INT. J. PROD. RES., 2002, VOL. 40, NO. 13, 3053–3073

An analytic-hierarchy-process based simulation model for implementation and analysis of computer-aided systems

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The many successful implementations of computer-aided systems (CAx) have created major advantages for most companies in the competitive world market. In particular, some companies have implemented these systems in order to keep up their competitive power, as computer applications in various fields of production systems are more widely used than before. Unfortunately, these companies have met some problems in their implementation processes, such as a lack of well-educated personnel, in sufficient management support, wrong implementation strategies and techniques, and so on. In order to overcome these problems, in this paper a systematic structure for the implementation and analysis of CAx systems is presented to eliminate—or at least reduce—these kinds of problems. In addition, some techniques, such as the analytic hierarchy process (AHP), benchmarking and simulation approach are used together to make the implementation and analysis studies more effective, easy and applicable for the companies. The objectives of the research are: first, to use the AHP technique for the evaluation of the hardware and software components for a targeted CAx system, secondly, to use a simulation generator integrated with the AHP in order to try the alternatives that are ranked by the AHP study, on a real-life product organization model of a company, until a model is found that provides the best performance values as determined by the company's management.

1. Introduction

Manufacturing organizations in developing countries are under intense competitive pressures. Major changes are being experienced with respect to resources, markets, manufacturing processes, and product strategies. As a result of international competition, only the most productive and cost-effective industries will survive. Manufacturing organizations are thus faced with the need to optimize the way in which they function in order to achieve the best possible performance within given constraints. This is a difficult task, both in terms of understanding the nature of the problem and the most effective solution strategies, and in forming and implementing plans that develop from this understanding. Many of the efforts in this direction are being carried out under the banner of computer integrated manufacturing (CIM) systems.

A computer integrated manufacturing system is capital intensive due to hardware and software requirements. As a result, it is essential that such a system achieves high levels of flexibility and productivity compared with traditional manufacturing systems. Modelling and analysis to gain a better understanding of the system com-

Received February 2002.

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International Journal of Production Research ISSN 0020–7543 print/ISSN 1366–588X online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/00207540210140059

plexities and to predict system performance are critical in the system design stage, and are often valuable for system management. Modern manufacturing systems tend to be tightly coupled. They are characterized by a high degree of automation, low levels of work-in-process inventory, and various forms of supervisory control. These systems are difficult to analyse using purely analytic models, such as queuing networks, dynamic and linear programming. Simulation is an indispensable tool for their design and operational performance analysis.

Computer-aided systems (CAx), as integrated parts of a computer integrated manufacturing (CIM) system, realize all kinds of business and manufacturing activities in a enterprise using computer technology in a good manner. The implementation process of a CAx can be difficult because the amount of investment required is generally too high relating to the degree of integration. That is why designing, planning and realizing these systems have received substantial attention in recent years—owing to the high initial investment cost of such systems, as well as the unprecedented mixture of success and horror stories on their implementation. Therefore, in this paper a systematic structure for the step-by-step implementation and analysis of CAx systems is described, where the analytic hierarchy process (AHP), simulation and benchmarking techniques are used effectively together. As the AHP technique is used for the evaluation and selection of the hardware and software components for a CAx system, a simulation generator integrated with this technique is used for further analysis in order to measure the system's benefits with regard to the company's modelled production organization. In other words, while the AHP technique, one of the multiple criteria decision making tools, helps companies both to select the best alternative and to sort the remaining alternatives by weight, a simulation generator integrated with the AHP is used to model the real-life production organization of a company automatically. Thus trying the AHP's ranked alternatives as simulation scenarios on the modelled organization. If the AHP first-ranked alternative does not satisfy the performance values determined by the company's management, the second best-ranked one is taken into account as the second scenario, until an alternative is reached that satisfies the values required. Furthermore, the generator integrated with the AHP technique also makes all the required calculations automatically. The AHP software allows also the user to make the AHP's complex and time-consuming matrix calculations automatically instead of making them manually, while the generator produces both the required files (model and experimental files) for the SIMAN simulation language and its results for the user, who may not have experience or knowledge of simulation, modelling and programming. The generator and its integrated part, the AHP software were developed using QBasic programming language for the PC. In the final section, in order to prove its applicability with a real-life system, this structure was applied to a company, which is the leading company (with ISO 9001 certification) in designing and manufacturing cutting tools.

2. Related research

The use of modelling and simulation techniques together in a manufacturing environment is not a new subject. A great number of simulation studies have been carried out so far, while new simulation software with outstanding graphics capabilities has been developed. However, most of these studies have been focused on a part or a sub-group of a production organization, not the whole organization (for example: the simulation of manufacturing systems, Kiran *et al.* 1989). In other words, the studies have been limited to a part of a production system, mostly related to manufacturing systems, such as production planning and shop floor planning and so on. In the literature, there are not as many studies on this subject as expected. However, Pruett and Vasudev (1990) modelled a whole manufacturing organization and developed a system called MOSES that allowed users to evaluate their ideas on the modelled manufacturing organization using a simulation technique. Love and Barton (1996) developed a simulator for a whole production system in a CIM environment in order both to analyse various design strategies and to evaluate these strategies on a financial basis. Love and Barton applied the simulator to a company and modelled its business and manufacturing functions and their relationships with each other. The effects of design changes on these functions were examined with this simulator. Furthermore, the authors developed an interface system linking CAD, CAPP and MRP systems.

Shang and Tadikamalla (1993) developed an approach to maximize the output of CIM. This approach also included a statistical technique to reduce the calculation time of a great number of simulation experiments because of the complexity of the manufacturing system. The objective of the study was to provide the output maximization of CIM by organizing its manufacturing factors, such as input values and so on. Biemans and Vissers (1991) advised a reference model to implement a CIM architecture, including the required steps in its implementation. First, the authors divided the production environment into units. In other words, they defined the whole manufacturing system as a structure consisting of these divided units. Botzer and Etzion (1995) developed a hierarchical optimization model to integrate different databases existing in a CIM system. Wunderli *et al.* (1996) defined multibase agents, each of which provides an interface system between CAx systems in order to integrate the systems into a whole CIM system. There are also some studies regarding a simulation technique used together with AHP in the literature. In a study, Levary and Wan (1999) developed a methodology for ranking entry mode alternatives encountered by individual companies considering foreign direct assessment. The methodology deals with the risks and uncertainties related to foreign direct investment. The AHP was used to solve the multiple-criteria decision-making problem using input from the company's management. A simulation approach is incorporated into the AHP to handle the uncertainty considerations encountered in a foreign direct investment environment. Although this study is not directly related to manufacturing systems, it is interesting that it brings together two different popular techniques—AHP and simulation.

