A Comparative Evaluation of Ten Manufacturing Simulation Packages

Vlatka Hlupic

Brunel University, Information Systems and Computing, Middlesex UB8 3PH, United Kingdom

This paper presents a comparative evaluation of ten well known and widely used packages for manufacturing simulation. These packages have been evaluated on the basis of various case studies in a real and hypothetical manufacturing environments. Following an evaluation and comparison, the suitability of packages for specific purposes is determined.

Keywords: Simulation, Evaluation, Manufacturing Simulation Packages.

1. Introduction

Simulation modelling of manufacturing systems has acquired wide acceptance by academic and industrial simulation specialists as a tool used for the design of new manufacturing systems and for improving the operations of existing ones. An increasing popularity of simulation is reflected by a growth in the number of simulation languages and simulators on the software market. New products are constantly being released on the scene, whilst the existing ones are regularly being improved. In general, simulation languages are becoming easier to use and simulators are capable to address a wider class of manufacturing problems (Law and McComas, 1992).

This paper presents an evaluation and comparison of ten widely used simulation packages especially designed for manufacturing applications. The evaluation is not performed in order to discover which is 'the best' package, because such a term does not exist in the context of simulation software as they are constantly revised. The evaluation presented in this paper was primarily performed to determine the suitability of each simulator for different software purposes.

Subsequently of a review of previous research studies in simulation software evaluation, evaluated packages are briefly introduced, as well as an evaluation framework used for their evaluation and comparison. On the basis of the evaluation, a method of rating packages is proposed. The suitability of the evaluated packages for different purposes is determined and discussed. The conclusions outline the main findings derived in this research. The lines for further research are addressed.

2. Background Research

The research presented in this paper was initiated by the review of the previous studies on evaluation and comparison of simulation software tools. This review has revealed that although there are many studies that describe the use of particular simulation language or simulator (eg. Taraman (1986), Bollino (1988)), there are very few comparative and critical evaluations.

Some of the studies related to evaluations of simulation languages include: a structural and performance comparison between SIMSCRIPT II.5 and GPSS V by Scher (1978); an efficiency assessment of SIMULA and GPSS for simulating sparse traffic by Atkins (1980); and a quantitative comparison between GPSS/H, SLAM and SIMSCRIPT II.5 by Abed et al. (1985).

SLAM, ECSL and HOCUS have been used by Ekere and Hannam (1988) for the evaluation of event, entity and process-based approaches to modelling and simulating manufacturing systems. Several criteria describing programming features, model development characteristics, experimental and reporting features, and commercial and technical features were specified.

The main characteristics and building blocks of AutoMod II, ProModel, SIMFACTORY II.5, WITNESS and XCELL+ are described by Law and Kelton (1991), though with a limited critical evaluation based on a few criteria. Likewise, Carrie (1988) presents features of GASP, EXPRESS, GENETIK, WITNESS and MAST, but again without an extensive comparison.

Tedford (1991) reports on a comparative evaluation of SIMFACTORY and Siman/CINEMA by modelling an automobile assembly line. SIMFACTORY was considered as more user-friendly and easier to learn than Siman/CINEMA. Siman-/CINEMA had better animation, running speed, simulation versatility but poorly designed manuals.

Banks et al. (1991) evaluate SIMFACTORY II.5, XCELL+, WITNESS and ProModelPC by modelling two manufacturing systems. The main results of the evaluation revealed that SIMFACTORY II.5 and XCELL+ did not have robust features, while WITNESS and ProModelPC had most of them. Such conclusions were obtained on the basis of twenty two criteria.

A simulation software survey and evaluation is carried out by Law and Haider (1989) on the basis of information provided by vendors. Both simulation languages and simulators such as FACTOR, MAST, WITNESS, XCELL+ and SIMFACTORY II.5 are included in this study. Instead of commenting on the information presented about the software, the authors conclude that there is no simulation package which is completely convenient and appropriate for all manufacturing applications.

An analysis of the studies in simulation software evaluation and comparison shows that several evaluation studies are based on information provided by vendors, and lack any criticism. It seems likely that many authors did not have an opportunity to test all the software tools considered and use them for developing complex models of real systems. Though some of the evaluation studies consider WITNESS, SIMFACTORY, XCELL+ and ProModelPC, none of these evaluations and comparisons is comprehensive nor do they include evaluation of INSTRATA, Taylor II, Siman/CINEMA, MicroSaint and AUTOMOD II.

3. Simulation Software Evaluation: the Evaluation Framework

This research deals with an evaluation and comparison of the following ten packages dedicated to manufacturing simulation: WITNESS, SIMFACTORY II.5, INSTRATA, AUTOMOD II, XCELL+, Taylor II, MicroSaint, Siman/-CINEMA, ProModelPC (Windows version) and ProModelPC (DOS version). Appendix A shows which versions of simulators under consideration were evaluated.

