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A CRITICAL STUDY AND COMPARISON OF MANUFACTURING SIMULATION SOFTWARES USING ANALYTIC HIERARCHY PROCESS

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Abstract

In a period of continuous change in global business environment, organizations, large and small, are finding it increasingly difficult to deal with, and adjust to the demands for such change. Simulation is a powerful tool for allowing designers imagines new systems and enabling them to both quantify and observe behavior. Currently the market offers a variety of simulation software packages. Some are less expensive than others. Some are generic and can be used in a wide variety of application areas while others are more specific. Some have powerful features for modeling while others provide only basic features. Modeling approaches and strategies are different for different packages. Companies are seeking advice about the desirable features of software for manufacturing simulation, depending on the purpose of its use. Because of this, the importance of an adequate approach to simulation software evaluation and comparison is apparent. This paper presents a critical evaluation of four widely used manufacturing simulators: NX-IDEAS, Star-CD, Micro Saint Sharp and ProModel. Following a review of research into simulation software evaluation, an evaluation and comparison of the above simulators is performed. This paper illustrates and assesses the role the Analytic Hierarchy Process (AHP) played in simulation software evaluation and selection. The main purpose of this evaluation and comparison is to discover the suitability of certain types of simulators for particular purposes.

Keywords: Simulation, Simulation software, Evaluation, Comparison,
Selection, Rating.

1. Introduction

Growing competition in many industries has resulted in a greater emphasis on developing and using automated manufacturing systems to improve productivity and to reduce costs. Due to the complexity and dynamic behavior of such systems, simulation modeling is becoming one of the most popular methods of facilitating their design and assessing operating strategies.

An increasing need for the use of simulation is reflected by a growth in the number of simulation languages and simulators in the software market. When a simulation language is used, the model is developed by writing a program using the modeling construct of the language. This approach provides flexibility, but it is costly and time consuming. On the other hand, a simulator allows the modeling of a specific class of systems by data or graphical entry, and with little or no programming.

An evaluation of some of the most popular data driven simulators dedicated to the simulation of manufacturing systems is presented in this paper. The evaluation is not performed in order to discover which is 'the best' simulator, because such a term does not exist in the context of simulation software. The main reason for this is a constant updating of existing software and the release of new software products. Hence, the evaluation presented in this paper is primarily performed to determine the suitability of each simulator for different software purposes.

Following a review of previous research in simulation software evaluation, an evaluation framework used for the evaluation is given. On the basis of the evaluation, a method of rating simulators is proposed. The conclusions outline the main findings derived in this research.

2. Research in Software Evaluation and Comparison

The starting point for the research was to review previous studies on the evaluation and comparison of simulation software tools. Although there are many studies that describe the use of particular simulation packages or languages, for example, Fan and Sackett [1], Taraman [2], Bollino [3] and so on, relatively few comparative assessments were found like Abed et al. [4], Law and Kelton [5].

Some of the evaluations of simulation languages include: a structural and performance comparison between SIMSCRIPT II.5 and GPSS V by Scher [6]; an efficiency assessment of SIMULA and GPSS for simulating sparse traffic by Atkins [7]; and a quantitative comparison between GPSS/H, SLAM and SIMSCRIPT II.5 by Abed et al. [4].

SLAM, ECSL and HOCUS were used for the comparison of event, entity and process-based approaches to modeling and simulating manufacturing systems by Ekere and Hannam [8]. Several criteria describing programming features, model development characteristics, experimental and reporting features, and commercial and technical features were specified.

Law and Haider [9] provided a simulation software survey and comparison 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 concluded that there is no simulation package which is completely convenient and appropriate for all manufacturing applications.

A similar approach to software comparison has been taken by Grant and Weiner [10]. They analyzed simulation software products such as BEAM, CINEMA, PCModel, SEE WHY and SIMFACTORY II.5, on the basis of information provided by the vendors. The authors do not comment on the features provided by the software tools.

Law and Kelton [5] described the main characteristics and building blocks of AutoMod II, SIMFACTORY II.5, WITNESS and XCELL +, with a limited critical comparison based on a few criteria. Similarly, Carrie [11] presented features of GASP, EXPRESS, GENETIK, WITNESS and MAST, but again without an extensive comparison.

SIMFACTORY II.5, XCELL +, WITNESS were compared by modeling two manufacturing systems by Banks et al. [12]. The main results of the comparison revealed that SIMFACTORY II.5 and XCELL + did not have robust features, while WITNESS had most of them. Such conclusions were obtained on the basis of twenty two criteria.

Mackulak and Savory [13] carried out a questionnaire survey on the most important simulation software features. The most important features identified include: a consistent and user friendly user interface; database storage capabilities for input data; an interactive debugger for error checking; interaction via mouse; a troubleshooting section in the documentation; storage capabilities for simulation models and results; a library of reusable modules of simulation code; and a graphical display of input and output.

Hlupic and Paul [14] presented criteria for the evaluation and comparison of simulation packages in the manufacturing domain together with their levels of importance for the particular purpose of use. However, it is indicated which criteria are more important than others, according to the purpose of software use.

Tewoldeberhan et al. [15] proposed a two-phase evaluation and selection methodology for simulation software selection. Phase one quickly reduces the long-list to a short-list of packages. Phase two matches the requirements of the company with the features of the simulation package in detail. Different methods are used for a detailed evaluation of each package. Simulation software vendors participate in both phases.