In this paper, a systematic structure for step-by-step implementation and analysis of CAx systems is presented as there are a few studies in the literature on estimating the benefits of these systems on a whole production organization.

3. Brief definition of a production organization

A production organization can be described as a configuration of interacting components, such as quoting, product design and engineering, tool engineering, production planning and control manufacturing, and quality control and so on. These components all play different roles on the company's performance. The overall performance of a production organization is, say, the variety and efficiency of the production targets that it can realize. However, a product organization is an intricate combination of many people and systems with a variety of responsibilities in material management, product design, scheduling and so on. It is not clear how their individual behaviours, or the improvement thereof, affect the performance of the production organization as a whole. In summary, one of the essential problems in improving the overall efficiency and flexibility of product organizations is to determine how every component affects the overall organization. Although all the functions play roles in the production organization performance, some play more important roles than others. That is why only indispensable functions are taken into consideration in this study, due to the complexity of production systems.

4. A systematic structure for the implementation and analysis of CAx systems

Figure 1 shows all of the required steps for the implementation and analysis of a CAx system. Before the study, a company should initially decide what kinds of CAx systems are planned to be implemented and integrated with its existing systems. Furthermore, if its management wants to realize more than one CAx system simultaneously (i.e. CAD/CAM and CAD/CAE) it could be very difficult because a great deal of investment is necessary and because the adaptation process of a new system into existing ones is not an easy task for employees and the production organization. Hence, the management should determine the priority sequences among the planned systems according to the company's goals. To this purpose, a step-by-step structure, consisting of eight steps, is described in order to realize a CAx system, as shown in figure 1.

Step 1

A project team is set up from the employees working in various departments of company. Furthermore, it is suggested that this team should be selected by the top management and mostly consist of the employees from the manufacturing and the IT departments. At least one member of the top management should be in the team, so that he or she can follow up the implementation process.

Step 2

After determining the company's needs as per the planned CAx, its current production organization should be examined for the implementation study. The project team should also analyse the relevant departments and the tasks carried out by them, which might be affected during the study.

Step 3

A project plan showing all the milestones of the project—such as resources, time, manpower and so on—should be prepared and presented to the top management for approval. This is a useful step in keeping the decision-makers involved in the problem solution. If the decision-makers maintain their involvement, there is much greater probability of implementation at project completion.

Step 4

Defined the criteria in order to select the best hardware and software configuration for a CAx system. These criteria that may change from one company to another, and should be defined by the implementation team according to the needs and goals of company. These criteria are used to evaluate candidate alternatives by using the AHP technique given in step 6.