Evaluation has been carried out on the basis of various case studies. The main case study relates to an automated system for electrostatic powder coating of metal components in an electronics company operating in the United Kingdom. Detailed description of this case study is provided in (Hlupic and Paul, 1994). Other case studies involve modelling of various hypothetical manufacturing systems, most of which were derived for teaching on the MSC in Simulation Modelling course (Paul and Hlupic, 1994). A variety of features that had to be modelled (such as assembling machines, conditional routing, conveyors and labour requirements modelling) provided a good basis for the evaluation of simulation packages under consideration.

Evaluation performed in this research is based on the evaluation framework derived by Hlupic (1993). This framework comprises more than 330 criteria grouped into 17 groups. These groups include:

1. General Features

Criteria included in this group describe general features of the package. Most of these criteria relate to modelling aspects such as the type of formal logic needed for modelling (if any), modelling flexibility, the level of modelling transparency etc. There are also some criteria that evaluate the level of experience and formal education in simulation needed from the user, and examine how easy it is to learn and use the package.

2. Visual Aspects

Graphical presentation of simulation models and animation of simulation are very important characteristics of simulation software. Criteria included in this group concern the type and quality of graphical facilities provided by the package. These criteria evaluate, for example, whether it is possible to perform animation of simulation experiments, the types of animation provided by the package (eg. 3-dimensional animation), and whether it is possible to manipulate icons.

3. Coding Aspects

The possibility of additional coding might be very important feature of a package, as it determines the flexibility and robustness of the software, which is especially valuable when complex systems are to be modelled. Criteria included in this group determine whether the package allows additional programming, if access to the code is possible, the characteristics of the added code, the programming concepts supported etc.

4. Efficiency

Criteria classified in this group determine the effectiveness and the power of simulation software. Efficiency is expressed both by the capability of the software to model a variety of complex systems and by the characteristics which can save the time needed for modelling and improve the quality of modelling such as model reusability, reliability, compilation time, execution time and multitasking.

5. Modelling Assistance

Criteria systematized in this group evaluate the type and level of assistance provided by the package during modelling. For example, these criteria examine the comprehensiveness of prompting, on-line help if it is provided, automatic data editing, whether the package enables modular model development and writing the documentation notes (this feature enables writing documentation concurrently with the model development), and whether the model and data can be separated.

6. Testability

This group comprises criteria that examine which facilities for model verification are provided by the package. These facilities include quality of error messages, displays of the values of logical elements such as functions and variables, the possibility of obtaining special files for verification such as list, trace and echo files, provision of step function etc.

7. Software Compatibility

These criteria evaluate whether the package can be interfaced to other software systems (such as statistical packages, spreadsheets, and CAD software) in order to exchange data with these systems. This feature can considerably enhance the capabilities of the package, especially when complex real systems are modelled.

8. Input/Output

Criteria included in this group investigate how the user can present the data to the package and the type and quality of output reports provided by the package. These criteria evaluate, for example, whether the package has a menu driven interface, whether static and dynamic output reports are provided, if summary reports for multiple runs and snapshot reports are available and how understandable these reports are.

9. Experimentation Facilities

Criteria classified in this group evaluate the variety and characteristics of experimentation facilities (such as multiple runs, accuracy checks, automatic determination of run length and speed adjustment). These facilities are required for improving the quality of simulation results and for speeding up the process of designing experiments and of the experimentation itself.

10. Statistical facilities

Due to the randomness that is present in the majority of simulation models, good statistical facilities are very important. Criteria included in this group examine the range and quality of statistical facilities (such as theoretical and user-defined statistical distributions, output analysis, random number streams, Goodness-of-fit tests and antithetic sampling) provided by the simulation package.

11. User Support

The criteria in this group evaluate the type and quality of user support provided by the software supplier, which can facilitate learning and using the package. These criteria not only include technical support in the form of documentation, demo disks etc. They also include a variety of services (such as user groups meetings and user help-line) provided by the software supplier which ease the use of the package and keep the user informed about plans for future software improvements.

12. Financial Features

Criteria included in this group examine features of the package related to its costs and technical characteristics. Some of the issues considered here are: how expensive it is to purchase a certain package, to install and maintain it, whether any additional hardware would have to be purchased for installation of the package etc.

13. Pedigree

Criteria in this group refer to the origin of the package and its prominence. They also evaluate how widely the package is used, and judge the reputation of the software supplier. A supplier's reputation is a general criterion which depends on many factors such as the length of the time the supplier is present in the software market, the number of employees and representative offices the supplier has and the type and level of user support that is provided.

