A study for different methods of modeling and simulation to minimizing manufacturing cost

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Abstract

Increased competition in many industries has resulted in a greater emphasis on developing and using advanced manufacturing systems to improve productivity and reduce costs. The complexity and dynamic behaviour of such systems make simulation modelling one of the most popular methods to facilitate the design and assess operating strategies of these systems. The growing need for the use of simulation is reflected by a growth in the number of simulation languages and data-driven simulators in the software market. This thesis investigates which characteristics typical manufacturing simulators possess and how the user requirements can be better fulfilled. For the purpose of software evaluation. a case study has been carried out on a real manufacturing system. Several simulation models of an automated system for electrostatic powder coating have been developed using different simulators. In addition to the Evaluation of these simulators.

Keywords:- Simulation software, Simulation features, Evaluation criteria.

I. Introduction

Advanced manufacturing systems are being used increasingly in many industries in order to improve productivity and reduce costs. Because of the complexity, dynamic and stochastic behavior of these systems, simulation modelling is becoming one of the most popular methods used to investigate their configuration alternatives and potential operation strategies (Hlupic and Paul, 2013a), (Ekere and Hannam, 2013), (Law and McComas, 2014). The rising acceptance of simulation has resulted in a growth in the number of simulation languages and simulators in the software market. When a model is developed using a simulation language, the simulation analyst has to write a program using the modelling constructs of the language. On the other hand, a simulator allows the modeling of the problem with little or no programming, where the analyst has to provide data related to the system being modelled. Although the existence of alternative software products is beneficial to simulation software users, this might become a problem when deciding which software package to choose. Whilst the selection of a suitable software product can result in significantly improved productivity and reduced manufacturing costs, the choice of an inadequate package can result not only in the loss of the actual purchase cost but also in the costly disruption of manufacturing processes (Ghanforoush *et aI*, 2014) and planned simulation projects. In addition, despite continuous advances in simulation software products, they should be further improved in order to make simulation modelling easier, faster and more effective.

1.1 Advanced Manufacturing Systems

A manufacturing system can be defined as a system in which raw materials are processed from one form into another, known as a product, gaining a higher or added value in the process (Pamaby, 2015). Since the beginning of the industrial revolution, and especially in the present competitive world, there has been a continuous attempt to improve manufacturing systems and make them more efficient. As a result of this, a number of new technologies and management concepts have emerged, generally known as Advanced Manufacturing Technology (AMT). AMT includes a variety of individual technologies such as Computer Aided Design (CAD), Computer-based production equipment, Group Technology (GT), Flexible Manufacturing Systems (FMS) and Computer Integrated Manufacturing (CIM). These technologies facilitate the following activities.

(i) The transformation of materials through the physical operations of cutting, mixing, printing, fabrication and assembly.

(ii) The movement of materials by means of conveyors, robots, guided vehicles etc.

(iii) The examination and inspection of materials through the use of automated testing equipment.

(iv) The storage of materials and their fast retrieval.

(v) Product design in terms of shape and properties as strength and weight.

(vi) Detenning how a product should be manufactured.

(vii) Production management systems which schedule products and control the level of Inventories. Manufacturing systems incorporate advanced manufacturing and aims to reduce operating costs, maintain high and consistent quality, and changes in product design.

1.2 Reasons for Simulation of Manufacturing Systems

Computer simulation has become the most widely used technique which facilitates the carrying out of experiments on models representing manufacturing systems. There are several reasons for using simulation in manufacturing environments, such as:

(i) Advanced manufacturing systems are very complex, and it is therefore difficult to predict their behaviour. Complexity is reflected in a variety of product types and quantities, diversity of production equipment, different possibilities for routing of parts, variety of operations etc. Due to such complexity, analytical methods are usually not appropriate for modelling these systems.

(ii) Advances in automation have resulted in manufacturing systems that involve large capital investments. This has engendered a need for careful modeling of any proposed system or change to an existing system.

(iii) Manufacturing systems are characterized by a stochastic behaviour. Various random events can occur such as equipment breakdown, variations in orders and machining times or blocking of transportation routes. With the capability of sampling from statistical distributions, most simulation software products can cope well with randomness.