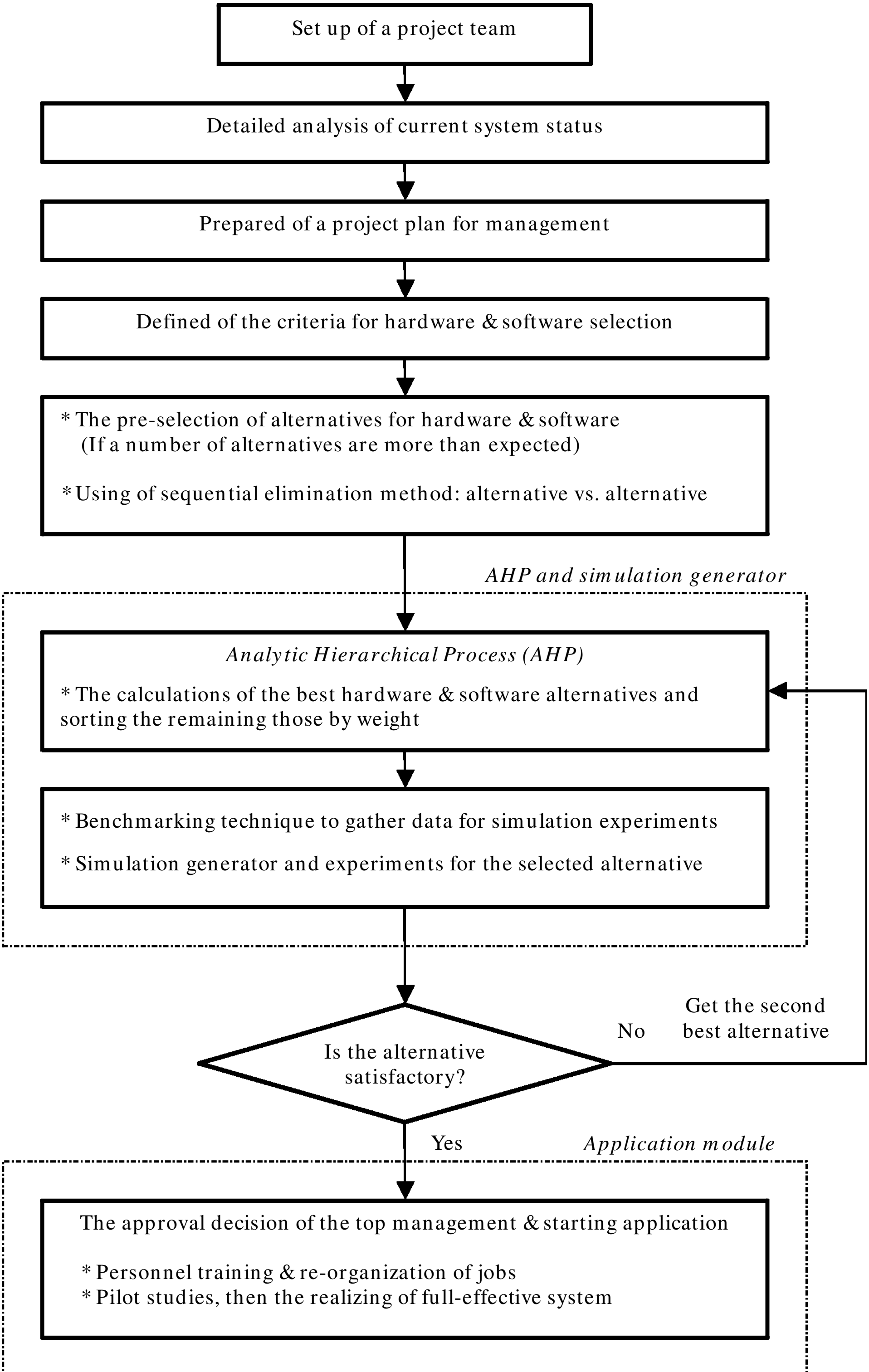

Figure 1. Flow diagram for the step-by-step implementation of a computer-aided system.

Step 5

The pre-selection process for alternatives of hardware and software: if the number of alternatives in some applications is more than expected, a study called '*the pre-selection process*' should be applied to reduce the number of alternatives so that the evaluation process is not time consuming. Therefore, '*sequential elimination methods*' are used to select the strong candidates, so that the AHP technique can evaluate only these candidates in order to calculate the best solution and to sort the remaining ones by weight faster and more easily. Sequential elimination methods are applicable when one can specify values (outcomes) for all criteria and alternatives. Those values should be scalar (measurable) or at least ordinal (rank orderable). The methods do not consider weighting, if any, of attributes. Sequential elimination methods are selected because they are understandable and easily applicable by everyone. There are two kinds of sequential elimination methods: *alternative versus standard and alternative versus alternative*. These techniques, defined briefly above, do not weight alternatives on each criterion as mentioned before. They are used only to decrease the dimensions of the selection process. In first technique, if the standard value is defined incorrectly, the results could obviously not be correct. In the second technique, since every alternative is compared with the others, it is more likely that reliable results may be obtained without making detailed analyses. Therefore, the second method is selected for the pre-selection process, and it will be used only if the number of alternatives is more than expected for the AHP process.

Step 6

After the pre-selection process, the remaining alternatives can now be evaluated using one of the various '*Multiple Criteria Decision Making*' techniques, which could be applied to the capability management process. These techniques can be used in two different ways: (1) to capture the decision-maker's preference or (2) in the further analysis of modelling and simulation outputs. Two of more popular techniques, the Analytic Hierarchy Process (AHP) and Multi-Attributed Utility Theory (MAUT), are briefly described in this section. The AHP technique consists of a systematic approach based on breaking the decision problem into a hierarchy of interrelated elements. The evaluation of the selection criteria is done using a scaling system showing that each criterion is related with the others. This scaling process is then converted to priority values to compare alternatives. This is a very useful tool to define the problem structure.

Multi-attribute utility theory (MAUT) is also a technique that uses the decision-maker's preferences, involving uncertainty, risk and other factors, in selecting alternatives. In MAUT, the decision-maker's preferences are captured in the form of a nonlinear utility function for each individual attribute or quantitative performance measure. These single attribute utility functions are then combined into a multi-attribute function, which is a single index of the overall desirability of an alternative. Probability distributions are used to quantify uncertainty in the multi-attribute function. MAUT provides a method of combining measures of performance and other quantifiable factors into measures of effectiveness (Saunders *et al*. 2000).

In this study, the AHP is selected, on one hand because it integrates quantitative and qualitative factors and, on the other, in view of the significant number of applications already developed in similar decision contexts (Cagno *et al*. 1997). In addition, it is one of more commonly used techniques in various fields such as the financial analysis of CIM or FMS systems (Varney 1985), for the evaluation of complex, multi-dimensional and multi-criteria problems using a hierarchical structure.

The AHP evaluation study can be still time-consuming, even if the pre-selection process is used. This is because, as the number of criteria increase, the dimension of problem naturally expands. This means there will be a long and boring calculation time if all calculations are done manually. Because of this, a computer program, integrated into the simulation generator, is prepared by using Qbasic, in order to make the AHP evaluation easier and quicker for the user. In the user interface part of this program, the user enters all the requested data—such as a number of alternatives, criteria, their relationships among them and so on—for the study through a data-driven interactive tool in a user-friendly environment after reading the instructions given in detail on the screen. The program then calculates the best alternative and sorts the remainder by a calculated final weight for each alternative in case the best one may fail in the simulation study defined in the next step.

In figure 2, the flow diagram of the AHP program is an integrated part of the simulation generator. Furthermore, as seen in figure 2, there are two different sections, one of which is the *data entry module*, gathering all the required data from the user, and the other section is the *AHP program and output modules*, which calculates the best solution and sorts the remainder by weight (Nikoukaran 1998).

Step 7. *AHP module and simulation generator*

This module brings together three popular techniques—AHP, simulation and benchmarking—to analyse the benefits of a planned CAx system on the performance of a company's product organization before it is implemented (figure 3). The AHP technique was explained in detail in the previous step.

Step 7.1. *Gathering the data for the simulation study*

Six different methods can be defined to obtain all the required data for the simulation experiments. (1) Similar studies realized in the literature can provide more important information for a new system analysis. (2) Feedback from experienced employees who know their old system well and can compare it with a new system. However, to obtain the correct information, first they should believe that a new system will bring very important benefits to the company as well as to themselves. (3) Decisions made by a decision maker or a member of the top management who has authority to realize a new system. (4) Data obtained from a vendor and the vendor's experience. (5) Other companies that have implemented the same or a similar new system. (6) Information obtained from the benchmarking process that investigates the benefits of any candidate system on the product organization of the company.

