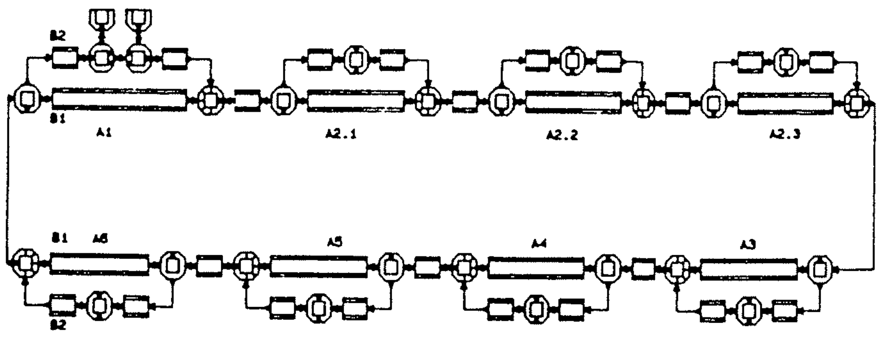
3.2.8.5. Allgemeine Nachteile

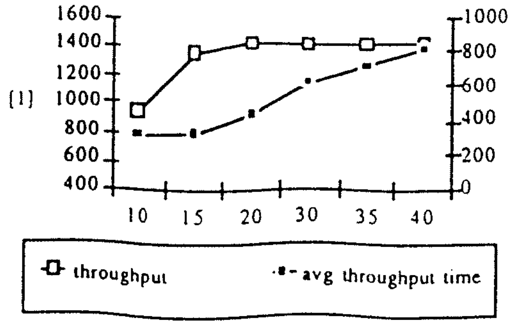
Für komplexere Modelle muß man auf die Programmierebene (PASCAL) zurückgreifen. Die Elemente dieses Simulators sind nur auf Materialflußsysteme zugeschnitten.

3.2.8.6. Schlußfolgerung

DOSIMIS3 bietet sich für nicht zu komplexe Materialflußprobleme an, es erfordert nur eine kurze Einarbeitungszeit.

Beispiele für Modell- und Ergebnisbeschreibung:





3.2.8. DOSIMIS3

3.2.8.1. Allgemeines

Der elementorientierte Simulator DOSIMIS3 arbeitet mit einer chronologischen Ereignisliste und wurde speziell zum Simulieren von diskreten Materialflußsystemen (MFS) entwickelt.

3.2.8.2. Produktdaten

3.2.8.2.1. Hersteller:

Fraunhofer Institute für Materialfluß und Logistik
Emil Figgestr. 75
W-4600 Dortmund
Tel: +49-(0)231 7549 171 Fax: +49-(0)231 7549 211

3.2.8.2.2. Distributor:

(wie oben)

3.2.8.2.3. Plattformen, Systemerfordernisse:

PC

3.2.8.2.4. Preis:

auf Anfrage

3.2.8.2.5. Verfügbarkeit:

3.2.8.3. Evaluierungsresultate

3.2.8.3.1. User Interface

DOSIMIS3 besitzt keine textuelle Simulationssprache, sondern nur ein Menü-orientiertes, graphisches User Interface. Um komplexere Probleme zu modellieren, muß auf das Programmier-Interface (PASCAL) zurückgegriffen werden.

3.2.8.3.2. Dokumentation

Manual

3.2.8.3.3. Grundprinzipien

DOSIMIS3 basiert auf ereignisorientierter Abarbeitung. Die 20 Standardelemente entsprechen den realen Elementen eines Materialflußsystems, z.B.: source, sink, junction,..., und werden direkt am Bildschirm plaziert. Die Eigenschaften der einzelnen Elemente , z.B.:Länge, Geschwindigkeit,..., werden über Parametermasken zugewiesen.
DOSIMIS3 basiert auf der Programmiersprache Pascal.

3.2.8.3.4. Granularität

DOSIMIS3 ist feinstrukturiert, die Blöcke haben einfachen Aufbau.

3.2.8.3.5. Grenzen

Die Modellgröße wird durch DOS Hardware beschränkt.

3.2.8.3.6. Modellbeschreibung

Das Modell wird mit prozeßorientierten Blöcken dargestellt, die sich speziell an Materialflußsystemen orientieren.

3.2.9. TOMAS

3.2.9.1. Allgemeines

Das Simulationssystem TOMAS (Technology Oriented Modeling And Simulation) wurde Ende der 70er Jahre von der Fakultät für Informatik an der TU Dresden entwickelt und 1990 als TOMAS/16 von der DVZ Neubrandenburg für MS-DOS PCs implementiert und auf den Softwaremarkt gebracht. TOMAS wird vor allem für das Simulieren von Fabrikationsabläufen eingesetzt.

3.2.9.2. Produktdaten

3.2.9.2.1. Hersteller:
DVZ Neubrandenburg GmbH
Bereich Softwareentwicklung und Systemberatung
Woldegker Straße 12
0-2000 Neubrandenburg, Germany
Tel: +37-90-587 443 Fax: +37-90-587 302

9.2.9.2.2. Distributor:
(wie oben)

3.2.9.2.3. Plattformen, Systemerfordernisse:
PC's unter MS-DOS

3.2.9.2.4. Preis:
auf Anfrage

3.2.9.2.5. Verfügbarkeit:
letzte Version: TOMAS/16 (1990):

3.2.9.3. Evaluierungsresultate

3.2.9.3.1. User Interface
Das User Interface von TOMAS ist Menü-gesteuert und bietet online zahlreiche Hilfsfunktionen.

3.2.9.3.2. Dokumentation
Manual

3.2.9.3.3. Grundprinzipien
TOMAS besteht aus 12 Modulen, aus denen der Anwender Modelle bilden kann. Diese Module (Generatoren und Operatoren) entsprechen typischen Prozessen des Fabrikationsablaufes und werden während der Simulation von Operanden (z.B. Aufträge, Fahrzeuge,...) durchlaufen. Das Verhalten der einzelnen Operatoren und Generatoren wird durch das Parametrisieren der Elemente festgelegt.

3.2.9.3.4. Granularität
Verschiedene Ebenen ergeben unterschiedlich fein strukturierte Blöcke.

3.2.9.3.5. Grenzen
Die maximale Problemgröße hängt vom Betriebssystem DOS ab.

3.2.9.3.6. Modellbeschreibung
Das Modell wird in prozeßorientierten Modulen beschrieben, die speziell auf Fabrikationsabläufe ausgelegt sind.

3.2.9.3.7. Experimentbeschreibung
Der Simulationsablauf wird über ein Menü gesteuert.

3.2.9.3.8. Output-Analysen
TOMAS unterstützt die Aufbereitung der Simulationsergebnisse mit statistischen Tabellen und Postprocessing.

