ON THE SELECTION OF SIMULATION SOFTWARE FOR MANUFACTURING APPLICATION

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ABSTRACT

The growing complexity of manufacturing along with the need for higher efficiency, greater flexibility, better product quality and lower cost urged the use of simulation in manufacturing systems. The number and variety of simulation software packages on the market increased as well. Consequently, the varieties of these packages led to some bewilderment on the part of potential users when faced the selection process. The present article addresses an overview of material addressed in journals, conferences, and textbooks on the selection of appropriate simulation software. It also suggests a classification of main criteria to be considered in evaluating simulation software packages. Moreover, a checklist of simulation software features with five levels of indication will be included. A proposed methodology has been employed in interpreting the checklist. Finally, future trends towards the provision of more effective selection tools will be discussed.

KEYWORDS: Simulation Software, Package Evaluation Criteria, Checklist.

1. INTRODUCTION

Due to the increasing complexity of manufacturing systems and the advent of computer technology a new industrial era arrived. Over the last three decades, computer simulation (one of the advanced techniques) has been applied to various activities in manufacturing systems such as process planning, maintenance and diagnosis, scheduling, and quality management. The use of simulation as a tool to help these complex, dynamic and stochastic systems involve large capital investments, as it is cheaper and easier to experiment with simulation models, rather than experimenting with the real systems. There is a variety of potential benefits of simulation in manufacturing environments including: greater understanding of systems, reduced operating costs, risk reduction, lead time reduction, reduction of capital costs, and faster configuration changes. As a result, managers and administrators have begun to look to simulation for an aid to day-to-day operational problems as well as tactical and strategic issues. The growing use of simulation for the analysis of manufacturing systems has resulted in a rise in the number of both general purpose and application oriented simulation software packages. Choosing amongst the vast amount array of available packages has the potential to overwhelm newcomers to the field. In fact, a survey of hundreds of corporate software development projects indicates that more than 60% of software projects are considered unsuccessful [1] due to wrong software selection decision and implementation. The simulation software selection decision is often costly and time consuming (careful selection can take as long as a year [2]). However, it is essential that an appropriate simulation package is selected as it can have a significant impact on the ultimate validity of the model and on the timeliness with which the simulation project is completed. [3] The research presented in this paper has been initiated by a review of literatures pertaining to simulation software evaluation specifically those literatures dealing with manufacturing

applications. This is done in order to develop a wide range of issues that should be considered on the evaluation and comparison of simulation software packages.

2. LITERATURE SURVEY

The following researchers have contributed their own classifications of evaluation criteria. Table 1 extends the literature proposed by Nikoukaran *et.al* [4] in order to cover major studies in this subject. Law and Haider [5] classified the criteria into six groups based on a vendor survey of 23 packages. Law expanded this research with McComas [6] by considering a wider range of criteria. Holder [7] gave an explanation for a set of six features with straightforward questions such as; are the graphics of high or low quality. Law *et.al* [8] contributed some literatures in evaluation criteria in his textbook. They presented five main groups with description of each criterion. Banks *et.al* [9] tested four simulation software products based on five groups of features. They listed numerous sub-groups to consider in selecting a simulator. Mackulak *et.al* [10] presented 54 features in a questionnaire survey and rated the features on four levels. They categorized the features into eight main groups. Davis *et.al* [11] used a collection of criteria to develop a list of eight criteria, which reflect the issues that need to be addressed when choosing simulation software. They proposed AHP (Analytical Hierarchy Process) as an aid for structuring a sound decision between five different packages. Bank *et.al* [12] listed 24 features and divided them into three main groups. Kuljis [13] considered six groups while testing six simulators. Unlike previous scholars she highlighted 'on-line user assistance' as a main criteria. Hlupic [14] categorized the features into eleven groups and developed the first software to evaluate simulation software 'SimSelect' which includes 40 different features. Nikoukaran *et.al* [15] presented a hierarchical framework for simulation software evaluation that includes seven main groups and several sub-groups. They provided explanation of each criterion in the framework. Harrington *et.al* [16] proposed eight main criteria for evaluating simulation software products with explanation of each criterion. They recommended the user 'understand what he/she needs, and then find someone who wants to do it'. Banks *et.al* [17] included 46 criteria classified into five main groups with a brief description of each criterion. Arisha [18] classified the criteria into two main groups; business criteria and technical criteria. The study included several sub-criteria and related features in a checklist to facilitate the evaluation process of simulation software packages based on customer preferences.