The above-mentioned methods have some disadvantages as well as their advantages; for example, the information from the literature or the studies realized before was obtained under certain conditions. Although very useful for simulation experiments, the correctness and confidence of the information can be discussed. First of all, therefore, a sensitive analysis should be done of the conditions of the previous work. However, this process can be time-consuming. Although employees working in the relevant department of company are one of the most important sources of the necessary information about an old system, their views can be subjective and may not reflect the real values. Information from a vendor may not be sufficient as the vendor has less information on customers' applications than required. Companies

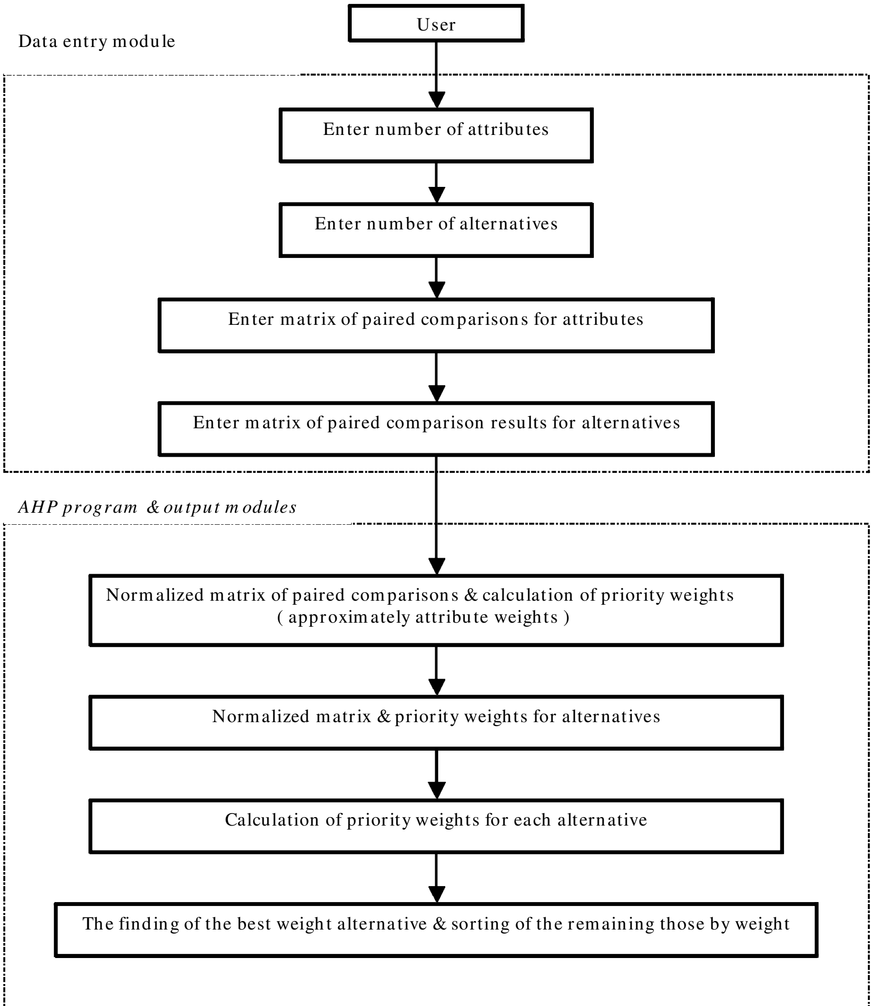

Figure 2. Flow diagram of the AHP program.

using the same or similar systems can also provide significant information. But each company has a different production system, so information obtained from other user companies can only be used to get a rough view for the analysis.

Finally, all of these above-mentioned methods have some disadvantages as well as their advantages. However, gathering correct and trustworthy data to use in a simulation study is the one of the most important parts of this study. Therefore, of all the methods, the benchmarking technique realized on the company's outstanding activities is going to provide more valuable and trustworthy information than the others, but the other methods can be used to roughly test the acceptability of the results of a benchmarking process. The benchmarking technique is used to evaluate an alternative obtained from the AHP study in order to gather data by measuring its benefits on the real-life product organization of the company. There are two ways to use the benchmarking technique: (1) the deterministic samples: these samples, the