(iv) Manufacturing systems are dynamic, involving parallel activities. In these systems, discrete products move through the production process from raw material to the final product, which means that discrete event simulation should be used as the basic modelling paradigm.

(v) Advances in hardware, software, and simulation methodology have made simulation more accessible even by small sized companies.

(vi) The provision of visual interactive facilities in simulation software packages has resulted in a greater comprehension and application of simulation not only by simulation specialists, but also by production engineers and managers.

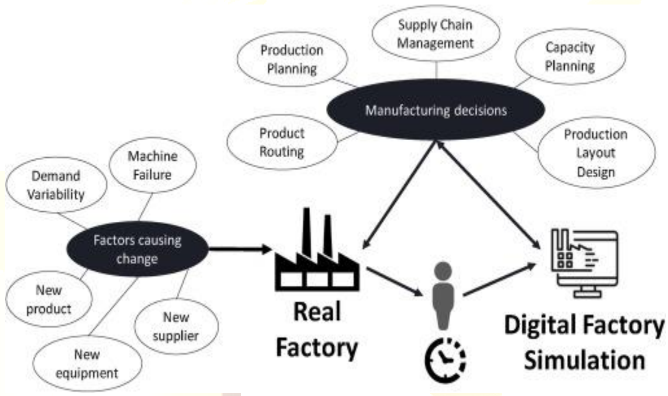

Fig.1 A Data-Driven Simulation to support re manufacturing operation

1.3 Rapid Manufacturing

With increased competition from the global economy, manufacturers face the challenge of delivering new customised products more quickly than before to meet customer demands. The use of a CAD-based automated AM process to construct parts that are used directly as finished products or components is known as Rapid Manufacturing (RM). It has been developed to shorten the design and production cycle and promise to revolutionize many traditional manufacturing procedures.

What is commonly considered to be the first RP technique, Stereo lithography, was developed by 3D Systems of Valencia, CA, USA and since then, a number of different RP techniques have been developed. Now, the functional parts are fabricated directly by RM techniques such as Electron Beam Melting (EBM) and Direct Metal Laser Sintering (DMLS) processes developed by Arcam EBM systems, Sweden and Electro Optical Systems - EOS GMBH,

The main difference between the EBM process and all of the other processes listed below is the energy source used to heat the metal powder during processing. The use of an electron beam, in lieu of a laser, provides much more energy. This allows for faster processing times, but more importantly EBM produced parts have a more fully melted microstructure when compared to sintered structures. The process also builds parts in a vacuum at higher temperature, both of which are different as compared to laser-based processes. DMLS is the most established direct metal fabrication technique. Depending on the particular model the process uses either a CO2 or ytterbium fiber laser to sinter fine metal powders into near fully dense components.

2. Background Research Material

Increased competition in many industries has resulted in greater emphasis on developing and using automated manufacturing systems in order to improve efficiency and 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 appraising operating strategies.

The growing need for the use of simulation is reflected by a growth in the number of simulation software products in the software market. Although simulation software for manufacturing applications has many characteristics in common with simulation software designed for general purpose or other specific application areas, there are some special features that make manufacturing simulators unique. Some of these features include modeling of material handling systems, special types of machines, part routing etc.

Research studies related to the use of simulation in manufacturing environments, and especially studies regarding simulation software are analyzed. The chapter is structured as follows.

The application of simulation in advanced manufacturing environments is addressed with examples of publications that review a number of different simulation studies, carried out in order to facilitate the solving of different problems that arise in advanced manufacturing systems. These survey studies illustrate the popularity of simulation and its strength in approaching manufacturing problems.

The next section deals with research studies related to simulation software. This section is the core presentation of background research material, because it relates most closely to the subject of the research in this thesis. It contains publications sub-divided in several groups, according to the main focus of a particular study. For example, studies that relate to the evaluation of simulation software are separated from those that address simulation software selection or describe surveys. Nevertheless, overlaps between some of the groups is inevitable. For example, there are studies presenting software evaluation on the basis of intonation obtained from a survey, whilst some studies that focused on the use of a certain method for software selection also provide a list of evaluation criteria.