3.2.9.3.9. Import/Export von Datenformaten
ASCII-Files können zum Im- und Exportieren von Daten verwendet werden.

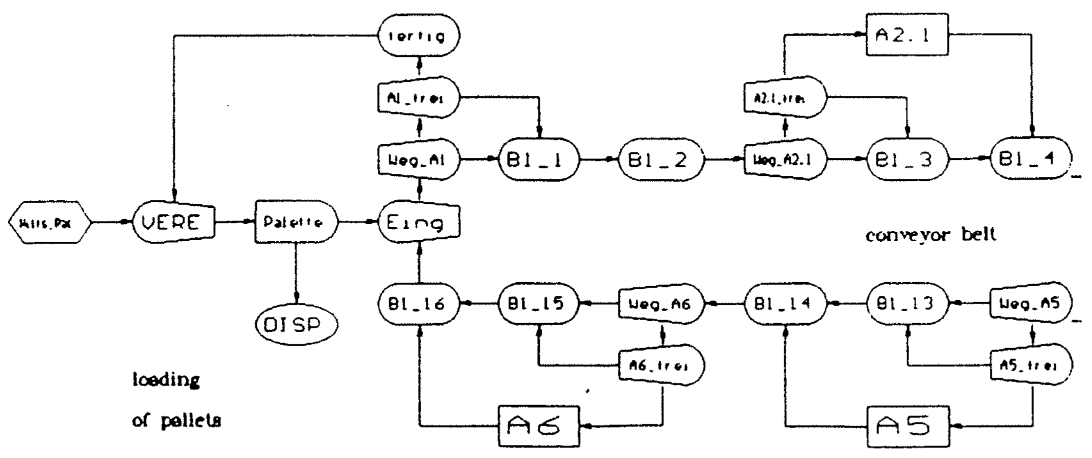
3.2.9.3.10. Animation
Die Animation erfolgt im Modell-Layout.

3.2.9.4. Allgemeine Vorteile
TOMAS ist einfach zu bedienen und bietet eine gute Online-Hilfe.

3.2.9.5. Allgemeine Nachteile
TOMAS ist speziell auf Fabrikationsabläufe ausgerichtet.

3.2.9.6. Schlußfolgerung
TOMAS erlaubt anwenderfreundliches Modellieren von Fabrikationsabläufen, die Einarbeitungszeit ist relativ kurz.

Beispiel für eine Modellbeschreibung:



3.2.11. SIMPLE

3.2.11.1. Allgemeines

SIMPLE ist ein echt objektorientierter Simulator nach dem Bausteinprinzip und wurde speziell für Fabrikationsabläufe (Produktion, Materialfuß, Logistik) konzipiert.

3.2.11.2. Produktdaten

3.2.11.2.1. Hersteller:
AESOP GmbH
Königstraße 82
Postfach 100 121
D-7000 Stuttgart 10
Tel: (0711) 163 59-0 Fax: (0711) 163 59-99

3.2.11.2.2. Distributor:
UNSELD & PARTNER
Lerchenfelderstraße 44/V
A-1080 Wien
Tel: +43-(0)222-4030371 Fax: +43-(0)222-4030372

3.2.11.2.3. Plattformen, Systemerfordernisse:
SIMPLE läuft auf vielen Plattformen: Workstations mit UNIX/X-Windows, PC's mit SCO-UNIX/X-Windows, Apple Macintosh mit AUX

3.3.11.2.4. Preis.
Hochschulversion: ungefähr 16.000.-
andere Versionen: auf Anfrage

3.2.11.2.5. Verfügbarkeit:
Neben der Vollversion bietet AESOP auch eine Hochschulversion an.

3.2.11.3. Evaluierungsresultate

3.2.11.3.1. User Interface
SIMPLE stellt ein menügesteuertes graphisches User Interface zur Verfügung und besitzt auch einen eigenen Editor zum Arrangieren der Module und zum Erstellen von Entscheidungstabellen.

3.2.11.3.2. Dokumentation
Anwendungsbericht: Simulationsystem SIMPLE. Beschreibung SIMPLE, Manual

3.2.11.3.3. Grundprinzipien
SIMPLE stellt in einer Bausteinbibliothek eine Reihe von Objekten, z.B.: Rutsche, Band, Maschine, Fahrzeug, Steuerung,Listen,... zur Verfügung. Das Modellieren besteht darin, die Objekte der abzubildeten Anlagen zu identifizieren und ihnen Attribute und Verhaltensmuster zuzuweisen. Reichen die Grundeigenschaften eines Elements nicht aus, kann man Attribute auch durch lokale oder globale Steuerungen zuweisen. Objekte mit gleichen Eigenschaften können zu Klassen zusammengefaßt werden. Von Klassen können Instanzen erzeugt werden. Das "Konzept der Vererbung" bildet einen wichtigen Vorteil: Eigenschaften einer allgemeinen Klasse gehen auf eine speziellere Klasse über (werden "vererbt"), können aber auch modifiziert

3.2.10. CASSANDRA

3.2.10.1. Allgemeines

Der Simulator CASSANDRA (Cognizant Adaptive Simulation System for Application in Numerous Different Relevant Areas) 2.1 basiert intern auf einer objektorientierten Struktur, die Elemente von Petri-Netzen nützt.

3.2.10.2. Produktdaten

3.2.10.2.1. Hersteller:
KFKI Research Institute of the Hungerian Academy of Sciences
P.O.Box 49
H-1525 Budapest, Hungary
Tel: +36-1 1699499 Fax: +36-1 1553894

3.3.10.2.2. Distributor;
(wie oben)

3.2.10.2.3. Plattformen, Systemerfordernisse:
PC'S unter MS-Windows 3.0

3.2.10.2.4. Preis:
auf Anfrage

3.2.10.2.5. Verfügbarkeit:
momentane Version: CASSANDRA 2.1.

3.2.10.3. Evaluierungsresultate

3.2.10.3.1. User Interface
Mit dem System IGENJA kann CASSANDRA um ein graphisches, Menü-, und Maus-gesteuertes User Interface erweitert werden, sonst besitzt CASSANDRA nur ein textuelles Interface.

3.2.10.3.2. Dokumentation
Manual

3.2.10.3.3. Grundprinzipien
CASSANDRA arbeitet objektorientiert und nützt Petri-Netz-Elemente, um das Modell zu beschreiben, dadurch wird eine strukturierte Sichtweise des zu beschreibenden Systems gewährleistet. Der Simulator kann durch höhere Modellierungselemente (z.B. Macros) und I/O-Schnittstellen erweitert werden.