3. SIMULATION SOFTWARE EVALUATION CRITERIA

The simulation software selection process is regarded as one of the most critical milestones in simulation projects. Along with project goals, there are many considerations that should be taken into account while selecting the simulation package. The classification of the criteria into groups and sub-groups is an effective way to organize the list different features that should be considered in the evaluation process. The criteria can be classified twofold: technical criteria and business criteria as shown in Figure 1. These two groups represent the highest levels of the proposed framework. The business criteria concern the vendor, the user, and their contract features, while the technical elements consider most of the features of the simulation software. An explanation of each criterion and sub-criterion is presented to describe the feature and its importance in evaluating simulation software.

Table 1. Major Literature in Simulation Software Evaluation Criteria

Holder	**Banks**	**Law** ***et. al***	**Banks** ***et. al***	**Mackulak** ***et. al***	**Davis** ***et. al***	**Banks** ***et. al***	**Kuljis**	**Hlupic**	**Nikouk-aran** ***et. al et. al***	**Harrin-gton** ***et.al***	**Banks** ***et.al***	**Arisha**
1990	**1991**	**1991**	**1991**	**1994**	**1994**	**1996**	**1996**	**1997**	**1999**	**2000**	**2001**	**2002**
[7]	**[9]**	**[8]**	**[21]**	**[10]**	**[11]**	**[12]**	**[13]**	**[14]**	**[15]**	**[16]**	**[17]**	**[18]**
1.Technical	1.Input	1.General features	1.Robust features	1.General	1.Cost	1.Input features	1.Main system	1.General features	1.Vendor	1.Functionality	1.Model Building	1.Technical
2.System Development needs	2.Processing	2.Animation	2.Qualitative considerations	2.Data acquisition	2.Comprehensiveness of the system	2.Processing features	2.Data input/Model specification	2.Visual aspects	2.Model and input	2.Usability	2.Runtime Environment	-Model input
3.End user needs	3. Output	3.Statistical capabilities	3.Cost	3.Model development	3. Integration with other systems	3.Output features	3. Simulation experiment	3.Coding aspects	3.Execution	3.Reliability	3.Animation and Layout Features	- Simulation techniques
4.Future Development	4.Environ-ment	4.Customer support	4. Basic features	4.Validation and Verification	4.Documentation		4.Simulation results	4.Efficiency	4.Animation	4.Maintainability	4.Experimentation and Analysis Features	- Presentation features
5.Functionality	5.Cost	5.Output results	5. Special constructs	5.Model execution	5.Training		5.Printed manuals	5.Testability	5.Testing and efficiency	5.Scalability	5.Vendor Support and Product Documentation	- Model execution
6.Commercial				6.Documentation	6.Ease of use		6.On-line user assistance	6.Statistical facilities	6.Output	6.Supplier Quality		- Model Output
				7. Simulation project data	7.Hardware and installation			7.Input/Output	7.User	7.Supplier Services		2.Business
				8.Methods of user interface	8.Confidence related issues			8.Modelling assistance		8.Cost of Ownership		-Vendor
								9.Software compatibility				-Contract
								10.Experimental facilities				- User
								11.Financial and technical features				

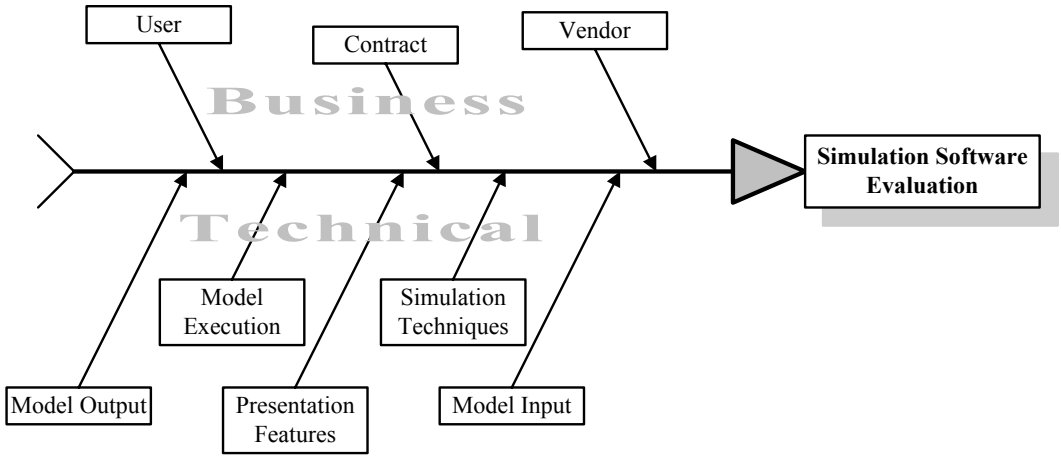

Figure 1. Simulation software evaluation criteria (cause and effect diagram)

3.1 Business

Apart from the technical features, this group of criteria has mainly three main elements to be considered: the vendor, the user and their contract.