Seila et al. [16] presented a framework for choosing simulation software for discrete event simulation. By evaluating about 20 software tools, the proposed framework first tries to identify the project objective, since a common understanding of the objective will help frame discussions with internal company resources a well as vendors and service providers. It is also prudent to define long-term expectations. Other important questions deal with model dissemination across the organization for others to use, model builders and model users, type of process (assembly lines, counter operations, material handling) the models will be focused, range of systems represented by the models, etc.

An analysis of the above studies in simulation software evaluation and comparison reveals that several comparative 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. Although some of the evaluation studies consider WITNESS, SIMFACTORY, XCELL+ and none of these evaluations and comparisons is comprehensive.

For these reasons, this research set out to produce a more extensive and critical evaluation and selection of four manufacturing simulators, based on 12 main groups of features and having more than 200 features.

3. Evaluation of Manufacturing Simulators

Four manufacturing simulators are evaluated in this research: NX-IDEAS, Star-CD, Micro Saint Sharp and ProModel. They are all data-driven, visual, interactive, manufacturing oriented simulators. Nevertheless, there are many differences between these software tools.

Evaluation has been performed using 13 main groups of features containing more than 220 features. These groups are used as the basis for rating the simulators. Such an approach is taken because it is assumed that it will be more convenient and useful to assess the general performance of each software tool regarding a particular group of criteria, rather than to evaluate every single criterion.

4. Simulation Software Evaluation Criteria

The criteria derived can be applied to the evaluation of any general or special purpose simulation package. For this study four main groups are defined to develop the framework for the evaluation. Features within each group are further classified into subcategories, according to their character. The main categories are:

1. *Hardware and software considerations*: coding aspects, software compatibility, user support;
2. *Modeling capabilities*: general features, modeling assistance;
3. *Simulation capabilities*: visual aspects, efficiency, testability, experimentation facilities, statistical facilities; and
4. *Input/Output issues*: input and output capabilities, analysis capabilities, Manufacturing Capabilities.

Owing to the comprehensiveness of the evaluation framework, individual criteria within each group are merely listed, and generally described in the context of a particular group. According to the type of each criterion, the classification determines whether, for example, a certain feature exists in the package, determines the quality of features provided, or lists types of alternatives available within a particular feature.

I. Criteria for hardware and software considerations

1.1 Coding aspects (Table 1)

The possibility of additional coding might be a very important feature of a package. This feature determines the flexibility and robustness of the software, which is especially valuable when complex systems are to be modeled. Criteria included in this group determine compilation efficiency, the programming concepts supported, logic builder availability etc.

1.2 Software compatibility (Table 2)

These criteria evaluate whether the package can be interfaced to other software systems, in order to exchange data with these systems. This feature can considerably enhance the capabilities of the package, especially when complex real systems are modeled.

1.3 User support (Table 3)

These criteria 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, and demo disks, but also include a variety of services provided by the software supplier which ease the use of the package and keep the user informed about plans for future software improvements.

II. Criteria for modeling capabilities

2.1 General features (Table 4)

Criteria included in this group describe general features of the package. Most of these criteria relate to modeling aspects such as the type of formal logic needed for modeling (if any), the method of changing the state of the model (process based, activity based, event based, three phase, or a combination of these methods), type of simulation (discrete event, continuous or combined), the level of modeling transparency, etc. There are also some criteria that evaluate the level of experience and formal education in simulation required by the user, and examine how easy it is to learn and use the package.

2.2 Modeling assistance (Table 5)

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

III. Criteria for Simulation Capabilities

3.1 Visual aspects (Table 6)

Graphical presentations of simulation models and animation of simulation are very important characteristics of simulation software. Criteria included in this group relate to the type and quality of graphical facilities provided by the package. These criteria evaluate, for example, whether it is possible to perform an animation of the simulation experiments, the types of animation provided by the package, and whether it is possible to manipulate icons.

3.2 Efficiency (Table 7)

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 time needed for modeling, and improve the quality of modeling, such as model reusability, reliability, compilation and execution time and multitasking.

3.3 Testability (Table 8)

This group comprises criteria that examine which facilities for model verification are provided by the package. These facilities include 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.

3.4 Experimentation facilities (Table 9)

Criteria classified in this group evaluate the variety and characteristics of experimentation facilities. 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.

3.5 Statistical facilities (Table 10)

Owing 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 provided by the simulation package.

IV. Criteria for input/output issues

4.1 Input/Output capabilities (Table 11)

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, and how understandable these reports are.

4.2 Analysis capabilities (Table 12)

4.3 Manufacturing capabilities (Table 13)

5. Rating of the Evaluated Simulation Softwares

This section provides a comparison of the evaluated simulation softwares. Information presented here is collected from various simulation software developer companies.

In order to compare the evaluated simulation softwares, a rating of these has been established, as shown in Table 14. This rating is based on an analysis of the simulation softwares being evaluated. As such it should be considered as a relative measure of quality of these softwares from the perspective of groups of criteria rather than as an absolute value.

Methodology to calculate Rating for various groups of features

There are total 13 groups of features i.e. coding aspects, software compatibility, user support, general features, modeling assistance, visual aspects, efficiency, testability, experimentation facilities, statistical facilities, input and output capabilities, analysis capabilities, manufacturing capabilities. The value (out of 10) of these groups of features is calculated for the four simulation softwares under consideration.

$$\text{Evaluated Value} = \frac{\text{Calculated Value} \times 10}{\text{Maximum Value}}$$

where

Maximum Value = Sum of highest possible values that can be selected in a particular group of features, and
Calculated Value = Sum of actual values selected in a particular group of features.