2.1 Research Studies relating to Simulation Software

This section is a part of the presentation of background research material that is the most relevant for the research presented in this thesis. It contains a summary analysis of various research studies related to simulation software. Although many studies combine different aspects of research such as evaluation, selection, or descriptions of simulation software.

2.2 Simulation Software Evaluation Criteria

Simulation models of real manufacturing systems are often large and complex, requiring a considerable time and effort for their development, verification and experimentation. Because of this, the facilities provided in the available simulation software tools are important. Studies presented below address this issue, providing criteria for the evaluation of simulation software tools in general as well as the requirements for manufacturing simulation software.

(i) Kochhar and Ma (2019b) address the essential and desirable features of simulation software for its effective use in manufacturing environments, providing the criteria which should be used for the selection of manufacturing simulation software tools. These criteria relate to modelling assistance provided, interactivity, graphics and the data handling capability. Other proposed criteria include the time scale for model development, the learning curve and the required skills for the use of software, ease of model editing, portability, simulation speed and interfacing the

Simulation package with external systems. The study concludes with a remark that the final decision to select a particular software tool must be based on the requirements of the organisation, the applications for which it will be used, and the skills of the users.

(ii) Addressing the issues related to simulation software products for analyzing manufacturing systems, Haider and Banks (2019) establish the following desirable features for simulation software.

3. Evaluation of Simulation Software

Publications presented in this sub-section relate to an explicit evaluation of various simulation software tools on the basis of certain criteria. Most of the studies concern the evaluation of software tools for manufacturing applications. Some studies have analyzed both special and general purpose simulation packages. A few earlier studies that evaluate only general purpose simulation languages are also included as an illustration of a long interest in research on simulation software evaluation.

Several manufacturing simulators have been evaluated in terms of a number of different criteria by Banks et al (2019). Four manufacturing simulators are examined, with a remark that their features indicate the types of considerations involved in selecting software. The following manufacturing simulators have been evaluated.

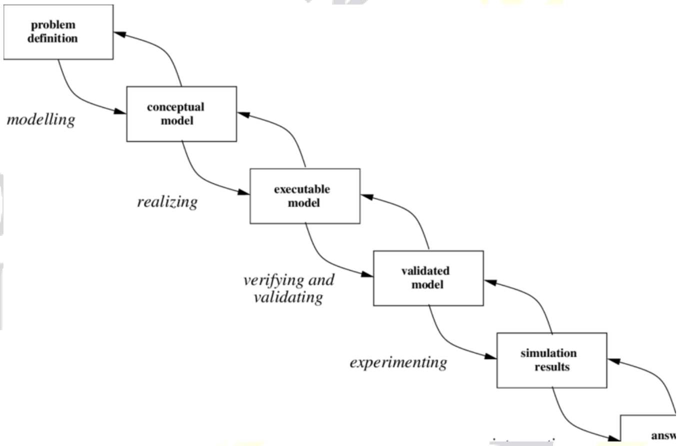

Fig.2.1 Mapping of group of general Criteria to phases of Simulation Process

3.1 Simulation Software Selection

Studies presented in this section generally relate to the selection of simulation software. They either provide general guidelines or approaches to simulation software selection, or demonstrate the use of a particular technique for software selection. Provides some general advice regarding selection of discrete simulation software. Concerning the assessment of vendors' claims, the author warns of several facts that the potential users should be sceptical about. For example, one should not believe any vendor who claims that his product is better then everyone else's for any application or that the software can run on any computer under any operating system. In addition, when asked about the support they can provide in case of problems caused by bugs, the majority of vendors would probably deny the possibility of the existence of bugs. Furthermore, the author claims that the type of simulation software to be chosen depends on the intended application and discusses which basic facilities should be provided in simulation software. Finally, general advice for simulation software selection is provided. Which includes: development of a preliminary model of application? Consideration of available resources and future applications, examination of the available software and asking the vendors for assistance if possible?

3.2 Criteria for the Evaluation of Simulation and Modelling Packages

This chapter establishes a number of criteria that can be used for the evaluation of simulation packages in general, and especially for the evaluation of packages for simulation of manufacturing systems. According to Law and Kelton (2019), simulation packages can be classified as simulation languages and simulators. However, in this research the term 'simulation package' is mainly used when discussing data driven simulators, and all criteria are derived and described from the perspective of this type of simulation software. On the other hand, some of the criteria (eg. criteria related to pedigree, user support or financial and technical features) might also be used for the evaluation of simulation languages, and this was the main reason why the more general expression 'simulation package' has been used. Criteria listed in this chapter represent a comprehensive evaluation framework that can be used for package selection by potential buyers as well as for guidance in further software development and improvement.