3.2.10.3.4. Granularität
CASSANDRA ist auf Petri-Ebene fein, auf Modul-Ebene grob strukturiert.

3.2.10.3.5. Grenzen
Die Problemgröße hängt vom verwendeten Rechner ab.

3.2.10.3.6. Modellbeschreibung
Der Aufbau des Modells erfolgt mit Grundbausteinen aus Petri-Teilnetzen.

3.2.10.3.7. Experimentbeschreibung

CASSANDRA erhöht die Effizienz der Simulation, indem die Rekonstruktion von Modellstrukturen und die Kontrolle über die Simulationsexperimente über sogenannte *demons* automatisiert werden.

3.2.10.3.8. Output-Analysen

Das Auswerten der Simulationsergebnisse wird mit statistischen Tabellen und Postprocessing unterstützt.

3.2.10.3.9. Import/Export von Datenformaten

Mit ASCII-Files können Daten eingebunden oder ausgegeben werden.

3.2.10.3.10. Animation

Ein Animationssystem für CASSANDRA besteht mit dem User-Interface IGENJA.

3.2.10.4. Allgemeine Vorteile

CASSANDRA arbeitet objektorientiert und stellt eine interessante Petri-Netz-Entwicklung dar.

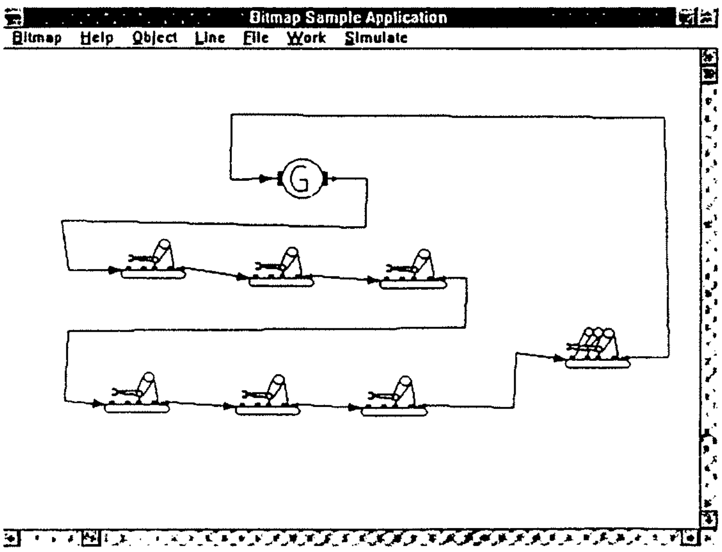
3.2.10.5. Allgemeine Nachteile

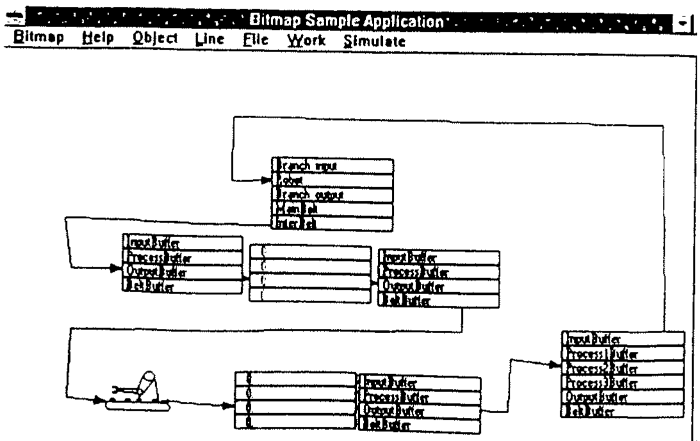
Die Entwicklung von CASSANDRA ist noch nicht abgeschlossen.

3.2.10.6. Schlußfolgerung

Der Simulator CASSANDRA ist für die Forschungsaufgaben gut geeignet, da er die Verwendung von Petri-Netzen erlaubt.

Beispiele für die Modellbeschreibung:





werden. Dieser Vorgang kann über beliebig viele Stufen erfolgen, sodaß eine Hierarchie entsteht. Einzelne Module können zu Macros zusammengefaßt werden.
SIMPLE basiert auf der Programmiersprache C++.

3.2.11.3.4. Granularität
SIMPLE ist grobstrukturiert und auf die Fertigung ausgerichtet. Feinstrukturierte Module können aber selbsttätig erzeugt werden.

3.2.11.3.5. Grenzen
Die Problemgröße der Hochschulversion wird vom Hersteller, die der Vollversion nur durch die Hardware begrenzt.

3.2.11.3.6. Modellbeschreibung
Durch die Strukturierung des Programmes in Objekte wird eine starke Modularisierung erreicht. Durch das Klassen- und Vererbungskonzept kann man Objekte leicht verändern.

3.2.11.3.7. Experimentbeschreibung
Die Experimentbeschreibung erfolgt Menü-gesteuert.

3.2.11.3.8. Output-Analysen
Statistische Ausgaben können für alle Objekte zu jeder Zeit in Form von Tabellen oder über Plotter-Funktionen abgerufen werden.

3.2.11.3.9. Import/Export von Datenformaten
SIMPLE kann Daten von ASCII-Files einlesen und auch exportieren.

3.2.11.3.10. Animation
Die Animation entsteht beim Entwickeln des Modells, erfolgt also im Layout des Modelles und erfordert prinzipiell keinen zusätzlichen Arbeitsaufwand. Nach Bedarf kann die Animation beliebig "verschönert" werden.

3.2.11.4. Allgemeine Vorteile
SIMPLE kann man auch ohne umfangreiche Programmierkenntnisse bedienen, und es entspricht dem modernen objektorientierten Aufbau.

3.2.11.5. Allgemeine Nachteile
SIMPLE ist derzeit nur auf Produktionsprozesse ausgerichtet.

3.2.11.6. Schlußfolgerung
SIMPLE gehört zu den neuen (objektorientierten) Simulationswerkzeugen, und ist momentan neben FACTOR/AIM das modernste Software-Tool für Fertigungsprozesse.