3.1.1 Vendor

Investments in simulation go well beyond the purchase price of the software package. In order to help protect this investment and ensure that the underlying simulation software will be supported during the project period and beyond. The evaluation of the credibility of the vendor and the software package must be considered Figure 2.

- ***Pedigree***

Pedigree relates to both the history of software and vendor. It tells how reliable the software and the vendor could be. [15] The details about the vendor history such as time in market, strength in competition, number of customers and reputation generate confidence to the user making a purchasing decision. More features such as company type (local, international) and contact availability (email, toll phone, fax, .. etc.) are good options for the user.

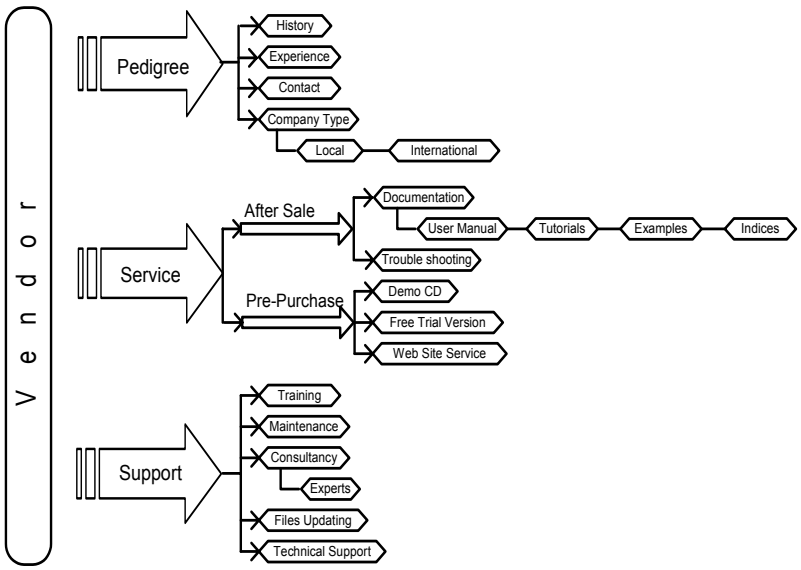

Figure 2. Criteria related to vendor

- ***Service***

Good services immediately before and after purchase are the key for future sales. Pre-purchase services including on-site demonstration, one-month free trial version or demo disks provide helpful software information to the user. After-sale, it is the vendors responsibility to provide documentation that free the user from dependence on the supplier for answers to minor problems. The availability of a helpful user manual, tutorial, examples, and indices can help the user to learn how to use the package and its main features. A good trouble-shooting guide could save time by quickly finding the errors and correcting them.

- ***Support***

The availability of support offered by the vendor companies is very important issue. Users cannot trust software without proper support. Adequate training courses should be considered along with technical support, maintenance, and the possibility of updating files of the old version. The success of support can be assessed in terms of users' confidence.

3.1.2 User

This group considers criteria related to the recognition of the user and his/her requirements and to some extent his/her characteristics Figure 3.