3.2 General Criteria

These criteria can be applied to the evaluation of any general or special purpose simulation package. However, they will be described from the point of view of manufacturing applications, to fulfil the thesis objectives.

The criteria within this group are 'naturally' grouped according to their character. Characteristics and speed of computer model development are influenced by criteria concerning modeling assistance, visual aspects, coding aspects, efficiency and the manner of data input. Software features regarding testability have a significant impact on model verification, whilst experimentation facilities might affect experimental design and experimentation. Input/output features are in charge of output reports both during and after experimentation. Statistical facilities might be used for data analysis, experimentation (eg. generation of random numbers) and for analysis of simulation output. Finally, software compatibility might be useful for the visual appearance of model (integration with CAD software), for data analysis (integration with statistical packages), for experimental design and experimentation (integration with expert systems and data base management systems) or for output analysis (integration with spread sheet packages, expert systems, statistical packages).

3.3 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 fonnallogic needed for modeling (if any), the method of changing the state of the model, the level of modeling 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 of the packages from the point of view of each criteria.

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, and whether it is possible to manipulate icons.

3.4 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, whether the package enables modular model development and writing the documentation notes (this feature enables writing a documentation concurrently with the model development), and whether the model and data can be separated.

Contain the criteria together with classification of the packages regarding software Compatibility. The criterion related to integration with programming languages is not included in this group of criteria, because it is contained in the coding aspects.

3.5 Experimentation Facilities

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.

3.5.1 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 provided by the simulation package. Embraces the criteria included in this group and a possible classification of the packages regarding user support.

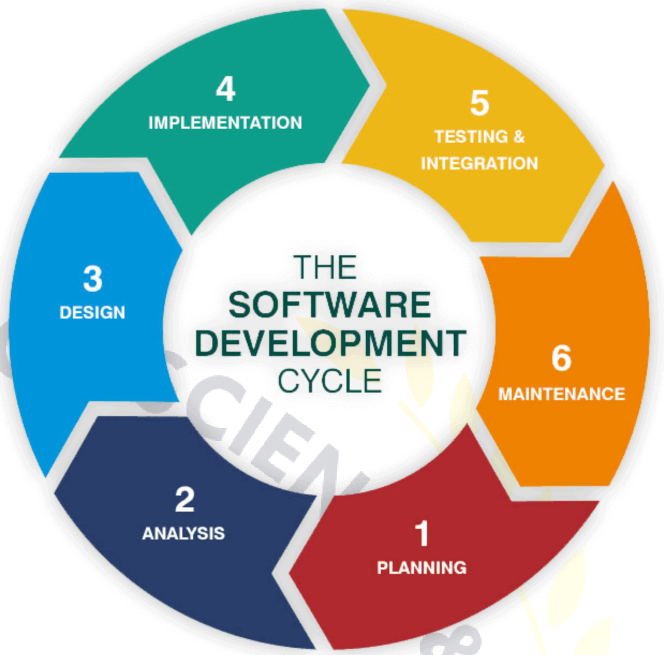

Fig. 3 the Methodology for software solution

3.6 Criteria Specific to Manufacturing Simulation Packages

Criteria listed in this section relate to the features specific only to packages dedicated to manufacturing simulation. Criteria within this group are further classified into sub-sections, from the perspective of their nature. General Manufacturing Modelling Features Criteria included in this group concern the general features related to manufacturing modelling. They evaluate whether the package allows modeling of logical elements such as part attributes, shifts modelling, and modeling of machine breakdowns. Some special operations typical for manufacturing systems are also included such as assembling, palletization and fluid composition.

3.2.3 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. The criteria included in this group and a classification of the packages regarding scheduling features.