Beispiele für Modell- und Experimentbeschreibung:

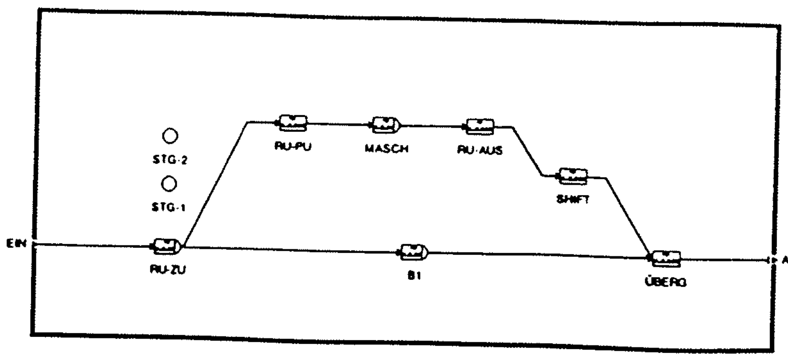


Fig.: basic sub-module

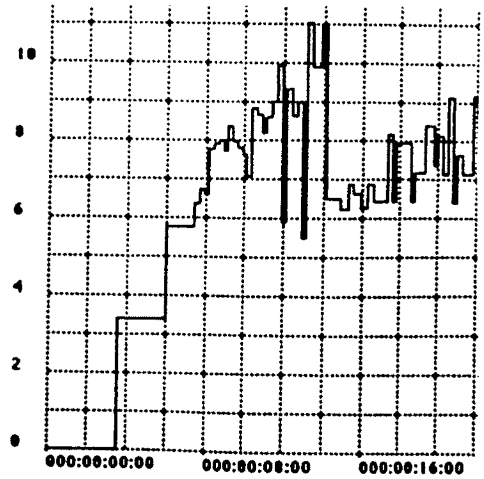


Fig.: throughput time

3.2.12. WITNESS

3.2.12.1. Allgemeines

Das Simulationssystem WITNESS ist objektorientiert und kann diskrete sowie kontinuierliche Vorgänge beschreiben.

3.2.12.2. Produktdaten

3.2.12.2.1. Hersteller:
Bremer Institut für Betriebstechnik und angewandte Arbeitswissenschaft BIBA
Postfach 330560
W-2700 Bremen 33
Tel: +49 421 22009-43 Fax: +49 421 22009-79

3.2.12.2.2. Distributor:
(wie oben)

3.2.12.2.3. Plattformen, Systemerfordernisse:
PC's (386) unter OS/2

3.2.12.2.4. Preis:
auf Anfrage

3.2.12.2.5. Verfügbarkeit:

3.2.12.3. Evaluierungsresultate

3.2.12.3.1. User Interface
WITNESS arbeitet mit einem graphischen User Interface, das auf verschiedenen Ebenen Menüs anbietet.

3.2.12.3.2. Dokumentation
Manual

3.2.12.3.3. Grundprinzipien
Die Elemente von WITNESS werden am Bildschirm graphisch erzeugt, dann werden über Parametermasken die notwendigen Eigenschaften zugewiesen: Kapazitäten, Durchlaufzeiten,.. aber auch Material-, und Informationsfluß zwischen den Elementen und Kontrollanweisungen zum Ablaufen des Modells.

3.2.12.3.4. Granularität
WITNESS ist grobstrukturiert, in "Objekte".

3.2.12.3.5. Grenzen
Theoretisch werden WITNESS keine Grenzen gesetzt, da es unter OS/2 läuft.

3.2.12.3.6. Modellbeschreibung
Das Modell wird in ereignisorientierten Modulen, aber auch mit kontinuierlichen Elementen graphisch beschrieben.

3.2.12.3.7. Experimentbeschreibung
Die Exprimente werden über ein Menü oder textuell eingeben und verändert.

3.2.12.3.8. Output-Analysen

WITNESS bietet einige Standardstatistiken, Graphiken und Tabellen , es können aber auch vom Anwender selbst erstellte Funktionen und Werte verwendet werden um Resultate zu präsentieren.

3.2.12.3.9. Import/Export von Datenformaten

Mit ASCII-Files können Daten eingebunden oder ausgegeben werden.

3.2.12.3.10. Animation

Beim Simulieren des Modells wird eine "online"-Animation erzeugt.

3.2.12.4. Allgemeine Vorteile

Vorteilhaft ist die rasche Modellierung und die leichte Erlernbarkeit von WITNESS.

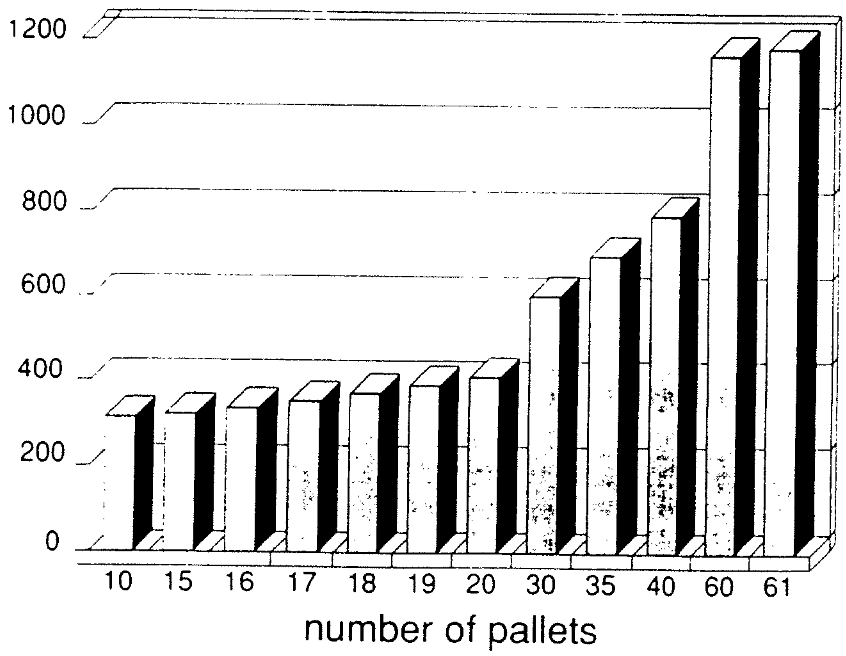
3.2.12.5. Allgemeine Nachteile

Leider steht WITNESS nur unter OS/2 zur Verfügung.

3.2.12.6. Schlußfolgerung

Mit WITNESS können allgemein diskrete (aber auch kontinuierliche) Systeme rasch und nach kurzer Einarbeitungszeit modelliert werden.

Beispiel für eine Ergebnisbeschreibung:



3.2.13. MODSIM

3.2.13.1. Allgemeines

MODSIM ist eine der neuen objektorientierten Simulationssprachen.