For example: If we take the case of Coding Aspects,

$$\text{Maximum Value} = 6+6+6+6+6+6+6+1+1+1+1+1+1 = 47$$

Table 15 shows a proposed rating for the simulation softwares being evaluated, in terms of the general quality of features within particular groups of criteria. The rating interval used in this assessment is similar to the one proposed by Ekere and Hannam [8]. The general quality of softwares with respect to particular groups of criteria is rated from 1 to 10, where 1-2 represents very low, 3-4 represents low, 5-6 represents medium, 7-8 represents high and 9-10 represents very high quality of features within particular groups of criteria.

6. The Analytic Hierarchy Process and Simulation Software Selection

The AHP separates the evaluation decision into hierarchy levels and attempts to reduce the inconsistencies in human judgement. It was originally used for socio-economic and political situations but of late it has proved useful for judgemental decision making in other areas, such as the selection of equipment for ice breakers [17], the selection of materials handling equipment [18] and perhaps more relevant, the selection of manufacturing software [19] and scheduling software [20]. Further applications, along with a good exposure of AHP, are given by Partovi et al. [21] and Zahedi [22].

In using the AHP technique all the criteria are compared in a pairwise way, using Saaty's intensities of importance [23] shown in Table 16, in order to establish which criteria are more important than others. The values are then placed in a matrix and the normalized principal eigenvector is found to provide the weighting factors which provide a measure of relative importance for the decision maker. The next step is to make pairwise comparisons of all alternative with respect to each criterion. Final rankings of the alternatives are made by multiplying the critical weights of the alternatives by the critical weights of the criteria. The alternative with the highest score is then deemed to be the preferred choice.

Step 1: To calculate weight factor (Importance) of each group of features desired by the user:

Depending upon the priority requirement of the user of one group of features over another, the matrix shown in Table 17 is filled. The entries are filled as per Saaty's intensities of importance. For example, in row 2 (coding aspects) and column 3 (compatibility), entry is 3. It means compatibility has weak importance over coding aspects. Therefore, entry in row 3 and column 2 will be 1/3. All diagonal elements will be 1. We are to fill only the upper triangular matrix and the lower triangular matrix will contain the reciprocal entries.

Once the matrix has been filled, the next step is to divide each element of each column by the corresponding sum of the column. Then the average of each row is calculated that gives us the weight (W) for each group of criteria.

Step 2: To calculate weight factor for each of the simulators against each group of features (Using Table 15)

(a) To calculate weight factor for coding aspects W_{ca}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{cs}
NX-IDEAS	1 (.10)	1/3 (.10)	1/3 (.10)	1/3 (.10)	0.10
Star-CD	3 (.30)	1 (.30)	1 (.30)	1 (.30)	0.30
Micro Saint Sharp	3 (.30)	1 (.30)	1 (.30)	1 (.30)	0.30
ProModel	3 (.30)	1 (.30)	1 (.30)	1 (.30)	0.30
SUM	**10**	**3.33**	**3.33**	**3.33**	

(b) To calculate weight factor for compatibility W_c

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_c
NX-IDEAS	1 (.13)	1/3 (.12)	1 (.13)	1/3 (.12)	0.125
Star-CD	3 (.38)	1 (.37)	3 (.38)	1 (.37)	0.375
Micro Saint Sharp	1 (.13)	1/3 (.12)	1 (.13)	1/3 (.12)	0.125
ProModel	3 (.38)	1 (.37)	3 (.38)	1 (.37)	0.375
SUM	**8**	**2.67**	**8**	**2.67**	

(c) To calculate weight factor for user support W_{us}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{us}
NX-IDEAS	1 (.30)	1 (.30)	1 (.30)	3 (.30)	0.30
Star-CD	1 (.30)	1 (.30)	1 (.30)	3 (.30)	0.30
Micro Saint Sharp	1 (.30)	1 (.30)	1 (.30)	3 (.30)	0.30
ProModel	1/3 (.10)	1/3 (.10)	1/3 (.10)	1 (.10)	0.10
SUM	**3.33**	**3.33**	**3.33**	**10**	

(d) To calculate weight factor for general features W_{gf}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{gf}
NX-IDEAS	1 (.07)	1/5 (.08)	1/5 (.08)	1/3 (.05)	0.07
Star-CD	5 (.36)	1 (.39)	1 (.39)	3 (.41)	0.395
Micro Saint Sharp	5 (.36)	1 (.39)	1 (.39)	3 (.41)	0.395
ProModel	3 (.21)	1/3 (.13)	1/3 (.13)	1 (.14)	0.152
SUM	**14**	**2.53**	**2.53**	**7.33**	

(e) To calculate weight factor for modeling assistance W_{ma}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{ma}
NX-IDEAS	1 (.13)	1 (.13)	1/3 (.12)	1/3 (.12)	0.125
Star-CD	1 (.13)	1 (.13)	1/3 (.12)	1/3 (.12)	0.125
Micro Saint Sharp	3 (.38)	3 (.38)	1 (.37)	1 (.37)	0.375
ProModel	3 (.38)	3 (.38)	1 (.37)	1 (.37)	0.375
SUM	**8**	**8**	**2.67**	**2.67**	