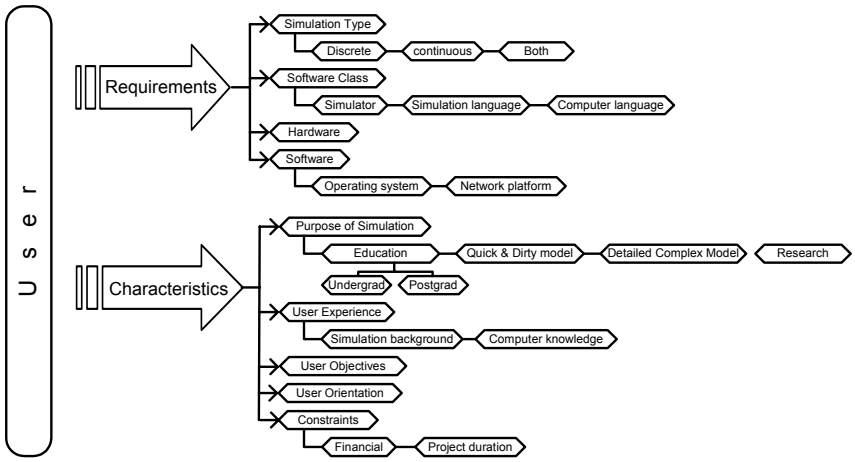

Figure 3. Criteria related to user

- ***User's requirements***

Users should specify the simulation package type (discrete, continuous, or both) needed in the application. Based on the user's background, a simulation software class will be selected whether a simulator, simulation language, or computer language. It is also important to consider the hardware and software available in the user system and compatibility with the simulation software. The user may specify a network version of the software or specific operating system.

- ***User's characteristics***

The user characteristics should be considered with some specific environmental considerations such as user orientation, user objectives, the simulation purpose ('Quick and Dirty' modelling, detailed/complex modelling in industry, Research, education, … etc.[19]), and other constraints. It would be helpful to find out if the user has any previous knowledge and experience in simulation. Obviously, one of the most important criteria is the cost of the software comprised by the sale price, installation cost, extra hardware cost, ...etc. Since the financial and time horizon of the simulation project are critical constraints, they should be well studied.

3.1.3 Contract

The contract between the user and the vendor should engender mutual effective issues trust, satisfaction and prevent future misunderstandings.

There are two main sub-criteria: Financial elements and technical terms (Figure 4). The price of the software package and attached costs (e.g. extra module cost, updating cost, license cost, maintenance cost, and training cost) are important issues to be considered. Discounts for education and multi-buy should be declared. Updating the old files and providing a new version of the released package are also important. There are some more technical options that can be negotiated with the vendor such as: security, group meetings, consultancy, and training.

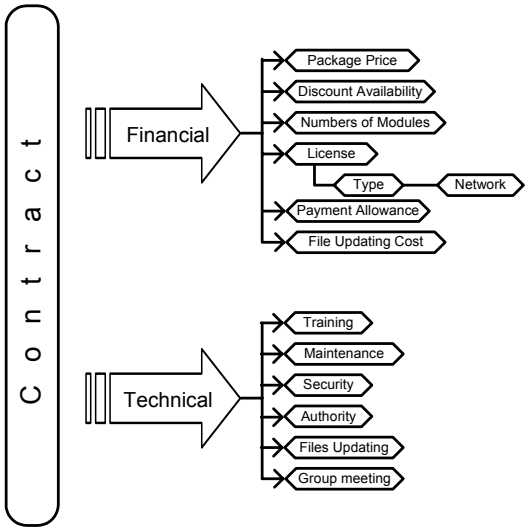

Figure 4. Vendor-user contract criteria

3.2 Technical

This group includes criteria concerning the technical elements in the simulation software package. The basic elements of most packages can be somehow similar but detailed features and varieties of options to facilitate specific applications properly may be altered. Technical elements are major issues in potential applications.

3.2.1 Model Input

Model Input is one of the most critical categories and includes issues related to model building and input features (Figure 5).

- ***Model building***

This sub-criteria group includes facilities that support model development. A model could be made graphically or by entering codes. A user-friendly package speeds up the process of model building by providing necessary options from the menu panel [15]. Input flexibility can be interactive data input, batch or accepting data from external files, data bases, spreadsheets. Some packages provide a feature that allows automatic data collection (online) from the entire system. The capability to add procedural logic through a high-level simulation language and to merge models into one integrated model

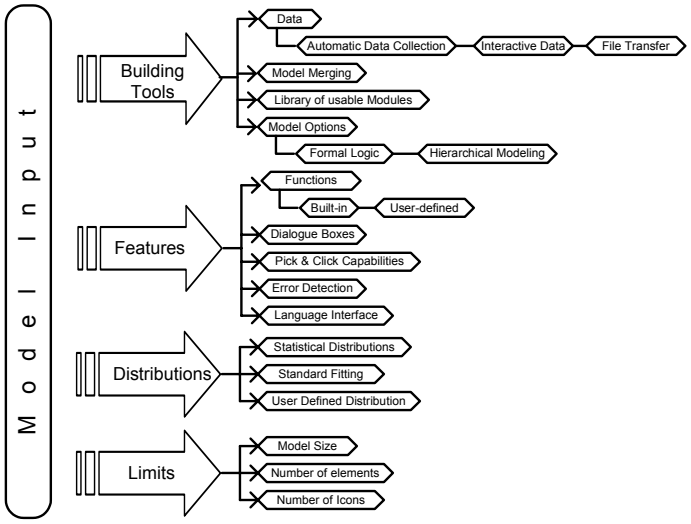

Figure 5. Criteria related to model input

are required features to enhance the model building. This is especially true for complex manufacturing systems such as semiconductor manufacturing. The option to add new objects to the entity library and reuse them if needed is advantageous for the user. Some packages offer more options such as hierarchical model building and more detailed sections.