3.2.13.2. Produktdaten

3.2.13.2.1. Hersteller:
CACI Products Company
3344 North Torrey Pines Court
La Jolla, California 92037
Tel: (619) 457-9681 Fax: (619) 457-1184

3.2.13.2.2. Distributor:
CACI Products Division
Coliseum Business Centre
Watchmoor Park, Riverside Way
Camberley, Surrey GU15 3YL, UK
Tel: 0276 671 671 Fax: 0276 670 677

3.2.13.2.3. Plattformen, Systemerfordernisse:
MODSIM ist für die meisten Plattformen erhältlich.

3.2.13.2.4. Preis:
von der Version abhängig; Einstiegspreis für PC ungefähr DM 4000.-

3.2.13.2.5. Verfügbarkeit:
neueste Version: MODSIM II (1991)

3.2.13.3. Evaluierungsresultate

3.2.13.3.1. User Interface
MODSIM stellt ein graphisches User Interface zur Verfügung.

3.2.13.3.2. Dokumentation
Manual

3.2.13.3.3. Grundprinzipien
MODSIM arbeitet objektorientiert.
Basis ist die Programmiersprache C++.

3.2.13.3.4. Granularität
MODSIM ist grobstrukturiert (in Objekte).

3.2.13.3.5. Grenzen
Die maximale Problemgröße hängt von der verwendeten Plattform ab.

3.2.13.3.6. Modellbeschreibung
Das Modell wird in Modulen beschrieben, die größtenteils prozeßorientiert sind.

3.2.13.3.7. Experimentbeschreibung
Die Beschreibung der Experimente erfolgt Menü-gesteuert.

3.2.13.3.8. Output-Analysen

MODSIM sammmelt während dem Simulationsablauf eine Reihe von statistischen Informationen und ermöglicht Postprocessing.

3.2.13.3.9. Import/Export von Datenformaten

MODSIM kann Daten mit ASCII-Files in das Modell einbinden und daraus exportieren.

3.2.13.3.10. Animation

MODSIM bietet vielfältige Animationsmöglichkeiten im Modell-Layout.

3.2.13.4. Allgemeine Vorteile

Ein Vorteil von MODSIM ist der modulare Aufbau.

3.2.13.5. Allgemeine Nachteile

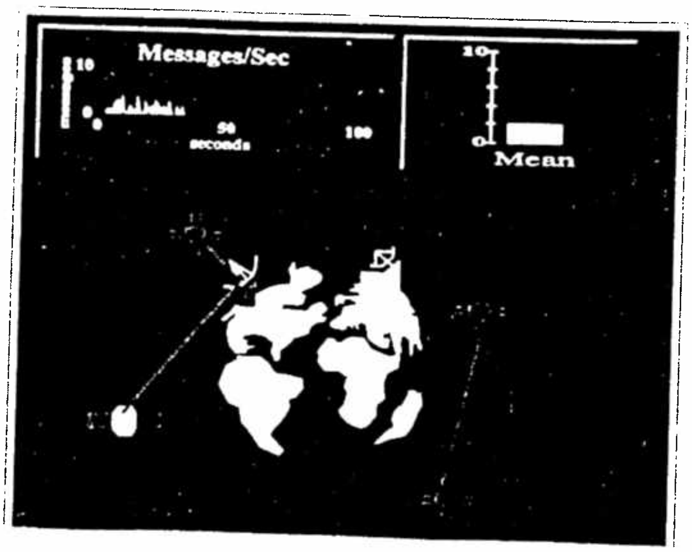
Für komplexe Aufgaben erfordert es eine längere Einarbeitungszeit.

3.2.13.6. Schlußfolgerung

MODSIM kann als sehr moderne, allgemein für diskrete Prozesse einsetzbare Software verwendet werden.

Beispiele für die Modellbeschreibung:

```
FROM Animate IMPORT DynImageObj;
FROM GrpMod IMPORT QueueObj;
TYPE
  PlatformObj = OBJECT(DynImageObj)
      OrbitPosition : REAL;
      OrbitVelocity : REAL;
      OrbitRadius   : REAL;
      Messages      : QueueObj;
      Quadrant      : INTEGER;
      TELL METHOD  SendTo(IN platform : PlatformObj);
      TELL METHOD  Receive From(IN platform : PlatformObj);
      ASK METHOD   ComputePosition;
  END OBJECT;
```



3.2.14. Pro Model PC

3.2.14.1. Allgemeines

Die erste Version von Pro Model PC wurde 1988 von der Production Modeling Crporation unter dem Namen PROMOD (PROduction MODeler) auf den Markt gebracht.

3.2.14.2. Produktdaten

3.2.14.2.1. Hersteller:
Production Modeling Corporation International
1875 South State, Suite 3400
Orem, Utah 84058
Tel: (801) 226-6036 Fax: (801) 226-6046

3.2.14.2.2. Distributor:
(we oben)

3.2.14.2.3. Plattformen, Systemerfordernisse:
IBM PC XT, AT, PS/2 oder kompatible;
Enhanced Graphics (EGA) oder Video Graphics (VGA)

3.2.14.2.4. Preis:
Einstiegspreis etwa DM 6000.-

3.2.14.2.5. Verfügbarkeit:
Die momentane Version heißt Pro Model PC. Neben der Vollversion wird auch ein "Starter Package" angeboten.

3.2.14.3. Evaluierungsresultate

3.2.14.3.1. User Interface
Die Modelle werden mit einem eigenen Texteditor, mit Online-Hilfe erstellt.

3.2.14.3.2. Dokumentation
Manual

3.2.14.3.3. Grundprinzipien
Im *Automatic Model Build* -Mode werden zunächst den Modellelementen über sogenannte *routings* alle Eigenschaften und logische Steuerungen, Verteilungen,Output, Move Time,...nächster Block, Auswahlkriterien,..., zugewiesen. Ist die Modelldefinition beendet, wird nach dem graphischen Layout für die Animation verlangt: Symbole für Ressourcen und Wege können mit Maus oder Cursortasten ausgewählt und plaziert werden. Pro Model PC stellt dafür eine graphische Bibliothek, die 30 vordefinierte und 12 vom Anwender zu definierende Symbole enthält, zur Verfügung.

3.2.14.3.4. Granularität
Je nach Ebene ist Pro Model PC feiner oder gröber strukturiert.

3.2.14.3.5. Grenzen
Die maximale Problemgröße des Starter Package ist vom Hersteller beschränkt,die der Vollversion hängt vom verwendeten Rechner ab.

3.2.14.3.6. Modellbeschreibung
Das Modell wird mit ereignis- oder prozeßorientierten Blöcken beschrieben.

3.2.14.3.7. Experimentbeschreibung
Die Experimentbeschreibung und -änderung wird durch ein Menü gesteuert.

3.2.14.3.8. Output-Analysen
Pro Model PC erstellt automatische statistische Reporte in Form von Tabellen und Graphiken (wie etwa Histo-, und Balkendiagramme, Torten,...). Der Anwender kann für spezielle Zwecke aber auch eigene Reporte und Graphiken definieren.

3.2.14.3.9. Import/Export von Datenformaten
Pro Model PC speichert die Daten im ASCII-Format, so kann das Output-File in andere Softwarepakete, Lotus. Excel, Quattro, , eingebunden werden.