3.2.4 Hierarchy of Criteria

An important issue to be considered concerning the use of the established criteria is the differing Importance of specific criteria to different types of users. From the point of view of this research, a hierarchy of criteria applicable for the selection of a package for education will differ from a hierarchy that concerns the selection of a package to be used in industry. Although some of the criteria might be considered to be of equivalent importance, such as criteria regarding pedigree

Or efficiency of the software, there are also many dissimilarities concerning the relevance of criteria for each group of users. These issues are addressed in the next two sub-sections.

3.2.5 Criteria for the evaluation of simulation packages

Importance for specific purposes of software use. For each group. A subset of the group's individual criteria are listed which are believed to be the most relevant the level of importance for each group of criteria is established in the range from 1 to 5.

3.2.6 Selection of a Package for Education

It was assumed that the users in this group would use simulation packages mainly for educational purposes in manufacturing simulation, and that the main users are students with little or no previous experience in simulation modelling. The use of software at educational institutions for modelling complex real life manufacturing problems was excluded. For that purpose, as well as for the research, a hierarchy of criteria proposed for users in industry can be applied.

3.2.7 Selection of a Package for Industry

The selection of a package for use in industry is divided into two groups according to the purpose of modelling. The first group presents a hierarchy of criteria that might be applied for the selection of a package to be used for 'quick and dirty' modelling, whilst the second group

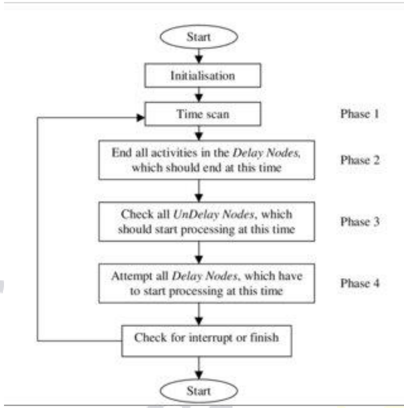

Fig. 4 ACD Symbols in Simulation and Modelling Process

4. Evaluation of Manufacturing Simulators, What Is Needed and How to Choose

This chapter deals with the evaluation of several manufacturing simulators, as applied to the development of the models in the case study. These simulators are considered as typical representatives of different types of widely used manufacturing simulators. The evaluation is not performed in order to discover which is 'the best' simulator, because such a term most likely 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. Additional factors are the intended software purpose and the personal preferences of simulation software users.

This chapter provides a further development and completion of the knowledge acquired during this research. It considers manufacturing simulators from the users' perspectives and analyzes those features that are needed, how these simulators can be improved, and how to choose an adequate simulator.

4.1 Evaluation of manufacturing simulators

Varieties of measures of manufacturing performance are provided by the software, or could be obtained with additional programming. Nevertheless, there is no schedule related respond such as a Gantt chart, and it is not possible to obtain a production sequence summary report. The efficiency is reflected by the criteria such as interaction and adaptability. For example, special Dynamic Interaction fools are provided where the user can change characteristics of the elements and perceive the effect of these changes to the rest of current simulation run. Statistical facilities significantly contribute to the positive features of this simulator. Several theoretical statistical distributions are provided as well as user defined distributions.

4.2 Positive Features

The most distinctive general features of this data-driven simulator that can be regarded as its advantages are the ease of learning and use. XCELL+ is manufacturing oriented and it incorporates manufacturing terminology. This simulator is primarily designed for non-simulation professionals, and therefore it does not require a substantial level of user's experience or formal education in simulation. Generally, it is user friendly once the basic concepts have been captured through the documentation.

The main intention is to produce ideas that can be of a practical use for users, vendors and developers of manufacturing simulators and simulation software in general. A survey has been carried out to find out users' opinions about simulation software, problems they experience using this software, and their requirements for the enhancement of simulation software. A methodology for software selection is derived on the basis of the experience gained during this research and from studying the literature. Finally, improvements to manufacturing simulators are proposed with regard to their purposes, which should result in easier and more effective modelling.

4.3 A Survey

This section presents the results of a survey on the use of simulation software in manufacturing environments. The survey of a number of simulation specialists in industry and universities across Europe was carried out to discover whether users are satisfied with the simulation software they use, and how this software might be further improved.