14. General Manufacturing Modelling Features

Criteria included in this group concern general features related to manufacturing modelling. They evaluate whether the package allows modelling of logical elements such as part attributes, shifts modelling, and modelling of machine breakdowns. Some special operations typical for manufacturing systems are also included, such as assembling, palletization and fluid composition.

15. Physical elements

The following criteria examine which physical elements typical for different types of manufacturing systems can be modelled by a particular package. These criteria mainly relate to different types of machines and means of transport that can be modelled by a specific package.

16. Scheduling Features

Criteria embraced in this group investigate the variety of scheduling strategies that can be modelled by the package. These criteria are dominated by a variety of features needed for part and vehicles scheduling.

17. Manufacturing Performance

Whilst criteria included in the "input/output" group examine the type and quality of general output reports, criteria included in this section relate to reports typical for manufacturing. Criteria classified in this group provide standard reports needed for an insight into the performance of the manufacturing system being modelled (such as throughput, work in progress, tardiness and machine utilisation).

Some of the criteria do necessarily overlap, for example ease of use and quality of documentation. It may be arguable therefore, as to why a specific criterion is included in one sub-section and not in another. There are also some criteria that are more general, comprising several specific criteria. For example, ease of use of the package depends on many factors such as the quality of documentation, on-line help and tutorials, availability of a help line and the experience of the user.

However, to emphasize their importance all these criteria are specified separately. In addition, the aim was to use a comprehensive evaluation framework that can be of practical use than to invent a strict classification of criteria. The above groups of criteria were used as the basis for rating the simulators evaluated in this research. Such approach was taken because it was presumed that it is more beneficial to assess the general performance of each software tool with regard to a particular group of criteria, rather than to evaluate every single criterion (Hlupic and Paul, 1995).

4. A Comparative Evaluation of Simulation Packages

This section deals with a comparative evaluation of ten software packages especially designed for simulation of manufacturing systems. The main sources of information provided in this section relate to evaluation of these packages using various case studies and to the overall impressions and experience of the author gained through learning and using these simulators.

A rating of the evaluated packages has been established for the purpose of their comparison, as a relative measure of their quality from the perspective of groups of criteria. As such, this rating does not represent an absolute value.

Table 1. Comparison of evaluated simulators in terms of groups of criteria

SIMULATORS / GROUPS OF CRITERIA	WITNESS	SIMFACTORY	Siman/CINEMA	TAYLORII	MicroSaint	ProModelPC W	ProModelPC D	INSTRATA	AUTOMOD II	XCELL+
General Features	**8**	**8**	7	7	7	7	7	7	**8**	7
Visual Aspects	**8**	7	**8**	**8**	6	7	6	7	**8**	5
Coding Aspects	7	5	**8**	7	7	6	6	6	7	1
Efficiency	**8**	7	7	7	7	7	7	6	7	6
Modelling Assistance	**8**	7	**8**	**8**	7	7	6	7	**8**	7
Testability	**8**	7	**8**	7	6	7	5	6	**8**	6
Software Compatibility	6	7	**8**	5	6	6	7	6	6	6
Input/Output	**8**	7	**8**	7	6	7	7	7	7	6
Experimentation Facilities	7	**8**	7	7	7	7	**8**	7	7	6
Statistical Facilities	**7**	**8**	7	**8**	7	7	7	7	7	5
User Support	**8**	**8**	7	7	7	7	7	7	7	7
Financial Features	4	6	5	5	6	6	**8**	5	5	7
Pedigree	**9**	8	**9**	8	8	7	8	8	8	8
General Manufacturing Modelling Features	**8**	**8**	**8**	**8**	6	7	7	**8**	**8**	6
Physical Elements	**8**	**8**	7	**8**	6	7	7	**8**	7	6
Scheduling Features	**8**	7	7	7	7	7	7	7	7	5
Manufacturing Performance	**8**	7	7	7	6	7	7	7	7	6

Table 1 shows a proposed rating for the evaluated packages, in terms of the general quality of features within particular groups of criteria. The highest rates achieved for a particular group of criteria are emphasized in bold. The rating interval used in this assessment is similar to the one proposed by Ekere and Hannam (1989). The general quality of simulators with respect to particular groups of criteria is rated from 1 to 10, where 1 represents very poor quality or absence of the features within particular groups of criteria, whilst grade 10 represents excellent quality. Appropriately, it is proposed that 5 is taken to be a 'nominal acceptance level', or NAL for short. The grades for a certain group of criteria that are above the NAL indicate that a package is performing adequately, whereas those below signify the opposite. Although the NAL is clearly subjective, it does provide a level against which the relative performance of a package can be measured and reflected on. As the evaluation cannot be entirely objective, this qualitative measure of performance, the NAL, provides a relative measure. Nevertheless, clearly any particular grade is merely a 'qualitative' number, and the rules of arithmetic can only be applied with caution, if at all.