- ***Input Features***

More features can be provided in some software packages for ease of use. Point and click capability is a desired feature for all the users and most software has migrated to this environment. The package may provide modelling assistance. Prompts and dialogue boxes advise on the action that should be taken next. [8] In addition, the rejection of illegal inputs will prevent many of the errors that may occur during the model run. The feature that makes it possible to delete item and its link with other modules is another recommended feature. The ability to change into another language for additional detail has a positive effect in some instances. A library of built-in functions and user-defined functions further enhance this sub-criterion.

- ***Distribution***

Input data analysis feature enables users to estimate empirical or statistical distributions from the data input. A list of standard statistical distributions such as normal, exponential, gamma, and rectangular distribution must be provided in the software package. Also the options which allow the user define different distributions is recommended.

- ***Limits***

Certain elements have limits, which are noticeable to the user (e.g. the size of the model, number of elements, number of icons displayed or in the library, the length of entity names, time units and length measures).

3.2.2 Simulation Techniques

This sub-criteria group provides some technical features of the software to perform the simulation of the model (Figure 6).

- ***Model coding***

The package flexibility is a proportional factor of this sub-criterion. The possibility to access the source code and link code with a general programming language such as C, C++, and FORTRAN is an important issue to be taken into consideration. [17] Attributes are the local values assigned to entities moving through the system (e.g. lot number and product type) while global variables are the values available to all entities moving through the system used to describe the state of the system (e.g. the number of parts completed). Attributes and global variables are often used in programming.

- ***Model Approach***

This sub-criterion includes three main approaches based on worldview modelling: event-base (event perspective), process interaction and three phases (continuous) modelling approach. [17]

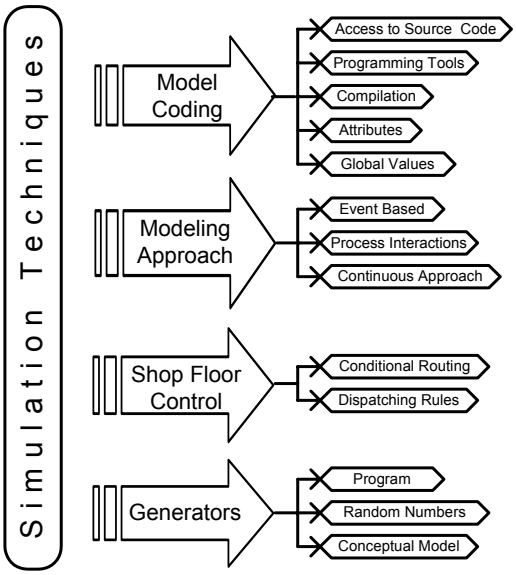

Figure 6. Criteria for **simulation techniques**

- ***Shop floor control***

This sub-criterion is very valuable for manufacturing simulation and especially for shop floor scheduling. Some packages provide different dispatching rules (priority rules) such as FCFS (First Come, First Serve), LCFS (Last Come, First Serve), SPT (Shortest Processing Time), LPT (Longest Processing Time) … etc. Conditional routing is another helpful feature for shop scheduling in particular for job shop scheduling. Routing enables the entities to be sent to different locations based on prescribed conditions or paths. [20]

- ***Generators***

Three different generators could be provided by the simulation software packages. The first is the program generator; it provides program code for the simulation model, which could be modified. The second is the random number generator − the main tool to run the simulation model. A variety of different random streams is necessary for experiment replications. Users may either define their own random generator or use the statistical distributions included in the software such as exponential, uniform, normal, triangle…etc. The third engine is the conceptual model generator. The software may have the capability to produce a graphical representation of the model's logic (e.g. activity cycle diagram, a Petri net…etc), which can help in the verification of the model.

3.2.3 Presentation Features

There are some sub-criteria related to evaluation of presentation features such as animation, display, and virtual reality presentation (Figure 7).

- ***Animation***

The animation feature concerns creation, running, and quality of animation and comes as an integral part of the package or it is added to the package.