(f) To calculate weight factor for visual aspects W_{va}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{va}
NX-IDEAS	1 (.19)	3 (.25)	1 (.19)	1/3 (.18)	0.202
Star-CD	1/3 (.06)	1 (.08)	1/3 (.06)	1/5 (.11)	0.077
Micro Saint Sharp	1 (.19)	3 (.25)	1 (.19)	1/3 (.18)	0.202
ProModel	3 (.56)	5 (.42)	3 (.56)	1 (.53)	0.517
SUM	**5.33**	**12**	**5.33**	**1.87**	

(g) To calculate weight factor for efficiency W_e

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_e
NX-IDEAS	1 (.19)	7 (.29)	1/3 (.19)	1 (.19)	0.215
Star-CD	1/7 (.03)	1 (.04)	1/9 (.06)	1/7 (.03)	0.04
Micro Saint Sharp	3 (.58)	9 (.38)	1 (.56)	3 (.58)	0.525
ProModel	1 (.19)	7 (.29)	1/3 (.19)	1 (.19)	0.215
SUM	**5.14**	**24**	**1.78**	**5.14**	

(h) To calculate weight factor for testability W_t

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_t
NX-IDEAS	1 (.17)	1 (.17)	1/3 (.17)	1 (.17)	0.17
Star-CD	1 (.17)	1 (.17)	1/3 (.17)	1 (.17)	0.17
Micro Saint Sharp	3 (.5)	3 (.5)	1 (.5)	3 (.5)	0.5
ProModel	1 (.17)	1 (.17)	1/3 (.17)	1 (.17)	0.17
SUM	**6**	**6**	**2.00**	**6**	

(i) To calculate weight factor for experimentation W_e

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_e
NX-IDEAS	1 (.30)	1 (.30)	1 (.30)	3 (.30)	0.30
Star-CD	1 (.30)	1 (.30)	1 (.30)	3 (.30)	0.30
Micro Saint Sharp	1 (.30)	1 (.30)	1 (.30)	3 (.30)	0.30
ProModel	1/3 (.10)	1/3 (.10)	1/3 (.10)	1 (.10)	0.10
SUM	**3.33**	**3.33**	**3.33**	**10**	

(j) To calculate weight factor for statistical facilities W_{sf}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{sf}
NX-IDEAS	1 (.10)	1/3 (.10)	1/3 (.10)	1/3 (.10)	0.10
Star-CD	3 (.30)	1 (.30)	1 (.30)	1 (.30)	0.30
Micro Saint Sharp	3 (.30)	1 (.30)	1 (.30)	1 (.30)	0.30
ProModel	3 (.30)	1 (.30)	1 (.30)	1 (.30)	0.30
SUM	**10**	**3.33**	**3.33**	**3.33**	

(k) To calculate weight factor for input/output W_{io}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{io}
NX-IDEAS	1 (.17)	1 (.17)	1/3 (.17)	1 (.17)	0.17
Star-CD	1 (.17)	1 (.17)	1/3 (.17)	1 (.17)	0.17
Micro Saint Sharp	3 (.5)	3 (.5)	1 (.5)	3 (.5)	0.5
ProModel	1 (.17)	1 (.17)	1/3 (.17)	1 (.17)	0.17
SUM	**6**	**6**	**2.00**	**6**	

(l) To calculate weight factor for analysis capabilities W_{ac}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{ac}
NX-IDEAS	1 (.13)	1 (.13)	1/3 (.12)	1/3 (.12)	0.125
Star-CD	1 (.13)	1 (.13)	1/3 (.12)	1/3 (.12)	0.125
Micro Saint Sharp	3 (.38)	3 (.38)	1 (.37)	1 (.37)	0.375
ProModel	3 (.38)	3 (.38)	1 (.37)	1 (.37)	0.375
SUM	**8**	**8**	**2.67**	**2.67**	

(m) To calculate weight factor for manufacturing capabilities W_{mc}

	NX-IDEAS	Star-CD	Micro Saint Sharp	Pro-Model	W_{mc}
NX-IDEAS	1 (.395)	5(.357)	3(.409)	1(.395)	.389
Star-CD	1/5 (.079)	1 (.071)	1/3(.045)	1/5(.079)	.069
Micro Saint Sharp	1/3 (.131)	3(.214)	1 (.136)	1/3(.131)	.153
ProModel	1 (.395)	5(.357)	3(.409)	1 (.395)	.389
SUM	**2.533**	**14**	**7.333**	**2.533**	

Step 3: Calculation of the overall rankings of the packages

	Coding Aspects	Compat-ibility	User-Support	General Features	Modeling Assistance
	0.244	**0.042**	**0.017**	**0.038**	**0.04**
NX-IDEAS	0.10	0.125	0.30	0.07	0.125
Star-CD	0.30	0.375	0.30	0.395	0.125
Micro Saint Sharp	0.30	0.125	0.30	0.395	0.375
ProModel	0.30	0.375	0.10	0.152	0.375

Calculation of the overall rankings of the packages (*contd.*)

	Visual Aspects	Effici-ency	Testa-bility	Experi-menta-tion	Statisti-cal
	0.98	**0.13**	**0.071**	**0.049**	**0.046**
NX-IDEAS	0.202	0.215	**0.17**	**0.30**	**0.10**
Star-CD	0.077	0.04	**0.17**	**0.30**	**0.30**
Micro Saint Sharp	0.202	0.525	**0.5**	**0.30**	**0.30**
ProModel	0.517	0.215	**0.17**	**0.10**	**0.30**

	I/O	Analy-sis	Manufactur-ing	Weight (*W*)
	0.051	**0.253**	**.129**	
NX-IDEAS	**0.17**	**0.125**	**.389**	**0.390166**
Star-CD	**0.17**	**0.125**	**.069**	**0.279806**
Micro Saint Sharp	**0.5**	**0.375**	**.153**	**0.583882**
ProModel	**0.17**	**0.375**	**.389**	**0.830532**

From the above calculation ProModel has the highest ranking and therefore is the best software according to the user's requirements.