Table 1 shows that all packages are rated quite high with regard to *general features*. They are all data driven and manufacturing oriented (with MicroSaint being more general purpose than the other packages). WITNESS, SIMFACTORY II.5 and ProModelPC for Windows are considered to be slightly more user friendly than the other packages because of several features such as pull-down menus, quality of graphics, assistance provided in modelling etc. On the other hand, XCELL+ is the easiest to learn and use because of its simplicity and similar applies to MicroSaint. ProModelPC (DOS version), INSTRATA, Taylor II and AUTOMOD II balance ease of learning and use with user friendliness and comprehensiveness. Siman/CINEMA is less easy to use, but it is very robust and flexible.

Visual aspects are rated highest for WITNESS, Taylor II, Siman/CINEMA and AUTOMOD II, which satisfy the majority of criteria within this group. AUTOMOD II and Taylor II provide 3-D graphics. SIMFACTORY II.5, ProModelPC for Windows and INSTRATA follow with quality of graphics, which is also above the NAL. The next in the sequence are ProModelPC and MicroSaint with no icon editor, and finally XCELL+ which uses symbolic graphics.

With respect to coding aspects, Siman/CINEMA is rated as the best. This package is a simulation language (Siman) based environment and as such it provides a good support for the major programming concepts. WITNESS, Taylor II, MicroSaint, and AUTOMOD II follow with the second highest rates. The reason for this is a availability of internal macro languages provided for additional coding. Next in the sequence are INSTRATA and both versions of ProModelPC. The quality of SIMFACTORY II.5 regarding this group of criteria is even lower (at the NAL level) due to inadequate flexibility, whilst XCELL+ does not allow for any programming at all.

The *efficiency* related rating of the packages also shows good quality. WITNESS is given the highest score, mainly because of its relatively high robustness and interactivity. Next in line are SIMFACTORY II.5, Siman/CINEMA, Taylor II, MicroSaint, AUTOMOD II and both versions of ProModelPC. SIMFACTORY II.5 and ProModelPC for Windows, for example, are better in features such as adaptability and interactivity, whilst Siman/CINEMA is better regarding robustness. XCELL+ is lacking robustness, but it has a short time scale for model building. Finally, INSTRATA is more robust than XCELL+, but it has a significant problem with reliability.

Modelling assistance is slightly better ranked for WITNESS, Siman/CINEMA, Taylor II and AUTOMOD II than for the other packages mainly because of prompting, on-line help and automatic data editing. Similar applies to SIMFACTORY II.5, MicroSaint and ProModelPC for Windows and INSTRATA. XCELL+ is graded quite high due to its prompting, and its rejection of invalid values. The last simulator in the sequence is ProModelPC (DOS version). Although it possesses several features regarding modelling assistance, some of them are of little use.

With regard to *testability*, WITNESS, Siman/-CINEMA and AUTOMOD II outperform all the other packages. They are rated quite high because they have many features that facilitate model verification such as logic checks, display of variables, function values, an access to attributes etc. Next are SIMFACTORY II.5, Taylor II and ProModelPC for Windows, all with good visual facilities for debugging. Then follows XCELL+, and finally the lowest rated ProModelPC (DOS version), because testability is perhaps the weakest feature of this simulator. The main reason for this is the poor quality of error messages, which do not even provide information about where an error has occurred.

The quality of features with regard to *software compatibility* is above the NAL, but not very high. Siman/CINEMA achieved the highest rate due to its compatibility with spreadsheets, statistical and scheduling packages. Whilst majority of simulators under consideration enable integration with word processors and spreadsheet packages, SIMFACTORY II.5 and ProModelPC (DOS version) are slightly better ranked, because they can be linked with data bases and statistical packages respectively. Taylor II is only compatible with spreadsheets. At the moment, none of them can be integrated with MRP II software or expert systems.

Concerning the *input/output* features, WITNESS has achieved the highest performance mainly because of its variety of standard and special user-defined reports, as well as its facilities for user friendly input of data. The same rate was given to Siman/CINEMA due to a variety of output reports provided, multiple inputs and outputs, periodic output of simulation results etc. Next in the sequence are SIMFACTORY II.5, Taylor II, INSTRATA, AUTOMOD II and both versions of ProModelPC, some of them providing facilities such as summary reports for multiple runs or snapshot reports. Finally, XCELL+ is the last in the sequence, mainly because of its lack of user defined reports and of summary reports for multiple runs. Similar applies to MicroSaint.