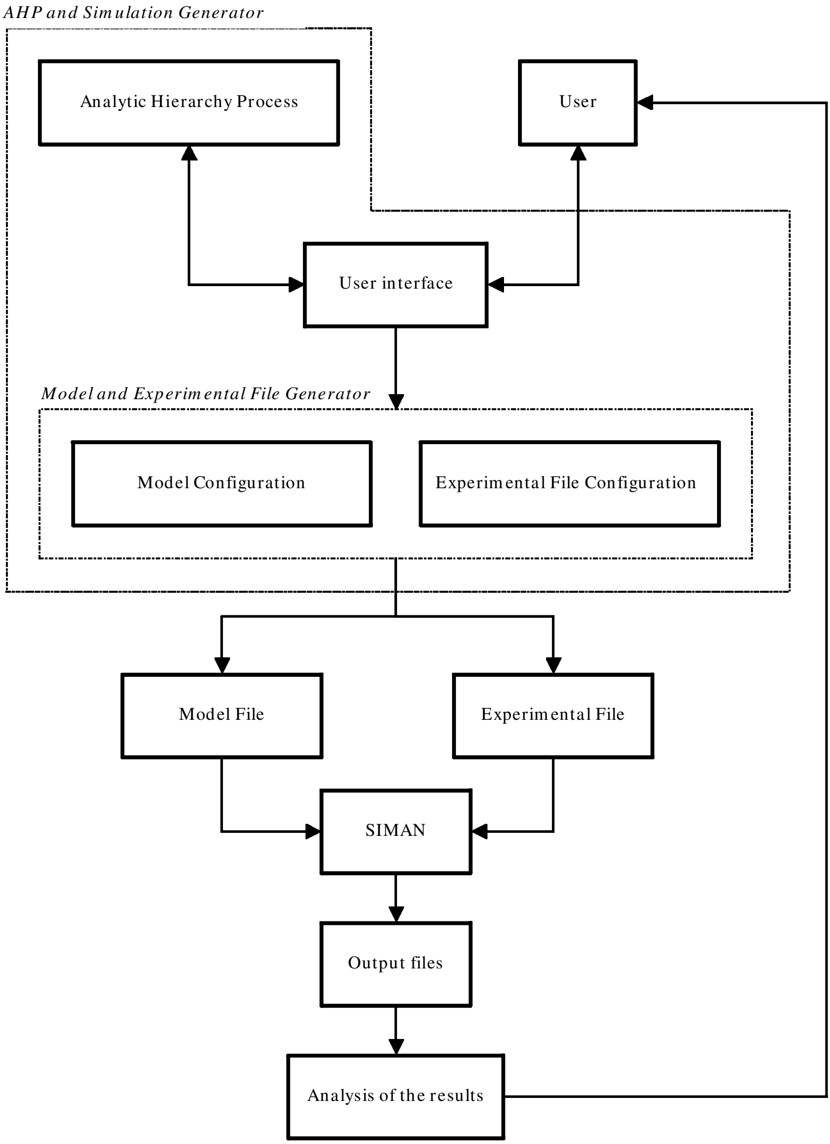

Figure 3. AHP and simulation analysis with a simulation generator.

results of which are certainly known, are selected and applied for the selected alternative in order to measure its performance based on the criteria (cost, time and quality etc.) on the company's product organization; (2) the stochastic samples: these samples—representing heavy-load conditions of the company production system—are taken into consideration to evaluate the performance of the same alternative under extreme conditions.

Step 7.2. *Simulation generator*

A simulation generator can be defined as: 'an interactive software tool that translates the logic of a model described in relatively general symbolism into the code of a simulation language and so enables a computer to mimic model behaviour'. Such simulators are sometimes referred to as data-driven simulators which do not require any formal programming by the analyst (Aytug and Dogan 1998). In this section, a simulation generator is created for a computer-aided system analysis. First, a cell-based structure is defined for building a production organization. All data are entered into the system thanks to a data-driven interactive tool by the user. A simulation generator then builds the product organization and automatically writes the model and experimental files representing the product organization in the target simulation language SIMAN by using the data entered by the user. A simulation model is then run for the selected alternative using the data from the benchmarking process and the results are evaluated. If the results for the alternative do not satisfy the management of the company, the second best alternative obtained from the AHP technique should be taken into consideration by following the same method until a satisfactory solution is reached. The code generator is written in Qbasic for the PC.

Step 7.2.1. *Modelling of a product organization*
In figure 4, a cell is shown as a cornerstone of a product. Cells, such as quoting, product design and engineering, manufacturing and so on, show the main functions in an organization, while information flow (input and output) defines the priorities among the cells.

It can be assumed that a product organization consists of cells with input and output information, and the tasks carried out by cells. A hypothetical production organization consisting of five cells is shown in figure 5. This organization, without being supported by computer systems, is taken as a base system for the implementa-

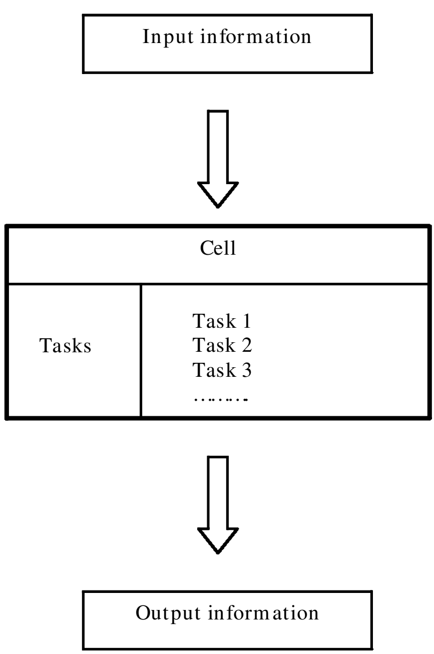

Figure 4. A cell with input–output values as a cornerstone of product organization.

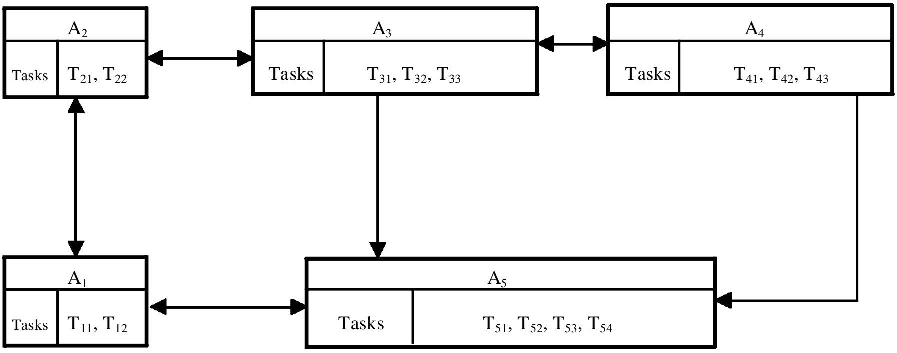

Figure 5. A hypothetical production organization consisting of cells with their input and output information flow, and tasks (the example is limited to 5 cells).

tion of CAx systems. As seen in the figure, only the effective elements on the performance of a product organization are taken into account for this study. The information transfer times are ignored as it is assumed that they do not affect the performance of a product organization.

Step 7.2.2. *User interface*

A user interface is designed and implemented. It is an interactive data-driven tool. Input is taken via the keyboard from the user to supply the simulation generator with the necessary information. The process of simulation analysis with the simulation generator is illustrated in figure 3. The user interfaces were tested and validated extensively for different cases. Some operational data are generated from the basic descriptions after the user completes data entry.

All data are gathered from a real system under certain assumptions. These assumptions relate the model behaviour to the physical system behaviour for two purposes: (1) the first purpose is to identify systems' details not included in the model because the systems do not influence performance; (2) the second purpose is to define how the included details are represented in the model. The following is a list of the key assumptions made for this study. (1) There is only information flow modelled; (2) the absence of employees is not included; and (3) rework is not included. The generator needs a precedence matrix for cells and the matrix of process times for each cell. Process times are based on the data that are gathered from the real system and which fit a distribution for the simulation analysis. Distributions are generated by using statistical data gathered from the real-life system. Table 1 shows a sample group of data entered by the user in order to model the product organization given in figure 5.