7. Summary and Conclusions

The selection process is greatly aided by the use of a structured approach in the form of the AHP and the use of the intuitive scale provided by Saaty [23] made the comparison procedure understandable. Also, there is no absolute measure of how well any package performed against a given criterion, only its relative performance compared with the other packages. However, the AHP is only a decision aid and perhaps we should not focus too closely on the intermediate stages of the procedure but assess its overall impact on the quality of the decision-making process.

The authors are satisfied with the overall results of using the AHP and have confidence in the selection made as being the one best suited to the company's needs. For the experienced user the AHP is certainly straightforward to use, but it may prove to be off-putting for general manufacturing personnel. However, there does exist software [24] to perform the calculations and aid the establishment of the hierarchies, and the authors have found that there is great interest in this methodology.

Throughout this work it was obvious that the awareness of the use of simulation and the potential benefits of that use needs to be improved in the manufacturing environment. Researchers and developers can aid this process by addressing issues of integration and vendors by re-examining their pricing levels. The Analytic Hierarchy Process proved to be a good aid for structuring a decision problem, making a good decision and focusing on any problem areas within the decision-making process. It would be ideal in a computer-aided environment which highlights any problem areas and allows interactive messaging of the process, but it is also available to anyone with a pen and paper aided by a calculator.

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Note

A copy of the Questionnaire can be obtained from the authors by mailing at *guptashu1@rediffmail.com*.

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Tables

Table 1. Items for Coding Aspects.

		Very High	High	Medium	Low	Very Low
1.1.1	Quality of the support for programming	O	O	O	O	O
1.1.2	Efficiency of Compilation	O	O	O	O	O
		Very Good	Good	Average	Poor	Very Poor
1.1.3	Built-in logic builder	O	O	O	O	O
1.1.4	Program Generator	O	O	O	O	O
1.1.5	Snippet code help	O	O	O	O	O
		Very Large	Large	Medium	Small	Very Small
1.1.6	Built-in functions	O	O	O	O	O
		Very Easy	Easy	Moderate	Tough	Very Tough
1.1.7	Ease of entering text/code	O	O	O	O	O
		Possible				Not Possible
1.1.8	User defined functions	O				O
1.1.9	Writing comments/notes in model building activity	O				O
1.1.10	Creation of macros and arrays	O				O
		Provided				Not Provided
1.1.11	Global variables	O				O
1.1.12	Interface to user written programs	O				O

Table 2. Items for Software Compatibility.

1.2.1	Integration with spreadsheet packages	O Excel	O Lotus	O Other ________
1.2.2	Integration with statistical packages (curve-fitting tools)	O SPSS	O Stat Fit	O Other ________
1.2.3	Integration with computer-aided software	O AutoCAD		O Other ________
1.2.4	Integration with database management systems	O SAP	O Oracle	O Other ________
1.2.5	Integration with manufacturing requirements planning software	O Possible		O Not Possible
1.2.6	Is it possible to do broad level scheduling with Simulation S/W	O Yes		O No

Table 3. Items for User Support.

		Very Good	Good	Average	Poor	Very Poor
1.3.1	Quality of manuals	O	O	O	O	O
1.3.2	Tutorial	O	O	O	O	O
1.3.3	Run-time help	O	O	O	O	O
1.3.4	Software maintenance facility	O	O	O	O	O
1.3.5	Training course	O	O	O	O	O
1.3.6	Web based support	O	O	O	O	O
1.3.7	Troubleshooting facility	O	O	O	O	O
1.3.8	Quality of documentation	O	O	O	O	O
1.3.9	Demo models	O	O	O	O	O
		Very Frequent	Frequent	Average	Rare	Very Rare
1.3.10	User group meetings	O	O	O	O	O
1.3.11	Frequency of training courses	O	O	O	O	O
		Provided				Not Provided
1.3.12	Discussion groups on the internet	O				O
1.3.13	User community web page	O				O

Table 4. Items for General Features.

2.1.1	Type of simulation	O Discrete event		O Continuous		O Both
2.1.2	Purpose	O General purpose		O Manufacturing Oriented		O Other
		Very High	High	Medium	Low	Very Low
2.1.3	Representativeness of models	O	O	O	O	O
2.1.4	User friendliness	O	O	O	O	O
2.1.5	Experience required for software use	O	O	O	O	O
2.1.6	Formal education in simulation required for software use	O	O	O	O	O
		Very Easy	Easy	Moderate	Tough	Very Tough
2.1.7	Ease of learning	O	O	O	O	O
2.1.8	Ease of using	O	O	O	O	O
		Very Good	Good	Average	Poor	Very Poor
2.1.9	Run-time interface capability for scenario creation	O	O	O	O	O
2.1.10	Conceptual model generator	O	O	O	O	O
2.1.11	Multiple branch decision making	O	O	O	O	O
2.1.12	Probabilistic branch decision making	O	O	O	O	O
		Possible				Not Possible
2.1.13	Distributed simulation on network environment	O				O
2.1.14	Cut, copy, paste of objects	O				O
2.1.15	Possibility to built near Real-time simulation models	O				O
		Provided				Not Provided
2.1.16	Easy to use templates	O				O
2.1.17	Customizable window environment	O				O
2.1.18	Splines, Polygon and orthogonal curve types	O				O

Table 5. Items for Modeling Assistance.