SIMFACTORY II.5 and ProModelPC (DOS version) are best ranked regarding *experimentation facilities*, providing features such as facilities for multiple runs, accuracy checks and the automatic determination of run length (SIMFACTORY II.5) or a facility for the automatic testing of 'what if' scenarios (ProModelPC). Experimentation facilities for WITNESS are slightly worse, mainly because the setting up of automatic experimentation is not straightforward. The same grade was given to other packages (except XCELL+) due to inadequate facilities for speed adjustment and specification of the warm-up period. Finally, XCELL+ is rated just above the average, because it cannot automatically run multiple experiments. None of the packages provides an adequate help for experimental design.

It is judged that SIMFACTORY II.5 and Taylor II have the best statistical facilities in comparison with the other evaluated simulators. They not only provide features such as numerous theoretical statistical distributions, they also enable distribution fitting and Goodness-of-fit tests. All other packages except XCELL+ follow, where WITNESS is lacking, for example, facilities for distribution fitting and output analysis, ProModelPC (DOS version) and AUTOMOD II are lacking a large number of random number streams and antithetic sampling, whilst INSTRATA is lacking an adequate facility for user-defined distributions. Finally, XCELL+ is rated at the NAL, because of its small number of theoretical statistical distributions, and a lack of antithetic sampling and distribution fitting.

With regard to *user support*, WITNESS and SIMFACTORY II.5 are rated highest. The suppliers of both simulators provide a high level of support in the form of user group meetings, help-lines etc. Other packages were also given grades above the NAL levels, but slightly lower.

ProModelPC (DOS version) is ranked as the best regarding *financial features*. Its price depends on the number of operations purchased, and even so, it is the least expensive package (in comparison with the other packages evaluated), with moderate hardware requirements. This was the main reason for such a high scoring, although it might be argued that it has a limited portability. The next simulator is XCELL+ with similar characteristics, but it is slightly more expensive. SIMFACTORY II.5 follows with a significantly higher price, but with high portability, and free software trials. In addition, this is the only simulator among those evaluated that does not require a security device. INSTRATA, Siman/CINEMA, Taylor II and AUTOMOD II have significant hardware requirements and need a security device. WITNESS is in the last position regarding this group of criteria, because its price is the highest and its hardware requirements are high.

Regarding their *pedigree* all simulators are rated highly because they are all quite well known and widely used. They are all of similar age, as most of them were released on the market around 1986, with the exception of INSTRATA and ProModelPC for Windows which were released a few years later. Information about these simulators appear in various sources of literature. However, WITNESS and Siman/-CINEMA are ranked slightly better then other simulators. WITNESS due to its SEE-WHY origin (SEE-WHY introduced visual interactive systems), whilst Siman/CINEMA due to its spread. ProModelPC for Windows is given the smallest rate because it is the newest package, and so not many information about its success is available.

Concerning the number and quality of *general manufacturing modelling features*, WITNESS, Siman/CINEMA, Taylor II, INSTRATA, AUTOMOD II and SIMFACTORY II.5 are rated highest. All of these packages enable modelling of a variety of features typical of manufacturing systems. They are followed by both versions of ProModelPC, and finally XCELL+ (whose main shortcoming is its inability to model part attributes) and MicroSaint (with more general modelling elements named tasks).

With regard to the *physical elements*, WITNESS, Taylor II, INSTRATA and SIMFACTORY II.5 explicitly provide a variety of physical elements typical of manufacturing systems, such as various types of machines and materials handling systems. Different physical elements are modelled by an appropriate routing logic when ProModelPC (DOS version) is used.

Similar applies to AUTOMOD II and Siman/-CINEMA. For example, due to its programming flexibility, Siman/CINEMA is capable of modelling a variety of physical elements, but there are no explicit facilities for rapid modelling. Finally, XCELL+ and MicroSaint are in the last position. XCELL+ requires, for example, the use of dummy elements if a certain type of machine is to be modelled, whilst MicroSaint, due to its generality, lacs explicit modelling facilities for physical elements.

Concerning *scheduling features*, WITNESS was given the highest grade, mainly because one can model a variety of scheduling strategies using both the in-built input/output rules and additional programming. INSTRATA, Siman/-CINEMA, Taylor II, MicroSaint, AUTOMOD II, SIMFACTORY II.5 and both versions of ProModelPC follow with similar characteristics, although the modelling of scheduling is less flexible (except for Siman/CINEMA). Finally, it was estimated that the scheduling features provided by XCELL+ are of an average quality, mainly because of its restricted flexibility to model a variety of scheduling strategies.