3.2.14.3.10. Animation
Die Animation erfolgt im Modell-Layout.

3.2.14.4. Allgemeine Vorteile
Pro Model PC ist relativ rasch erlernbar.

3.2.14.5. Allgemeine Nachteile
Bei größeren Modellen können Speicherprobleme auftreten. (DOS)

3.2.14.6. Schlußfolgerung
Mit Pro Model PC kann man kleinere Modelle rasch modellieren.

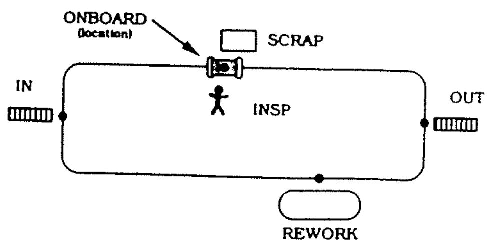
Beispiele für Modell- und Ergebnisbeschreibung:

ROUTING

Part	Location	Operation (min)	Output part	Next location	Condition	Qty	Move time( )
TRAN	IN	.05	TRAN	INSP	0	1	AGV
TRAN	INSP	GET AGV	IF V2<>1 THEN +3				
		2.6	TRAN	REWORK	0	1	AGV
		V1=D1	END				
		IF V1=2 THEN +5	IF V2<>2 THEN +3				
		AT3,+1	TRAN	OUT	0	1	AGV
		IF AT3=2 THEN +5	END				
		V2=1	TRAN	SCRAP	0	1	23
		END					
		V2=2					
		END					
		V2=3					
		FREE AGV					
TRAN	OUT	.05	TRAN	EXIT	0	1	0
TRAN	REWORK	12,15,19	TRAN	INSP	0	1	AGV
TRAN	SCRAP	:30	TRAN	EXIT	0	1	0

FUNCTIONS/DISTRIBUTIONS

D1
10,1 100,2



ProModel RESULTS FOR EXAMPLE1
*CIRCUIT BOARD DRILLING MODEL
DATE 11/2/89
SIMULATION TIME 2 00 HOURS

RESOURCE UTILIZATION SUMMARY

Resource	Capacity	% Util	Total entry	Avg min/ entry	Avg contents	Max contents	Final contents	% down
STORAGE	200	26.11	100	62.66	52.2	100	5	0.0
DRILL	2	100.00	95	2 53	2.0	2	2	0.0
INSPECT	1	76.01	93	0.98	.8	1	1	0.0
EXIT	1	0.00	92	0.00	0 0	1	0	0 0

3.2.15. EXAM

3.2.15.1. Allgemeines

Das *general purpose system* EXAM ist bestrebt alle Bereiche des Simulationsprozesses zu unterstützen: die Modellbeschreibung, die Experimentbeschreibung und die Simulation selbst.

3.2.15.2. Produktdaten

3.2.15.2.1. Hersteller:
Institute of System Analysis
Russian Academy of Science
9, Prospect 60 let Oktjabrja
117312 Moscow, Russia
Fax: +7-095-9382209

3.2.15.2.2. Distributor:
(wie oben)

3.2.15.2.3. Plattformen, Systemerfordernisse:
IBM-kompatible PC's unter MS-Windows

3.2.15.2.4. Preis:
auf Anfrage

3.2.15.2.5. Verfügbarkeit:
MS-Windows Version

3.2.15.3. Evaluierungsresultate

3.2.15.3.1. User Interface
EXAM arbeitet mit einem Menü-orientierten User-Interface, sodaß Modelle ohne besondere Programmierkenntnisse des Anwenders erstellt werden können.

3.2.15.3.2. Dokumentation
Manual

3.2.15.3.3. Grundprinzipien
EXAM basiert auf der objektorientierten Programmiersprache Turbo-Pascal.
EXAM trennt die Bereiche Modell-, und Experimentbeschreibung in zwei voneinander abgegrenzte Rahmen (*frames*): in den *Model Description Frame* (MDF) und in den *Experiment Description Frame* (EDF). Der Modellbilder erstellt die zur Modellerstellung nötigen Module, die den wichtigsten Features eines Prozesses entsprechen, verleiht ihnen die notwendigen Parameter und verbindet sie der Modell-Logik entsprechend.

3.2.15.3.4. Granularität
Je nach verwendeter Ebene, es können z.B. Subsysteme erstellt werden, feiner oder gröber strukturiert.

3.2.15.3.5. Grenzen
Grenzen werden nur durch die verwendete Hardware gesetzt.

3.2.15.3.6. Modellbeschreibung
Das Modell wird, von der Experimentbeschreibung strikt abgegrenzt, im *Model Description Frame* (MDF) graphisch beschrieben.

3.2.15.3.7. Experimentbeschreibung
Auch die Experimentbeschreibung erfolgt in einem eigenen Rahmen, dem *Experiment Description Frame* (EDF), in graphischer Form.

3.2.15.3.8. Output-Analysen
Simulationsergebnisse können in Form von Tabellen präsentiert werden. Darüber hinaus werden Optimierungsmöglichkeiten angeboten.

3.2.15.3.9. Import/Export von Datenformaten
Daten können mit ASCII-Files im-, und exportiert werden.

3.2.15.3.10. Animation
Die Animation erfolgt im Modell-Layout.

3.2.15.4. Allgemeine Vorteile

Der Modellbildner kann Systeme ohne Programmierkenntnisse mit Hilfe der benutzerfreundlichen Oberfläche von EXAM erstellen.

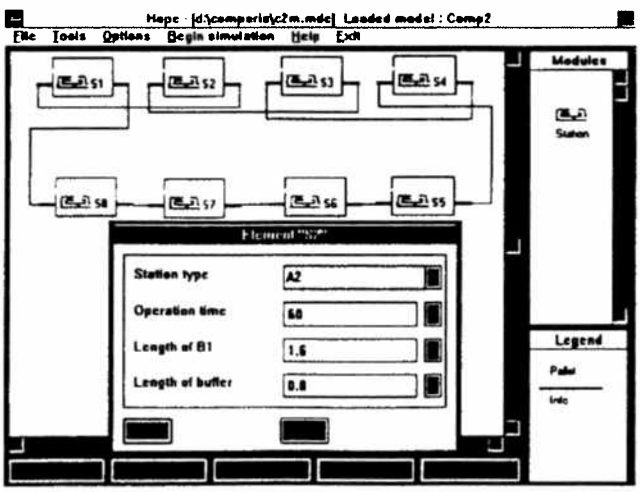
3.2.15.5. Allgemeine Nachteile

Nachteil von EXAM ist die geringe Verfügbarkeit.

3.2.15.6. Schlußfolgerung

Modelle können mit EXAM rasch, ohne lange Einarbeitungszeit und große Programmierkenntnisse erstellt werden.