		Very Good	Good	Average	Poor	Very Poor
2.2.1	Libraries and templates of simulation objects	O	O	O	O	O
2.2.2	Warning messages	O	O	O	O	O
2.2.3	Intelligent Prompting	O	O	O	O	O
2.2.4	Facility for designing reusable user defined elements	O	O	O	O	O
2.2.5	3D models library	O	O	O	O	O
2.2.6	Bubble help	O	O	O	O	O
2.2.7	Context sensitive prompt to facilitate model development	O	O	O	O	O
		Provided				Not Provided
2.2.8	Undo/redo commands	O				O
2.2.9	Facility to insert comments	O				O

Table 6. Items for Visual Aspects.

		Very Good	Good	Average	Poor	Very Poor
3.1.1	Shape libraries	O	O	O	O	O
3.1.2	3D-animator	O	O	O	O	O
3.1.3	Logical animation	O	O	O	O	O
3.1.4	Network animation	O	O	O	O	O
3.1.5	Scenario viewer	O	O	O	O	O
3.1.6	Antialias display	O	O	O	O	O
3.1.7	Dashboard facility	O	O	O	O	O
3.1.8	Customizable entity appearance	O	O	O	O	O
3.1.9	Customizable path appearance	O	O	O	O	O
3.1.10	Library for real-time simulations	O	O	O	O	O
3.1.11	Virtual reality animation	O	O	O	O	O
		Provided				Not provided
3.1.12	HotSpot Evaluator	O				O
3.1.13	Flowcharting Module	O				O
3.1.14	Animation of image changes	O				O
3.1.15	Facility for customizing the view of the model	O				O
3.1.16	Playback mode	O				O
		Provided				Not provided
3.1.17	Animation with visual clock	O				O
3.1.18	Zoom function	O				O
3.1.19	Panning	O				O
3.1.20	Print screen facility	O				O
		Possible				Not Possible
3.1.21	Import of AutoCAD drawings	O				O
3.1.22	Multiple screen layout	O				O
3.1.23	Merging icon files	O				O
3.1.24	Resizing of icons	O				O
3.1.25	Changing the color of the element status display	O				O
3.1.26	Change of icons during simulation	O				O

Table 7. Items for Efficiency.

		Very High	High	Medium	Low	Very Low
3.2.1	Robustness	O	O	O	O	O
3.2.2	Level of detail	O	O	O	O	O
3.2.3	Adaptability to model changes	O	O	O	O	O
3.2.4	Reliability	O	O	O	O	O
		Very Large	Large	Medium	Small	Very Small
3.2.5	Number of elements in the model	O	O	O	O	O
3.2.6	Number of queuing policies	O	O	O	O	O
3.2.7	Time scale for model building	O	O	O	O	O
3.2.8	Model execution time	O	O	O	O	O
		Very Good	Good	Average	Poor	Very Poor
3.2.9	Model Protection	O	O	O	O	O
		Possible				Not Possible
3.2.10	Model status saving	O				O
3.2.11	Multitasking	O				O
3.2.12	Model chaining (i.e. linking outputs from different models)	O				O
3.2.13	Editing partially developed models	O				O
3.2.14	Interactive handling of parameters during experimentation	O				O
3.2.15	Model reusability	O				O
		Provided				Not provided
3.2.16	Variable watches	O				O
3.2.17	Activity based costing	O				O

Table 8. Items for Testability.

3.3.1	Moment of error diagnosis	O Model entry	O Compilation			O Execution
		Possible				Not Possible
3.3.2	Display of attributes	O				O
3.3.3	Display of variables	O				O
3.3.4	Display of element's state	O				O
3.3.5	Replication of Run-length	O				O
3.3.6	Change in simulation speed	O				O
3.3.7	Execution trace	O				O
3.3.8	Logic checks	O				O
3.3.9	Runtime error viewer	O				O
		Possible				Not Possible
3.3.10	Explode function (showing a state of an element)	O				O
3.3.11	List of used elements	O				O
3.3.12	Backward clock	O				O
3.3.13	Step function (event to event jumping)	O				O
3.3.14	Display of parts flow tracking record collected during simulation run	O				O
3.3.15	Audible alarms	O				O
3.3.16	Rejection of illegal inputs	O				O
3.3.17	Syntax checker	O				O
3.3.18	Search & replace capability	O				O
3.3.19	Antithetic numbers	O				O
3.3.20	Multiple windows during simulation run	O				O
		Provided				Not provided
3.3.21	User Pause facility	O				O
3.3.22	OLE compatibility	O				O
		Very Good	Good	Average	Poor	Very Poor
3.3.23	Display of events on the screen	O	O	O	O	O
3.3.24	Display of the workflow path	O	O	O	O	O
3.3.25	Flow analysis	O	O	O	O	O
3.3.26	Interactive debugger	O	O	O	O	O
3.3.27	Line by line debugging	O	O	O	O	O
3.3.28	Interaction with model while running	O	O	O	O	O

Table 9. Items for Experimentation Facilities.