A similar gradation applies to the group of criteria related to *manufacturing performance*. Although all packages provide automatic collection of statistics, there is a difference in the number, quality and form of reports. An additional factor that was considered important is the facility to obtain special user-defined reports. Regarding these criteria, WITNESS was rated at the highest level, following by INSTRATA, AUTOMOD II, SIMFACTORY II.5, Siman/-CINEMA, Taylor II and both versions of Pro-

Table 2. Deviations from maximum scores specified for the groups of criteria

SIMULATORS / GROUPS OF CRITERIA	WITNESS	SIMFACTORY	Siman/CINEMA	TAYLORII	MicroSaint	ProModelPC W	ProModelPC D	INSTRATA	AUTOMOD II	XCELL+
General Features	0	0	-1	-1	-1	-1	-1	-1	0	-1
Visual Aspects	0	-1	0	0	-2	-1	-2	-1	0	-3
Coding Aspects	-1	-3	0	-1	-1	-2	-2	-2	-1	-7
Efficiency	0	-1	-1	-1	-1	-1	-1	-2	-1	-2
Modelling Assistance	0	-1	0	0	-1	-1	-2	-1	0	-1
Testability	0	-1	0	-1	-2	-1	-3	-2	0	-2
Software Compatibility	-2	-1	0	-3	-2	-2	-1	-2	-2	-2
Input/Output	0	-1	0	-1	-2	-1	-1	-1	-1	-2
Experimentation Facilities	-1	0	-1	-1	-1	-1	0	-1	-1	-2
Statistical Facilities	-1	0	-1	0	-1	-1	-1	-1	-1	-3
User Support	0	0	-1	-1	-1	-1	-1	-1	-1	-1
Financial Features	-4	-2	-3	-3	-2	-2	0	-3	-3	-1
Pedigree	0	-1	0	-1	-1	-2	-1	-1	-1	-1
General Manufacturing Modelling Features	0	0	0	0	-2	-1	-1	0	0	-2
Physical Elements	0	0	-1	0	-2	-1	-1	0	-1	-2
Scheduling Features	0	-1	-1	-1	-1	-1	-1	-1	-1	-3
Manufacturing Performance	0	-1	-1	-1	-2	-1	-1	-1	-1	-2

ModelPC. XCELL+ and MicroSaint are in the last position. XCELL+ mainly due to lack of any special user defined reports, whilst MicroSaint due to the lack of facilities for automatic collection of measures of manufacturing performance.

An additional analysis of the rating of the evaluated simulators in provided in Table 2. Table 2 shows deviations from maximum scores obtained by packages, specified for each group of criteria. Therefore, the closer a value of deviation is to zero, the better. The results obtained further support the claim that although some packages might have a better overall performance than the others, they do not perform equally well for all groups of criteria.

5. Suitability of the Evaluated Packages for Particular Purposes

Results of the comparative evaluation of ten simulation packages reveal several facts. Although some simulators scored higher than the others, for example WITNESS v. XCELL+, there is no such a package that satisfies all criteria, and shows good performance in all features. Usually, features of the simulators, such as robustness and comprehensiveness, require more learning and an increase in model development time, demanding at the same time purchasinghigher costs. Similarly, more user friendly and easy to learn packages usually lack flexibility and robustness.

In general, there is no package which is equally good for all the purposes of education, rapid modelling in industry, or complex and detailed modelling in industry. As is shown in Hlupic (1993), the level of importance of certain software features is different for different purposes. Simulators under consideration in this study were evaluated using the evaluation framework described in the second section of this paper. Following the evaluation, the results were analysed from the perspective of hierarchy of criteria derived by Hlupic (1993). This hierarchy shows that certain groups of criteria are more important than the others when a package is to be used for a particular purpose. In this context, on the basis of the evaluation of the packages, and on the basis of experience of the author obtained in using these packages, a suggested suitability of simulators for particular purposes is shown in Table 3.

Table 3 shows that XCELL+ and MicroSaint can be considered as the most appropriate for education purposes. The main reasons for this are their simplicity, ease of learning and use, and short model development time. The second best packages for education are SIMFACTORY II.5 and ProModelPC for Windows which can

Table 3. The suitability of evaluated simulators for particular purposes

RANK	EDUCATION	RAPID MODELLING-INDUSTRY	DETAILED/ COMPLEX MODELLING-INDUSTRY AND RESEARCH
1.	XCELL+ MicroSaint	SIMFACTORY II.5 Taylor II	Siman/CINEMA
2.	SIMFACTORY II.5 ProModelPC (W)	MicroSaint ProModelPC (W)	WITNESS
3.	INSTRATA	XCELL+	AUTOMOD II
4.	ProModel PC (D)	INSTRATA ProModelPC (D)	ProModelPC (D) Taylor II INSTRATA MicroSaint
5.	WITNESS AUTOMOD II Taylor II	WITNESS AUTOMOD II Siman/CINEMA	ProModelPC (W) SIMFACTORY II.5
6.	Siman/CINEMA		XCELL+

be fairly easily learnt and used, providing at the same time good overall features. At the third level is the more comprehensive and difficult to learn INSTRATA. ProModelPC (DOS version) follows, and finally WITNESS, AUTOMOD II and Siman/CINEMA are the least suitable for education, as they require more experienced users and have some features specially needed for detailed modelling.