- ***Icons***

Some packages provide a library of standard icons. The number and quality of these icons are important in providing more realistic animation. The icon editor is sometimes provided in the package. The possibility of creating new icons or importing them from other software packages such as CAD, bitmap, jpg, or a media control interface is another issue. It would be desirable to save the created icons in a library or add them to the library of standard icons. Icons could be 3-Dimensional and coloured. It might be possible to change the colour of the icons and resize them.

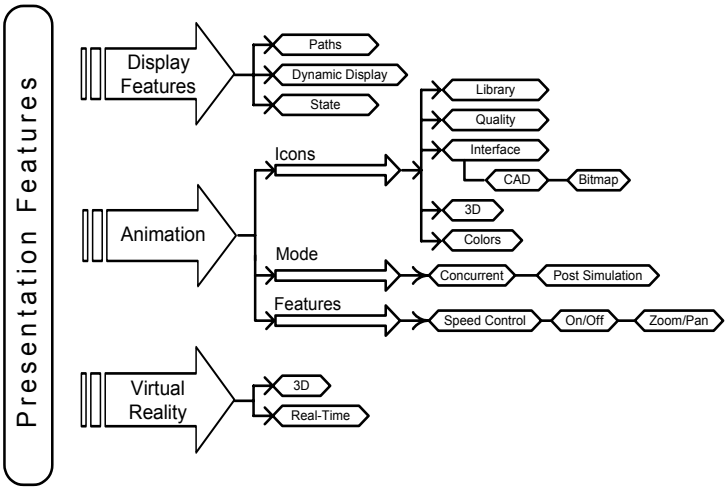

Figure 7. Criteria related to presentation features

- ***Mode***

Animation could run with the model concurrently but may have the effect of lowering the speed of the model run. On the other hand, there is a possibility of running the model first without animation, and then running the animation alone. In general, the quality of motion should be smooth not jerky.

- ***Features***

Features which can enhance the animation include: the ability to alter the speed of the animation run, the possibility of turning animation on and off, the possibility of zooming and panning. It is important to understand the hardware requirements for animation since some operates on standard personal computers and others demand a special video card or higher RAM.

- ***Display features***

Some packages display the paths and the movement of the entities in the shape of different icons alongside the paths during the run. Dynamic display of the value of variables, attributes, and functions, and the state of the elements and the events, helps in tracing and debugging.

- ***Virtual Reality***

In addition to the standard graphics, Virtual Reality (VR) presentation is recommended. The model can be transformed into 3D virtual world using the software VR option. [2] As a result, well understood processes are viewed in a totally new light and understanding of the business process improves considerably. This feature is widely used not only internally to facilitate a teamwork approach to problem solving, but also to enhance communication and buy-in to proposals across the whole organisation.

3.2.4 Model Execution

This criteria group includes issues related to experimentation (Figure 8).

- ***Speed Control***

Control of the speed of the model run is a desirable feature. One can see the flow of the model better at a low speed and use it for debugging, while running the model in a high-speed mode may save execution times. Some continuous-system simulation packages make it possible to run a simulation where externally operating devices, such as a flight controller, are in the loop. Speed control is a necessary feature for such real time applications.

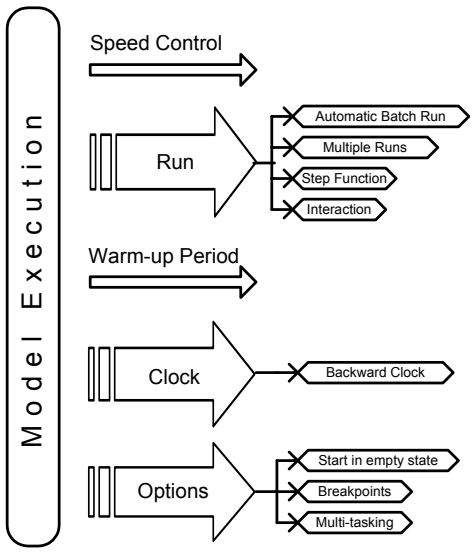

Figure 8. Model execution criteria

- ***Run***

Ideally a package would allow the user to automatically run the model several times while changing the random number generator seed each time. A summary output of the multiple runs could be written in a file. The automatic batch run feature is similar to multiple runs but has added advantage of changing the values some variables before each run automatically. The possibility to stop or pause the model run at any step and to change or read information and then continue running the model could help track changes in the model parameters. The option to run the model step by step or to start running at a specific time is helpful in tracing the model execution.