Step 7.2.3. *Simulation report generation*

The simulation generator creates custom report specifications within the experimental file. Results of a simulation run are divided into three major sections with the following headings: tally variables, discrete-change variables and counters. Under the tally variables section, observation-based statistics are listed. The average coefficients of variation, minimum, maximum and number of observations are reported for each item. The discrete-change variables section lists time-based statis-

- Interval time and size of customer order
- Distribution of product type
- Length of simulation
- Number of replications of the simulation
- Warm-up period of simulation
- Beginning time for the first replication
- Whether or not to initialize the system between replications
- Whether or not to discard statistics between replications
- Simulation model and user's name
- List of the departments (or cells)
- Cells: (1) name of cell, (2) its capacity, (3) process time for a product type in a cell, (4) Queue capacity for a cell, (5) whether or not employee absence occur (interval time of absences), (6) whether or not set-up times are used and so on.

Table 1. A sample group of data entered by the user.

tics. The average coefficient of variation, minimum, maximum and final values are reported for each variable. The final section reports the counter variables, such as the number of orders completed, the number of units designed, and the number units manufactured.

Step 7.2.4. *Verification and validation of the simulation generator*
Various steps were taken to verify and validate the SIMAN simulation programs generated and the results obtained from the simulation runs. Several examples were generated using the user interface. Programs generated were verified manually for their logical and structural correctness. If data taken via the user interface are employed to describe a product organization system, then the simulation generator creates the files for the SIMAN simulation language. Several performance measures, such as queue lengths, resource utilization, and cycle times are included as standard items in the output results to validate the simulation models. Finally, a few small models' logic is validated using the trace capability of SIMAN. All results indicated a valid and robust simulation generator.

Step 7.2.5. *Limitations of the simulation generator*
The simulation generator is written in Qbasic. It has no model size restrictions and generates simulation programs that can be run in all versions of SIMAN. The advantages of simulation generators are well known but there are also several limitations. O'Keefe and Haddock (1991) indicate that the disadvantages for the user occur in three areas: (1) the perceived ease of use; (2) weaknesses resulting from the underlying language; and (3) the limitations of the generator. Furthermore, if the assumptions made in developing a simulation generator are not explicitly stated by the developer and not understood by the user, the results can be invalid.

These disadvantages are also valid for the simulation generator discussed here. The simulation generator is easy to use, but it requires a large amount of data. It also requires basic statistical skills. The same arguments can be made for the design of the simulation experiment and for the analysis of the simulation results. There are a few weaknesses resulting from the underlying language, SIMAN. SIMAN does not have real subroutine capabilities, so that several modules must be repeated many times causing long model files. However, this can be viewed as an advantage since the code is more readable in its current form.

Step 8
The application module given in figure 1 can be realized where the alternative (hardware and software of the computer-aided system) is satisfactory after many simulation runs. First, it is presented to the management for approval. Then, as the first step, users of the previous system should be trained on the hardware and software of the new computer-aided system, as a pilot study is started in a selected area for certain kinds of products (for example: for a CAD investment, all CAD users used to design using a manual system before, should be trained for new system, which is supported by computer technology, newly organized work, and of course, CAD software). During the pilot study, even though system performance may decrease a little for reasons such as personnel training and newly organized jobs and so on, a certain time later (as specified in the project plan), the new system will be more productive than the previous one. The length of this transition time depends on criteria such as the quality of personnel, kinds of jobs, performance of the implementation team and the support and contribution of top management, etc.

5. Case study

A systematic structure has been presented above for the step-by-step implementation and analysis of a computer-aided system (CAx). In this section, a case study is realized to prove its applicability and validity. Therefore, a machine tool manufacturer, a leading company in designing and manufacturing all kinds of cutting tools (twist drills, reamers, taps, nuts, carbide-tipped tool holders, centre drills, masonry drills and so on) was selected for this study. The company also serves various sectors, such as the automotive, manufacturing, defence and paper sectors. The company's top management decided to establish CAD and CAM systems, respectively, for their design and manufacturing activities, which had been making manually before. Furthermore, this study was also limited to two CAx modules (CAD and CAM) due to the nature of the company's product organization.

Step 1. After the CAD and CAM systems were chosen as the systems, a project team was set up to implement them. This team consisted of five people, four of whom were from manufacturing, design, product planning and control, and quoting, while the fifth person was from management: the vice general manager of manufacturing operations.

Step 2. In this step, the company's current production organization was analysed and examined along with all the business and manufacturing functions that could affect the performance of its production organization. There are two kinds of products in this company: products designed and manufactured on-site, and products that are only bought and sold to customers. The products that are designed and manufactured in the company, are classified into three categories such as N (standard products), S (semi-standard products) and P(custom products). A German software, called INTEPS, is used as a production planning and control system, which controls all the business functions from customer order to shipping order and also includes accounting and finance departments (except for the design functions which are done separately and manually without any help from computer technology). The design and product development studies are evaluated in two categories, one of which is the geometrical design to be evaluated in this study, another is the new material development study that is mostly related to metallurgy science. One of the most important departments in the organization is the product design and engineering department that can be more affected by CAD and CAM implementation studies. All of the tasks, such as custom-tailored design based on customer specifications, supplying code and drawing numbers to products, revision of drawings, preparation of production tables used in similar products, archiving of drawings, classification of samples coming from customer are realized in this department. The manufacturing site includes several multi-axis NC controlled-machines, as well as conventional machines. In addition, there are five manufacturing facilities divided up as per the product groups except for the heat treatment department, which servicing to all of the facilities: (1) drills, (2) cutters, (3) taps, (4) saws, (5) carbide-tipped tool holders.

Step 3. The project plans showing all of the required steps of these implementation studies on a time-basis were prepared for the top management as well as members of the team, as defined in figure 1. The management approved the plans, and the Gantt project planning technique was used to build the plans so their resources and activities can be tracked easily on a time basis.

Step 4. Because there are various alternatives for the software and hardware components of CAD and CAM systems on the market, some criteria (partly shown in table 3) were defined as per the needs of company in order to evaluate the systems among the possible alternatives.