With respect to rapid modelling in industry, it is appraised that SIMFACTORY II.5 and Taylor II are the most suitable packages. In addition to their relatively easy learning and use, they have quite straightforward modelling of many features typical of manufacturing systems. The second position is assigned to MicroSaint and ProModelPC for Windows, which are even easier to learn and use, but are more inflexible. Then follows XCELL+ and INSTRATA with ProModelPC (DOS version). Finally, although WITNESS, Siman/CINEMA and ProModelPC can also be used for rapid modelling in industry, they are in the last position because it takes quite a long time to learn and use them properly.

For detailed/complex modelling in industry and research, it is estimated that Siman/CINEMA the most suitable package. The main reason for this is the highest flexibility achieved by Siman programming constructs. It is followed by WITNESS, and AUTOMOD II. Both WITNESS and AUTOMOD II are quite comprehensive, robust and flexible, as much as simulators can be. At the same time they are quite user friendly and easy to use once they are learnt. The subsequent most suitable packages are ProModelPC (DOS version) (mainly because of its programming flexibility and possibility of linking to a lower language, although its models are not easy to debug), INSTRATA (with a library of constructs and phrases, which quickly becomes too restrictive unless the user is able to program in GENETIK), Taylor II and MicroSaint (with internal macro languages). The next package is SIMFACTORY II.5, which, despite many good general features, is quite limited in flexibility and robustness. Finally XCELL+ might be considered as the least suitable for complex and detailed modelling due to its simplicity and inflexibility.

6. Conclusions and Future Work

This paper provides a comparative evaluation of ten software packages designed for manufacturing simulation. The aim of research was to generally comprehend basic features of each package, rather than to examine specific features via single criteria within each group. It is likely that specific features are going to change or be added to with new releases of the packages under consideration.

In order to perform a comparative analysis of the evaluated packages, the general quality of each group of criteria was ranked for each package. This showed that although the packages have many common features, there is also a variety of differences between them. Our research has revealed that none of the packages satisfies all criteria, and none is equally good for all purposes. Although some packages are more comprehensive and flexible than the others, there is no package that can adequately fit any manufacturing problem unless it is entirely based on a simulation language or it provides a link to a lower programming language such as Pascal, C, or FORTRAN. Those packages that are more robust and adaptable are usually less user friendly, more expensive, difficult to learn and difficult use properly. The less work required from the user the more must be done by the package itself, which increases its complexity, size, cost and execution times (Carrie, 1988).

A general conclusion to be drawn from this research supports the fact that the selection of a piece of simulation software is a matter of compromise between many, usually conflicting factors. One of the most important factors that determines a suitability of a particular software package is its intended purpose. For example, the requirements for a package to be used for education or rapid modelling in industry are undoubtedly different from the features needed for a package to be used for complex/detailed modelling in industry. There are many other factors to be considered, such as the budget available for software purchase, types of systems to be modelled, and subjective factors such as individual preferences and previous experience in using simulation software.

There are several lines for further research in this area. Other simulation packages are to be

Appendix A: Versions of the simulators being evaluated

SIMULATOR	VERSION
WITNESS	Release 3, version 7.3.0
SIMFACTORY II.5	Release 4.2
Siman/CINEMA	Version IV
TAYLOR II	Version 4.0
MicroSaint	Version 2.0
ProModelPC (Windows)	Version 1.10
ProModelPC (DOS)	Version 5.0
INSTRATA	Version 3.01
AUTOMOD II	Version 2.0
XCELL+	Release 4.0

evaluated, with constant updating of the evaluation framework. The final objective is to embody all the research findings into an intelligent software system, which will assist the users in simulation software selection.

References

ABED S. Y., BARTA T. A., MCROBERTS K. L., "A qualitative comparison of three simulation languages: GPSS/H, SLAM, SIMSCRIPT", Computers and Industrial Engineering, 9, (1985a), 136–144.

ABED S. Y., BARTA T. A., MCROBERTS K. L., "A qualitative comparison of three simulation languages: GPSS/H, SLAM, SIMSCRIPT", Computers and Industrial Engineering, 9, (1985b), 145–166.

ATKINS M. S., "A comparison of SIMULA and GPSS for simulating sparse traffic", Simulation, 34, (1980), 93–98. "AUTOMOD Users Manual", Autosimulations inc, Utah, USA, 1993.

BANKS J., AVILES E., MCLAUGHLIN J. R., YUAN R. C., "The Simulator: New Member of the Simulation Family", Interfaces, 21/1, March-April, (1991), 76–86.