- ***Warm-up period***

This feature enables a simulation run to reach the steady state of the model and then collect statistics.

- ***Clock***

Time tracing in model execution is a vital feature. Running the model in real time is required in some applications. The ability to set up the simulation time and the time units either

global or per run is crucial. Few packages allow the model to run backward to help debugging the errors, which could not be detected in normal run.

- ***Options***

Some packages have extra options for model execution such as breakpoints and multitasking. Breakpoints can be predetermined points of time when the model breaks the run in order to set or change some options and then continues. Multi-tasking is another option that enables the software to run more than one model at the same time. Sharing resources (where the models can use same resource at same run) is an optional feature in a few packages. Some packages do not allow execution to being in an empty state. This option would make it possible for the user to specify initial values for variables and attributes and determine the situation of the entities, queues, and activities.

3.2.5 Model Output

An important criterion group for evaluation of simulation software is output (Figure 9).

- ***Reports***

The simulation software package produces some standard reports such as work in process items (WIP), average waiting times, resource utilization, arrival time of items, ..etc. Customized report is a required option that enables the user to design the report to include specific variables which are more presentable to the application and management.

- ***Output form***

The output form can be a file, a hardcopy device (printer), or an interface with other software. The rate of reports should be controlled by the user. The ability to change the form of output is good option.

- ***Status***

The simulation model results can be either static or dynamic. The reports and graphics could be displayed on the screen dynamically, changing with model run progress.

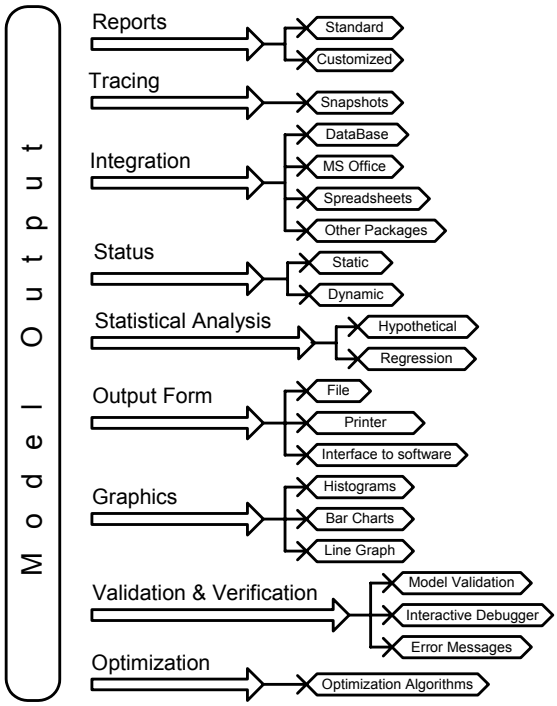

Figure 9. Criteria related to model output

- ***Graphics***

The simulation software usually provides a standard set of graphics presentation of the output such as histograms, bar chart, pie chart, …etc. Graphics could be presented dynamically or at the end of the simulation.

- ***Integration***

In some of the potential applications for simulation, it is essential that links are made to shop floor data collection systems or material handling systems and a 'real time' scheduler for the simulation to be of any real benefit. However, the other systems are not limited to these types of application. Integration with some standard packages such as MS office, AutoCAD and Databases can be useful.

- ***Statistical Analysis***

This criterion is very important for simulation output. The possibility to provide statistics such as mean, variance, and standard deviation and more sophisticated analysis such as best-fit curve and ANOVA (Analysis of Variance) could support management in decision-making.

- ***Tracing***

The availability of tracing models offered by the software package is considered along with the actual effectiveness of the software to test the model performance during execution. Taking a snapshot to record the values of some variables at specified points can be good option.

- ***Validation and Verification***

These criteria are considered required features in simulation software. Several options could be provided for this purpose such as an interactive debugger, on-line error messages, and on-line help. Logical error checks, errors handling of a package, and model validation tests are also helpful features. [15]

- ***Optimization***

Numerous simulation software packages provide an optimization module. The Module can integrate with the model and offer intelligent experimentation to reduce the time spent in experimenting by automatically finding the optimum solution to satisfy chosen performance criteria using sophisticated mathematical techniques. Genetic Algorithms (Evolutionary), Tabu search, and Linear Programming are some of the optimization techniques used in this module. The optimizer is considered a significantly helpful tool to guide the user towards the most successful options for a process by identifying the effect of changes to model parameters (sensitivity analysis).