Beispiel für eine Modellbeschreibung:



3.2.16. POSES

3.2.16.1. Allgemeines

Das Simulationssystem POSES (Prädikat-Transitionsnetz-Orientiertes-Simulations und Entwurfs-System), das an der Technischen Universität Chemnitz entwickelt wurde, basiert auf Petri-Netzen (Prädikat-Transitionsnetzen).

3.2.16.2. Produktdaten

3.2.16.2.1. Hersteller:
Gesellschaft für Prozeßautomation & Consulting mbH
Senefelder Str. 38
D-O-9022 Chemnitz
Tel.: +49-(0)371 50593 Fax: +49-(0)371 505 94

3.2.16.2.2. Distributor:
(wie oben)

3.2.16.2.3. Plattformen, Systemerfordernisse:
PC 's

3.2.16.2.4. Preis:
auf Anfrage

3.2.16.2.5. Verfügbarkeit:
aktuelle Version: POSES V4.3

3.2.16.3. Evaluierungsresultate

3.2.16.3.1. User Interface
POSES besitzt eine eigene Shell mit Editor, Compiler und Linker, in der die Modelle textuell beschrieben und verarbeitet werden.

3.2.16.3.2. Dokumentation
Manual

3.2.16.3.3. Grundprinzipien
POSES beruht auf Netzwerk-orientierten Ansätzen. Die Daten- und Netzstruktur eines Modells wird mit der Sprache POSES, ähnlich der Programmiersprache PASCAL, beschrieben (in einer Shell).
Benützerdefinierte PASCAL oder C-Routinen können eingebunden werden.

3.2.16.3.4. Granularität

3.2.16.3.5. Grenzen
Die Grenzen werden durch DOS gesetzt.

3.2.16.3.6. Modellbeschreibung
In der POSES-Syntax wird das Modell aus Petri-Netz-Elementen (Places, Transitions) aufgebaut, dabei sind komplexe Verarbeitungs- und Routing-Daten formulierbar.

3.2.16.3.7. Experimentbeschreibung

Nahezu alle Parameter (Kapazitäten, Prioritäten,..) können während der Experimentierphase definiert oder verändert werden.

3.2.16.3.8. Output-Analysen

Ergebnisse können in Form von Tabellen zusammengefaßt werden.

3.2.16.3.9. Import/Export von Datenformaten

Daten können mit ASCII-Files im-, und exportiert werden.

3.2.16.3.10. Animation

POSES bietet keine Animation.

3.2.16.4. Allgemeine Vorteile

POSES ist in vielen Bereichen einsetzbar.

3.2.16.5. Allgemeine Nachteile

POSES erfordert gute Programmierkenntnisse und somit eine lange Einarbeitungszeit. Ein weiterer Schwachpunkt ist die fehlende Animation.

3.2.16.6. Schlußfolgerung

POSES ist geeignet für Anwender, die mit der Petri-Netz-Terminologie vertraut sind, und für viele Bereiche verwendbar.

Beispiel für eine Modellbeschreibung:

```
system  Philosoph;

const   MAX             = 5;
type    Nr              = 0.. (MAX-1) ;
        BufferType      = ram [MAX] of Nr;
var     x               : Nr;
buffer  Meditating      : BufferType
(<<0>>+<<1>>+<<2>>+<<3>>+<<4>>) ;
  Chopsticks            : BufferType (<<0>>+<<1>>+<<2>>+<<3>>+<<4>>) ;
  Eating                : BufferType;

net     GetSticks(in    Meditating [<<x>>],
                        Chopsticks [<<x>> + <<x mod MAX + 1>> ]
                  out   Eating [<<x>>]);

        PutSticks(in    Eating [<<x>>]
                  out   Meditating [<<x>>],
                        Chopsticks [<<x>> + <<x mod MAX + 1> >]);

end     Philosoph
```

3.2.17. FACTOR / AIM

3.2.17.1. Allgemeines

FACTOR/AIM stellt in gewisser Weise eine Weiterentwicklung von SLAM dar, und ist auf Fertigung und Scheduling spezialisiert. FACTOR/AIM faßt Simulation (AIM) und Scheduling und Capacity Management (FACTOR) zusammen.

3.2.17.2. Produktdaten

3.2.17.2.1. Hersteller:

Pritsker & Associates, Inc.
P.O. BOX 2413
West Lafayette
Indiana 47906

3.2.17.2.2. Distributor:

(wie oben)

3.2.17.2.3. Plattformen, Systemerfordernisse:

PC 's unter OS/2

3.2.17.2.4. Preis:

Grundpreis etwa DM 10.000.-, günstige Hochschulangebote

3.2.17.2.5. Verfügbarkeit:

FACTOR/AIM unter OS/2

3.2.17.3. Evaluierungsresultate

3.2.17.3.1. User Interface

FACTOR/AIM ist auf allen Ebenen Menü-Gesteuert (mit OS/2 - Techniken).Eingabe und Resultatausgabe kann mit integrierten Oberflächen - spezifischen Programmen weiterverarbeitete werden..

3.2.17.3.2. Dokumentation

Manual

3.2.17.3.3. Grundprinzipien

FACTOR stellt als integriertes System Modellbausteine für Scheduling und Capacity Management zur Verfügung. AIM ist ein Simulationstool unter FACTOR, das die Modellbausteine von FACTOR verwendet (generelle Fertigungsabläufe) und um eigene dynamische Komponenten zur Zeitreihenanalyse erweitert.

3.2.17.3.4. Granularität

Mithilfe der Modellbausteine kann auf beliebig hoher bzw. niedriger Ebene modelliert werden.

3.2.17.3.5. Grenzen

Theoretisch keine Modellgrenzen, da das System unter OS/2 läuft.

3.2.17.3.6. Modellbeschreibung

Modellbausteine erlauben einen graphischen Modelllaufbau. Bausteine können auch von Datenbanken kommen (Scheduling-Tabellen,etc.). Die Bausteine können mit beliebig komplexen Routing-Folgen versehen werden.

3.2.17.3.7. Experimentbeschreibung
Die Simulation erfolgt über Menüs, Reports können online erzeugt und verändert werden. AIM ist das Simulationstool in FACTOR, weitere Experimente können mit anderen FACTOR-Anwendungen ausgeführt werden: SDM (Schedule Development) und SMM (Schedule Management) erlauben Detailstudien, Planung und Optimierung.

3.2.17.3.8. Output-Analysen
Innerhalb des integrierten Systems sind statistische (dynamische) Ausgaben jeder Art möglich: online zur Simulation, Vergleich von Simulationsvarianten (Postprocessing), etc. .

3.2.17.3.9. Import/Export von Datenformaten
Entsprechend der OS/2-Philosophie können alle Datenformate der Umgebung verwendet werden.