BOLLINO A., "Study and realisation of manufacturing scheduler using FACTOR", Proceedings of the 4th International Conference on Simulation in Manufacturing, London, (1988), 9–20.

CARRIE A., "Simulation of Manufacturing Systems", Wiley, Great Britain, 1988.

CONWAY R., MAXWELL W., MCCLAIN J., WORONA S., "User's Guide to XCELL+", The Scientific Press, San Francisco, 1990.

EKERE N. N., HANNAM R. G., "An evaluation of approaches to modelling and simulating manufacturing systems", International Journal of Production Research, 27/4, (1989), 599–611.

HLUPIC V., "Simulation Modelling Software Approaches to Manufacturing Problems", Unpublished Ph.D. Thesis, The London School of Economics, The University of London, 1993.

HLUPIC V., PAUL R. J., "Simulating an Automated Paint Shop in the Electronics Industry", Simulation Practice and Theory, 1/5, (1994), 195–205.

HLUPIC V., PAUL R. J., "Evaluation of Four Manufacturing Simulators", International Journal of Production Research, 33/10, (1995), 2757–2766.

LAW A. M., MCCOMAS, "How To Select Simulation Software For Manufacturing Applications", Industrial Engineering, July 1992, (1992), 29–35.

"INSTRATA Manual", Insight Logistics Ltd, Oxon, 1992.

KOCHHAR A. K., MA X., "Use of Computer Simulation:Aids for Solving Production Management Problems", Pròceedings of the 3rd European Simulation Congress, Edinburgh, SCS, San Diego, (1989), 516–522.

LAW A. M., KELTON W. D., "Simulation Modelling & Analysis", Second Edition, McGraw-Hill, Singapore, 1991.

LAW A. M. AND HAIDER S. W., "Selecting Simulation Software for Manufacturing Applications: Practical Guidelines & Software Survey", Industrial Engineer, 34, May 1989, (1989), 33–46.

"MicroSaint User's Guide", MicroAnalysis & design Inc., Boulder, Colorado, USA, 1987.

PAUL R. J., HLUPIC V., "Designing and Managing a Masters Degree Course in Simulation Modelling", Proceedings of the WSC'94 — Winter Simulation Conference, Orlando, USA, December 1994, (Ed. by Tew J. D., Manivannan S., Sadowski D. A. and Seila A. F.), Association for Computing Machinery, New York, pp. 1394–1398, (1994).

PEDGEN D., SHANNON R. E., SADOUSKI R. P., "Introduction to Simulation using SIMAN" , System Modelling Corporation, USA, 1991.

"ProModelPC User Manual", Version 5.0, Production Modelling Corporation, Orem, 1991.

"ProModel for Windows User's Guide", Production Modelling Corporation, Orem, 1994.

SCHER J. M., "Structural and performance comparison between SIMSCRIPT II.5 and GPSS V" , Proceedings of the 9th Annual Pittsburgh Conference on Modelling and Simulation, (edited by W. G. Vogt and M. H. Mickle), (1978), 1267–1272.

"SIMAN IV Reference Guide", Systems Modelling Corporation, Sewickley, USA, 1989.

"SIMFACTORY II.5 Reference Manual and User's Guide", San Diego, California, CACI Products Company, 1990.

TARAMAN S. R., "An Interactive Graphic Simulation Model for Scheduling the Factory of the Future" , AUTOFACT'86 Conference Proceedings, Detroit, (1986), 4–31, 4–3814.

"Taylor II User's Guide", F&H Logistics and Automation B. V., Tilburg, The Netherlands, 1993.

TEDFORD J., "A Comparative Evaluation of Simulation Software for Use in an Automobile Assembly Line" , Mechanical Engineering, 16,/2, (1991), 163–167.

"WITNESS User Manual", AT&T ISTEL Ltd., Redditch, 1991.

Received: May, 1995
Accepted: February, 1997

Contact address:
Vlatka Hlupic
Brunel University
Department of Information Systems
and Computing
Uxbridge UB8 3PH
Middlesex
United Kingdom
Tel: +44 1895 27400 Ext.2231
Fax: +44 1895251686
E-mail: (JANET) Vlatka.Hlupic@brunel.ac.uk

VLATKA HLUPIC is a Lecturer in Simulation Modelling at the Department of Information Systems and Computing at the Brunel University, United Kingdom. She received a B.Sc(Econ) and a M.Sc in Information Systems from the University of Zagreb, and a Ph.D. in Information Systems at the London School of Economics, England. She is researching into, and has published extensively, in simulation modelling software approaches to manufacturing problems. She has practical experience in the manufacturing, water treatment and waste disposal industries. She also held a variety of teaching posts in England and Croatia. Her current research interests are in simulation software evaluation and selection, business information systems, simulation in business and in simulators and simulation languages.