Step 5. The pre-selection process was not used in the case study because the number of alternatives was not more than expected. The alternatives for both systems were selected based on the cutting tool design and manufacturing.

Step 6. The AHP process was used both to determine the best software and hardware components, and to sort the remainder by weight for CAD and CAM systems respectively. Table 2 shows three strong alternatives for each system. Letters are used instead of the real names. Each alternative is taken as a configuration of software and hardware components for CAD and CAM systems.

The AHP program was used to make all the necessary calculations faster and more correctly during the evaluation. The study for each system was performed thanks to this program. The data entered by the user for the analysis are: (1) enter the number of criteria; (2) enter the number of alternatives; (3) enter the matrix of paired comparisons (in decimal units) for attributes; (4) enter the matrix of paired comparison results (with respect to ‘System cost’). Here, only a part of the data used in the AHP process is shown due to its complexity (tables 3 and 4).

The hardware selection for the CAM system is related to upgrading the CAD system hardware if necessary. The software, together with its hardware, is evaluated

	Software & Hardware		
System	Alternative 1	Alternative 2	Alternative 3
CAD for all product types	X	Y	Z
CAM for the tool holders	U	V	T

Table 2. The alternatives for software and hardware of CAD and CAM systems.

Criteria	A	B	C	D	E	...
A. System cost	1	2	3	4	3	...
B. Parametric feature	0.5	1	2	3	4	...
C. Concurrent eng. support	0.33	0.5	1	2	2	...
D. Animation feature	0.25	0.33	0.5	1	0.5	...
E. Graphics card capability	0.33	0.25	0.5	2	1	...
......						
Total	7.48	15.3	30.11	33.08	26.0	...

Table 3. A part of the matrix of paired comparisons (in decimal units) for attributes.

A	A-1	A-2	A-3
A-1	1	3	2
A-2	0.33	1	2
A-3	0.5	0.5	1
Total	1.83	4.5	5

Table 4. A part of the matrix of paired comparison results (in decimal units) (with respect to 'System cost').

as an alternative, as in the evaluation of the CAD system alternatives. The CAM system was limited to only certain kinds of products (carbide-tipped tool holders) in the beginning because of management demands. The 3D geometric data of any carbide-tipped tool holder were transferred to the CAM system in order to generate NC codes for CNC machining centres automatically. The data were also transferred to a drafting system for some parts not machined in CNC controlled machining centres, in order to prepare their manufacturing drawings. The results of the AHP studies for both system implementations are presented in table 5 where all the alternatives are sorted by weight. Furthermore, these implementations allow some departments to share the data with others, such as the quoting department, which mostly needs existing technical data to make a new quote for a customer order that is being manufactured for the first time; the process planning department, which uses geometrical data to make the process plan for an order; production planning and control, which plans and controls all the activities of an order on a time basis. Thanks to this data sharing system, the other departments that are indirectly related could see any technical data, as required, via the computer instead of asking other technical personnel and visiting other departments.

Step 7. Using the simulation generator for the analyses of CAD and CAM implementations respectively, some of the required data are shown to model the company's product organization (tables 6 and 7).

(1) *Analysis of CAD supported system*. Each alternative calculated and sorted by the AHP is accepted as a scenario, as presented in table 8. The generator uses all the required data obtained from the benchmarking process for each

System	1st rank	2nd rank	3rd rank
CAD for the entire products	Y (0.43)	X (0.40)	Z (0.39)
CAM for the tool holders	T (0.37)	U (0.35)	V (0.18)

Table 5. The results of the AHP technique.

	Cells (A_i)												
Cells (A_i)	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}
A_1		1											
A_2	1		1										
A_3	1	1			1								1
A_4				1		1						1	
A_5							1	1					
A_6						1			1	1			
A_7						1					1		
A_8										1			
A_9											1		
A_{10}												1	
A_{11}													1
A_{12}				1									1
A_{13}												1	

Table 6. Precedence matrix of cells.

alternative ranked in the AHP study and shown in table 5. The tasks carried out before are presented with their relevant data (process times for each product type, S and P) together with the data for after CAD implementation (table 8). The process times are assumed not to change for standard (N) product types.

(2) *Analysis of CAD/CAM supported system.* The analysis of the CAM system implementation is similar to that of the CAD systems. Each alternative ranked by the AHP study is also assumed as a scenario given in table 9. All the data for both system analyses, which are shown in tables 8 and 9 were entered into the simulation generator by the user. The user modified the data for each ranked alternative for the CAD and CAM systems respectively until the alternative provided the satisfactory results determined by the company management.

(3) *The verification and validation of the generated model.* All data were obtained from the company's real-life product organization in order to build its simulation model. To prove its accuracy, the TRACE command, one of the SIMAN output commands was used to verify the model. It allows user to watch a step-by-step running of the model on a time basis in order to see on how well it runs in comparison with its real-life system. In addition, in order to check the validity of this model, extreme conditions from the real-life system were taken into consideration to understand how well this model represented them. Formal, qualitative and observation characteristics were examined on the model (Birta and Ozmizrak 1996). Furthermore, the t distribution was used to prove the validity of the simulation model using

the product cycle time for all products variable at 95% confidence level. The simulation duration was selected to be 300 working days (approximately 1 year) so that the required data could statistically be obtained from the experiments. The results were exported to Excel as an ASCII file by using a SIMAN output command, so that the results could be represented graphically. To find a warm-up period or transition period, the PLOT command of the SIMAN output analysis module was used on the average product cycle time of all products, and the warm-up period duration was found to in 100 days. To calculate the confidence intervals, FILTER and INTERVALS commands were also used for each performance criteria (Pegden 1990).

(4) *Simulation results*. Table 10 shows the benefit comparisons of CAD- and CAM-supported systems on the company's production organization. In the table, the comparison is presented of the average cycle time of the implemented systems after eliminating the warm-up period data. As can be seen, the best values of performance criteria are obtained by using 'Z' for the CAD and 'U' for the CAM systems as the result of the simulation experiments.