		Very Good	Good	Average	Poor	Very Poor
3.4.1	Quality of experimental design facility	O	O	O	O	O
		Very High	High	Medium	Low	Very Low
3.4.2	Warm-up period	O	O	O	O	O
		Possible				Not Possible
3.4.3	Automatic batch run	O				O
3.4.4	Restart from non-empty state	O				O
3.4.5	Stepwise simulation run	O				O
3.4.6	Resource variability	O				O
		Provided				Not provided
3.4.7	Independent replications of experiments for multiple runs	O				O
3.4.8	Breakpoints	O				O
3.4.9	Accuracy check	O				O
3.4.10	Automatic determination of run length	O				O
3.4.11	Shift editor	O				O
3.4.12	Scheduled execution of scripts	O				O
3.4.13	Sensitivity analysis	O				O

Table 10. Items for Statistical Facilities.

		Very High	High	Medium	Low	Very Low
3.5.1	Quality of data analysis facility	O	O	O	O	O
		Very Large	Large	Medium	Small	Very Small
3.5.2	Number of theoretical statistical distributions	O	O	O	O	O
3.5.3	Number of different random number streams	O	O	O	O	O
		Provided				Not provided
3.5.4	Time dependent distributions	O				O
3.5.5	Ability to specify the random number seed	O				O
3.5.6	Random number generation by probability distributions	O				O
3.5.7	Distribution fitting	O				O
3.5.8	Goodness-of-fit tests	O				O
3.5.9	Output data analysis	O				O

Table 11. Items for Input/Output Capabilities.

		Very Good	Good	Average	Poor	Very Poor
4.1.1	Static graphical output	O	O	O	O	O
4.1.2	Dynamic graphical output	O	O	O	O	O
4.1.3	Snapshot reports	O	O	O	O	O
4.1.4	Database maintenance for input/output	O	O	O	O	O
4.1.5	Dialogue boxes	O	O	O	O	O
4.1.6	Data Charting	O	O	O	O	O
4.1.7	Custom report generation	O	O	O	O	O
		Very High	High	Medium	Low	Very Low
4.1.8	Quality of output reports	O	O	O	O	O
4.1.9	Understandability of output reports	O	O	O	O	O
		Possible				Not Possible
4.1.10	Multiple inputs	O				O
4.1.11	Multiple outputs	O				O
4.1.12	Output export to excel	O				O
4.1.13	Printed report after each simulation run	O				O
4.1.14	Exchange data via internet	O				O
4.1.15	Task timeline report	O				O
4.1.16	Task execution report	O				O
4.1.17	Queue data collection report	O				O
		Provided				Not provided
4.1.18	Automatic rescaling of histograms and time series	O				O
4.1.19	Periodic output of simulation results	O				O
4.1.20	Writing reports to files	O				O
4.1.21	Summary reports for multiple run	O				O
4.1.22	Formattable result summary	O				O

Table 12. Items for Analysis Capabilities.

4.2.1	Capability to do What-if Analysis	O Yes	O No
4.2.2	Conclusion-making support	O Provided	O Not provided
4.2.3	Optimization	O Provided	O Not provided

Table 13. Items for Manufacturing Capabilities.

		Possible	Not Possible
4.3.1	Equipment breakdown modeling	O	O
4.3.2	Shifts modeling	O	O
4.3.3	Maintenance modeling	O	O
4.3.4	Assembly operation modeling	O	O
4.3.5	Containerization modeling	O	O
		Provided	Not provided
4.3.6	Robots	O	O
4.3.7	AGV's and trucks	O	O
4.3.8	Conveyors	O	O
4.3.9	Multi-station machines	O	O
4.3.10	Workstation buffers	O	O
4.3.11	Pallets	O	O
4.3.12	Fixture stores	O	O
4.3.13	Cranes	O	O
4.3.14	Automated tool storage	O	O
4.3.15	Pallet shuttles	O	O
4.3.16	Vehicle scheduling	O	O
4.3.17	Vehicle acceleration	O	O
4.3.18	Scheduling optimization	O	O
4.3.19	Batch index	O	O
4.3.20	Preemption	O	O
4.3.21	Utilization of production equipment	O	O
4.3.22	Due dates monitoring	O	O
4.3.23	Manufacturing costs analysis	O	O
4.3.24	Transportation time of the parts	O	O
4.3.25	Rework and scrap level	O	O
4.3.26	Interruption reports	O	O
4.3.27	Production sequence summary	O	O
4.3.28	Throughput	O	O

Table 14. Scaling Values.

0	Not Provided, Not Possible, No	1	Provided, Possible, Yes
2	Very Low, Very Poor, Very Small, Very Rare	3	Low, Poor, Small, Rare
4	Average, Medium, Moderate	5	Easy, Large, Good, High
6	Very Easy, Very Large, Very Good, Very High		

Table 15. Assessment of Simulation Packages with Respect to Each Group of Criteria.