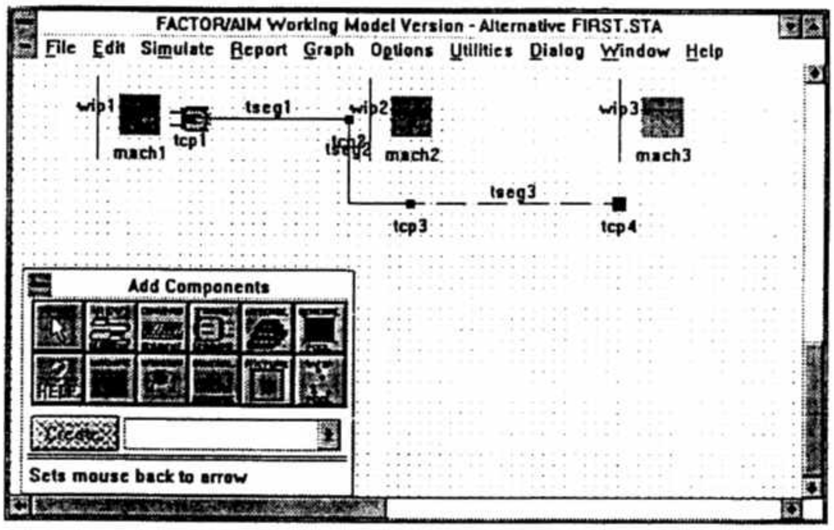
3.2.17.3.10. Animation
Die Animation erfolgt im Modell-Layout, das beliebig graphisch verändert werden kann.

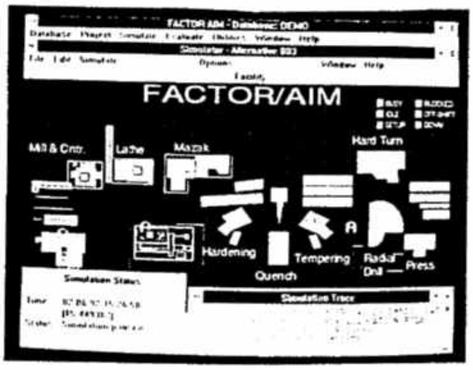
3.2.17.4. Allgemeine Vorteile
FACTOR/AIM entspricht dem modernen integrierten Aufbau eines Simulationspaketes; es kann benutzerfreundlich und ohne Programmierkenntnisse verwendet werden.

3.2.17.5. Allgemeine Nachteile
FACTOR/AIM ist nur auf Fertigungsprozesse ausgerichtet und läuft momentan nur unter OS/2."

3.2.17.6. Schlußfolgerung
FACTOR/AIM gehört neben SIMPLE derzeit zu den modernsten Simulationswerkzeugen für Fertigungsprozesse. Zur Simulation werden auch Werkzeuge für Planung und Kapazitätsvorsorge angeboten,worin FACTOR/AIM derzeit führend ist.

Beispiele für die Modellbeschreibung:





EUROSIM Comparisons

Publication of Solutions

July 1995

	C1	C2	C3	C4	C5	C6	C7	CP
SNE 0	Def							
SNE 1	5	Def						
SNE 2	4	4	Def					
SNE 3	4	3	3	Def				
SNE 4	1	5	5	3	Def			
SNE 5	4	-	1	1	2			
SNE 6	-	2	-	2	1	Def		
SNE 7	1	2	1	2	-	1	Def	
SNE 8	-	1	-	-	-	1	3	
SNE 9	-	-	-	-	-	2	3	
SNE 10	1	2	-	-	-	2	2	Def / 1
SNE 11	2	2	1	-	1	-	-	2
SNE 12	1	-	1	-	-	-	2	3
SNE 13	-	-	-	-	-	-	3	1
SNE 14	3	-	1	-	-	-	2	-
Total	**26**	**21**	**13**	**8**	**4**	**6**	**15**	**7**

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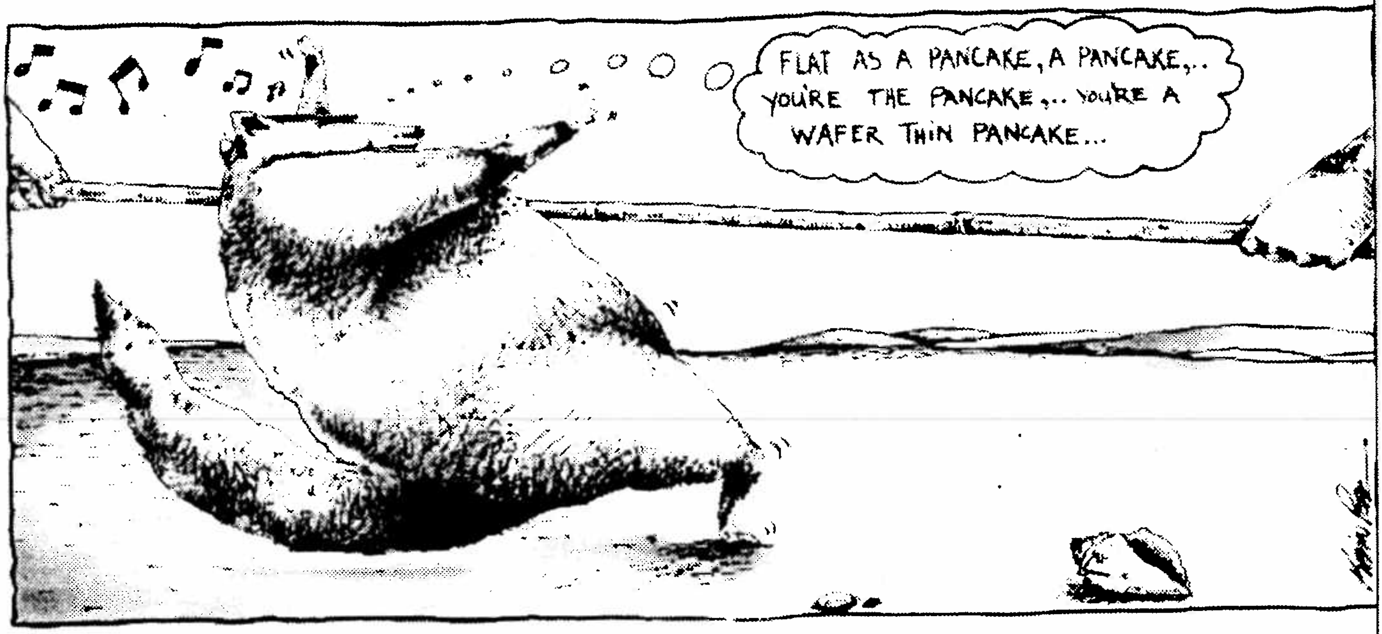

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