4.5 Purpose of the Survey

The main purpose of the survey was to investigate users' requirements of simulation software, especially software used for manufacturing simulation, and to seek opinions about ways of improving current simulation software tools to better satisfy their needs. This survey was conducted at the later stages of the research presented in this thesis, in order to improve, expand and conformation research findings. It was believed that information about simulation software provided by other users could contribute to achieving the objectives of this research.

4.6 Manufacturing simulators: what is needed and how to choose

Simulation languages. Examination of the number of simulation software tools used shows that all users use only one simulation software product (100%). Considering the simulation purpose, 90.9% of participants use simulation only for modelling real systems, whilst 9.1 % use simulation both for modelling real systems and education, and none of them use simulation only for education.

4.7 Manufacturing simulators*:* what is needed and how to choose percentage of academics that are involved only in education (at least concerning simulation) is relatively low (10.3%), which supports the point concerning the diversity of activities performed in an academic environment. As expected, a vast majority of users in industry use simulation for modelling real systems, a small proportion of them are involved both in modelling real systems and education, and none of them are involved only in education.

4.8 A Methodology for Selecting a Manufacturing Simulator

This section provides a methodology for selecting manufacturing simulators. This methodology has been derived from all findings gained during this research. Since the main subject of research is manufacturing simulators, the methodology for software selection has been established and described from the perspective of this type of simulation software. Nevertheless, the guidelines presented can be also used for selection of other types of simulation software (general or special purpose).

4.9 Method and Methodology

There are numerous definitions of the terms 'method' and 'methodology'. For example, a definition provided in Conform (2019) defines a 'method' as "a description of a specific technique in some symbolic language such that it can be communicated, taught or become an aspect of standard practice". According to the Oxford Advanced Learner's Dictionary (2019), "method is a way of doing something" or "orderly arrangement" To summarize, a methodology provides"a very useful distinction between what is to be done next, who is to do it, and how" (Avgerou and Comford, 2020). In the context of this research, a proposed methodology for selecting simulation software represents a structured set of stages and tasks that have to be carried out in order to select adequate simulation software.

4.10 Proposed Methodology for Selecting a Manufacturing Simulator

On the basis of all findings gained during this research, a structured approach to simulation software selection was derived and is presented in this sub-section. Once a need for purchasing simulation software has been established, several factors have to be initially considered. These factors include the intended simulation purpose, the existing constraints within the company, the main types of models to be simulated, and information regarding the modellers and potential users. With regard to the intended simulation purpose, it should be decided whether the simulation software is going to be used for education, 'quick and dirty' modelling in industry or for complex/detailed modelling in industry, and/or research. In the case that software is to be used for several different purposes, the most demanding purpose should be chosen as the basis for software evaluation. For example, if software is to be used both for education and research, then software features that are essential for research should be requested.

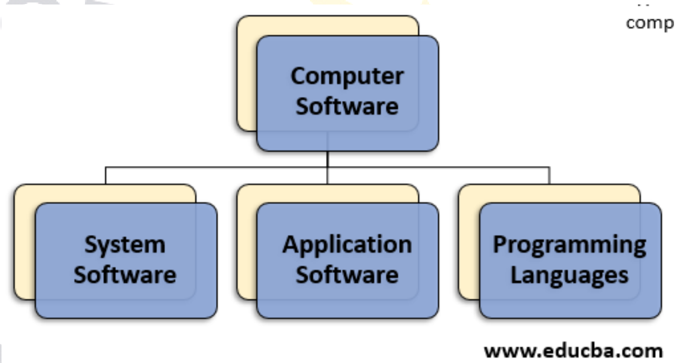

Fig.4 Comparison of the types of software used by survey participants

Conclusion

This case study used for different methods of modeling and simulation to minimizing manufacturing cost. It can be expected that areas and opportunities will emerge in the industries.

Model development using activity cycle diagrams is carried out through the following stages:

(i) The first stage First, the relevant entities of the model have to be chosen as well as the appropriate queues and activities.

(ii) The second stage at this stage, the activity cycle diagram is constructed by linking the life cycles of the entities engaged in the model in one connected diagram. It is also necessary to specify whether the entities are temporary or permanent and how they enter or leave the model.

(iii) The third stage this stage relates to the determination of priorities where entities can be involved in more than one activity and to an indication of whether entities possess attributes that determine their movements through the model.

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