Feature Groups	NX-IDEAS	Star-CD	Micro Saint Sharp	ProModel
Coding Aspects	8 (High)	10 (Very High)	10 (Very High)	9 (Very High)
Compatibility	4 (Low)	5 (Medium)	4 (Low)	5 (Medium)
User-Support	8 (High)	8 (High)	8 (High)	6 (Medium)
General Features	5 (Medium)	9 (Very High)	9 (Very High)	7 (High)
Modeling Assistance	8 (High)	8 (High)	9 (Very High)	10 (Very High)
Visual Aspects	8 (High)	6 (Medium)	8 (High)	9 (Very High)
Efficiency	7 (High)	2 (Very Low)	9 (Very High)	8 (High)
Testability	7 (High)	8 (High)	9 (Very High)	7 (High)
Experimentation	7 (High)	7 (High)	7 (High)	6 (Medium)
Statistical	6 (Medium)	7 (High)	7 (High)	7 (High)
Input/Output	7 (High)	8 (High)	10 (Very High)	7 (High)
Analysis	7 (High)	7 (High)	10 (Very High)	10 (Very High)
Manufacturing	9 (Very High)	5 (Medium)	7 (High)	9 (Very High)

Table 16. Saaty's Intensities of Importance.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	The judgement is to favor one activity over another, but it is not conclusive
5	Essential or strong importance	The judgement is to strongly favor one activity over another
7	Demonstrated importance	Conclusive judgement as to the importance of one activity over another
9	Absolute importance	The judgement in favor of one activity over another is of the highest possible order of affirmation
Reciprocals of above non-zero numbers	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with i	

Table 17. Matrix Filled Using Saaty's Intensities of Importance and Calculation of Weight Factor, *W*.

	Coding Aspects	Compa-tibility	User-Support	General Features	Modeling Assistance	Visual Aspects	Efficiency
Coding Aspects	1 (.11)	3 (.071)	5 (.106)	5 (.115)	7 (.183)	9 (.42)	9 (.682)
Compatibility	1/3 (.036)	1 (.024)	3 (.064)	1/5 (.005)	1/3 (.009)	1/7 (.007)	1/5 (.015)
User-Support	1/5 (.021)	1/3 (.008)	1 (.021)	1 (.023)	1/3 (.009)	1/5 (.009)	1/7 (.011)
General Features	1/5 (.021)	5 (.118)	1 (.021)	1 (.023)	1/5 (.005)	1/7 (.007)	1/9 (.008)
Modeling Assistance	1/7 (.015)	3 (.071)	3 (.064)	5 (.115)	1 (.026)	1/5 (.009)	1/5 (.015)
Visual Aspects	1/9 (.012)	7 (.166)	5 (.106)	7 (.161)	5 (.131)	1 (.047)	1/3 (.025)
Efficiency	1/9 (.012)	5 (.118)	7 (.149)	9 (.207)	5 (.131)	3 (.14)	1 (.076)
Testability	1/7 (.015)	1/3 (.008)	3 (.064)	5 (.115)	3 (.079)	1 (.047)	1/3 (.025)
Experimentation	1/5 (.021)	1/3 (.008)	5 (.106)	3 (.069)	1 (.026)	1/3 (.016)	1/3 (.025)
Statistical	1/3 (.036)	5 (.118)	3 (.064)	1 (.023)	3 (.79)	1/5 (.009)	1/5 (.015)
Input/Output	3 (.329)	1/5 (.005)	1 (.021)	1 (.023)	1/3 (.009)	1/5 (.009)	1/7 (.011)
Analysis	1/3 (.036)	7 (.166)	7 (.149)	5 (.115)	5 (.131)	3 (.14)	1 (.076)
Manufacturing	3 (.329)	5 (.118)	3 (.064)	1/3 (.008)	7 (.183)	3 (.14)	1/5 (.015)
SUM	**9.1**	**42.2**	**47.0**	**43.5**	**38.2**	**21.42**	**13.2**

	Experimen-tation	Statistical	I/O	Analysis	Manufactur-ing	Testability	Weight (Wgf)
Coding Aspects	5 (.220)	3 (.106)	1/3 (.007)	3 (.217)	1/3 (.016)	7 (.277)	0.244
Compatibility	3 (.132)	1/5 (.007)	5 (.108)	1/7 (.01)	1/5 (.009)	3 (.119)	0.042
User-Support	1/5 (.009)	1/3 (.012)	1 (.022)	1/7 (.01)	1/3 (.016)	1/3 (.013)	0.017
General Features	1/3 (.015)	1 (.035)	1 (.022)	1/5 (.014)	3 (.143)	1/5 (.008)	0.038
Modeling Assistance	1 (.044)	1/3 (.012)	3 (.065)	1/5 (.014)	1/7 (.007)	1/3 (.013)	0.040
Visual Aspects	3 (.132)	5 (.177)	5 (.108)	1/3 (.024)	1/3 (.016)	1 (.039)	0.98
Efficiency	3 (.132)	5 (.177)	7 (.151)	1 (.072)	5 (.238)	3 (.119)	0.13
Testability	1/3 (.015)	1 (.035)	3 (.065)	1/5 (.014)	7 (.333)	1 (.039)	0.071
Experimentation	1 (.044)	3 (.106)	5 (.108)	1/5 (.014)	3 (.143)	3 (.119)	0.049
Statistical	1/3 (.015)	1 (.035)	3 (.065)	1/5 (.014)	1/3 (.016)	1 (.039)	0.046
Input/Output	1/5 (.009)	1/3 (.012)	1 (.022)	1/7 (.01)	1/5 (.009)	1/3 (.013)	0.051
Analysis	5 (.220)	5 (.177)	7 (.151)	1 (.072)	1/7 (.007)	5 (.198)	0.253
Manufacturing	1/3 (.015)	3 (.106)	5 (.108)	7 (.507)	1 (.048)	1/7 (.006)	0.129
SUM	**22.7**	**28.2**	**46.3**	**13.8**	**21.0**	**25.3**	