4. CHECKLIST

The conjecture that there are numerous differences in simulation software options is true. [11] Nevertheless, there is similarity among features and options, but with varying levels of quality and performance. The checklist shown in Figure 10 includes a summary of most of the features to be considered when evaluating/comparing software packages or assessing the user preferences. One of the shortcomings cited in previous software evaluations concerned inadequacy of 'yes' or 'no' checklists of simulation software features which indicate whether the software does or does not contain a particular feature [4]. The proposed checklist has five levels of indicators to provide a considerable range of variability and has been used in conjunction with structured methodology to select simulation software for manufacturing scheduling purpose. [18]

5. CONCLUSION

Selecting appropriate simulation software has risen in importance due to the increase of simulation software packages on the market. The paper addresses a list of the most important criteria, which reflect the issues that should be considered in evaluating and selecting the simulation software package. The classification of the criteria comes into two main categories (business and technical) to provide a comprehensive guide to the user in the evaluation process. Meanwhile, the list of evaluation criteria shows some of the considerations that the vendor might deem important while building or developing the simulation package. The checklist included in the research is an advantageous way to assess simulation software and user preferences with the help of an evaluation methodology or technique.

The need for more research to be conducted on the selection of simulation software packages is apparent. Nikoukaran *et.al* [4] mentioned the need to standardize various terminologies that used by experts and specialists to establish a common dynamic list of criteria.

Criterion	group	Sub-group	Feature	Indication Levels				
				A	B	C	D	E
Business	Vendor	Pedigree	Vendor history (Reputation)					
			Vendor experience					
			Contact facility					
			Company type (local, international…etc.)					
		Service	Service after sale					
			Trouble shooting					
			Documentation availability					
			Pre-Purchase services (CD demo, evaluation copy, …etc.)					
		Support	Training on the software					
			Technical support					
			Consultancy session					
	Contract	Financial	Package price					
			Discount availability					
			Number of modules					
			Type of license (network, individual…etc)					
			Payment allowance					
			Updating cost					
		Technical	Maintenance					
			Group meeting					
			Security / Authority					
Technical	Model Input	Building Tools	Data Collection options					
			Model merging possibility					
			Library of usable modules					
			Model options (formal logic, Hierarchical modeling … etc.)					
		Features	Functions (built-in, user defined…etc.)					
			Dialogue boxes available					
			Pick and click capability					
			Error detection					
			Language interface					
		Distributions	Statistical Distribution					
			Standard fitting					
			User Defined Distribution					
		Limits	Model size (no. of elements, entities, icons…etc.)					
			Number of tutorial examples					
	Simulation Techniques	Model Coding	Accessibility to source code					
			Programming tools					
			Attributes , Global Arrays , …etc					
		Modeling Approaches	Variety of modeling approaches (event based, process interactions… etc.)					
		Shop Floor Control	Conditional routing option					
			Dispatching rules					
		Generators	Program schedules generator					
			Random numbers generators					
			Conceptual modeling generator					
	Presentation Features	Animation	Icons (library, interface CAD, Bitmap, 3D, colors…etc.)					
			Model animation (concurrent, post-simulation.. etc.)					
		Display	Display (paths, values dynamically, state …etc.)					
		Virtual Reality	Virtual Reality features available					
	Model Execution	Speed Control	Model speed control while runs					
		Run	Run options (Automatic batch run, multiple runs, step function…etc)					
		Warm-up	Warm-up period determination options					
		Clock	Time control options (backward clock… etc)					
		Options	More options in execution (breakpoints, multitasking .. etc.)					
	Model Output	Report	Standard set of reports					
			Customized reports					
		Tracing	Snapshots option					
		Integration	Integration with other packages (Excel, Access … etc.)					
		Status	Static or dynamic results option					
		Statistical	Statistical analysis options (mean, variance, …etc.)					
		Output form	Output form (hardcopy, file, software interface…etc.)					
		Graphics	Output presentation options (Pie chart, bar chart… etc.)					
		Validation &	Options (interactive debugger, error messages… etc.)					
		Optimization	Optimization module					

Figure 10. Checklist to assess simulation software package and user preferences

Web simulation database development might successfully standardize the criteria terminology while facilitating the addition of new criteria within the standard list.
Artificial Intelligence has become one of the effective tools in solving many selection problems. Designing a user-friendly expert system to aid the non-specialist user in selecting the appropriate simulation software package is a worthy objective for future research in this area.

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