Cells Tasks	Process times (day)		
	N type	S type	P type
• Customer			
• Quoting	N (0.2, 0.1)	N (1.2, 0.5)	N (3, 0.8)
• Warehousing & Shipping	N (0.1, 0.2)	N (0.6, 0.2)	N (1, 0.4)
• Production Planning & Control			
○ Create work order	0.1	0.16	0.22
○ Calculating net orders	0.15	0.2	0.25
○ Preparing monthly reports	0.5	1.2	2.0
• Manual design & drafting			
○ Designing carbide-tipped tool holder	N (1.6, 0.5)	N (4, 0.4)	
○ Designing all kinds of cutting tools	N (1.1, 0.5)	N (3, 0.6)	
• Tool design			
○ New tool and fixture design for an order	N (4, 1)	N (7, 1.8)	
○ Preparing tool and fixture manufacturing drawings	N (3, 0.6)	N (5, 1.2)	
○ Revising tool and fixtures as per product changes	N (1, 0.2)	N (1.6,0.5)	N (3, 0.8)
• NC codes (Carbide-tipped tool holders)			
○ Manual NC Code generation	N (3, 1.5)	N (6, 0.7)	
○ NC code preparation and transfer to CNC machines	0.3	0.5	
• Method studies	N (2.5, 0.4)	N (4, 0.8)	
• Process planning			
○ Preparing manual process plans for new orders	N (0.6, 0.2)	N (1, 0.2)	
• Soft operations before heat treatment	N (4, 0.5)	N (12, 2.5)	N (18, 3.5)
• Heat treatment	N (1, 0.2)	N (3, 0.5)	N (4, 0.8)
• Operations after heat treatment	N (2, 0.2)	N (6, 1.5)	N (10,0.4)
• Carbide-tipped tool holder manufacturing	N (1, 0.2)	N (1.6, 0.5)	N (3, 0.8)
• Quality control	N (0.1, 0.2)	N (0.4, 0.2)	N (1, 0.2)

Table 7. Cells and their tasks and process times for each product type.

	Current system		CAD supported system					
			Process time (day)					
	Process time (day)		Y		X		Z	
Tasks	S	P	S	P	S	P	S	P
Design of carbide-tipped tool holders	N (1.6, 0.5)	N (4, 0.4)	N (1.1, 0.5)	N (2.5, 0.4)	N (1.4, 0.4)	N (2, 0.4)	N (0.9, 0.5)	N (1.9, 0.4)
Design for the entire products	N (1.1, 0.5)	N (3, 0.6)	N (1.2, 0.2)	N (2.0, 0.5)	N (0.9, 0.2)	N (2.1 0.4)	N (1.0, 0.5)	N (1.5, 0.4)

Table 8. The data for the simulation study of CAD system.

	Current system		CAD/CAM supported system					
			Process time (day)					
	Process time (day)		T		U		V	
Tasks	S	P	S	P	S	P	S	P
NC code generation	(3, 1.5)	N (6, 0.7)	N (0.8, 0.2)	N (2, 0.4)	N (1.1, 0.3)	N (1.5, 0.3)	N (0.9, 0.2)	N (3, 0.1)
NC code transfer	0.3	0.5	0.1	0.2	0.07	0.12	0.12	0.2

Note: Process times are assumed to fit into a normal distribution (except for NC code transfer time). Each alternative is shown as a letter.

Table 9. The data for the simulation study of CAD/CAM system.

Performance criteria	Current system	CAD supported system			CAD/CAM supported system		
		Scenario I (Y)	Scenario II (X)	Scenario III (Z)	Scenario I (T)	Scenario II (U)	Scenario III (V)
Product cycle time for the entire products (day)	59.5	53.4 (10%)	54.2 (9%)	50.4 (15%)	52.9 (11%)	49.8 (12%)	53.8 (10%)
Design cycle time for the entire products (day)	0.75	0.4	0.42	0.37	0.38	0.36	0.42
Design cycle time for carbide-tipped tool holders (day)	2.1	1.25	1.15	1.2	1.3	1.22	1.4
Manufacturing cycle time for carbide-tipped tool holders (day)	67.2	66.5	67.8	67.5	48.7	47.5	50.5

Notes: The alternative satisfies the company management if the criteria 'product cycle time for the entire products' is less than 7.5 weeks (52.5 days). The values in brackets show the improvement degree of the scenario's comparison with the current system.

Table 10. The comparison of the average cycle time for the implemented systems (all values rounded up).

Step 8. In this final step, all the results from the analysis were presented to the management so they can approve further studies. After that, the training and pilot studies were started, leading to the full effective system implementation.

Conclusions

In most research and studies regarding implementation and analysis of computer-aided systems (CAx), researchers and authors have only evaluated their benefits on a certain part of a production organization. Consequently, there are some outstanding research and studies remaining regarding the analysis of computer-aided system benefits on the whole production organization. Therefore, in this paper, a systematic structure for the step-by-step implementation and analysis of CAx systems was presented, where an analytic hierarchy process (AHP), a simulation approach and benchmarking were used effectively together. The objectives of the research were, first, to use the AHP technique for the evaluation of hardware and software components for a targeted CAx system, secondly, to use the simulation technique in order to test the results of the AHP study (the ranked alternatives) on the modelled product organization, which represents the real-life product organization of a company. The generator evaluates each alternative by starting the best-ranked one from the AHP until reaching the alternative that satisfies the performance values defined by the company management.

I strongly believe that the structure mentioned in this study will be very helpful for a company that is considering implementing a computer-aided system and wishes to analyse its performance before it is implemented. In future studies, expert system logic (knowledge-based) can be adapted to the system in order to analyse and interpret the outputs of simulation experiments by using the user interface.

Acknowledgements

The author thanks his advisor, Murat Dincmen, Professor at the Industrial Engineering Department and Dean of the Faculty of Business Administration at Istanbul Technical University, for his contributions to this paper. He also thanks Ali Riza Kaylan, Gunduz Ulusoy, Atac Soysal and Bulent Durmusoglu for their contributions, as members of his PhD dissertation committee.

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