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# Expert System Applications in Sheet Metal Forming

R. Ganesh Narayanan
*Department of Mechanical Engineering, IIT Guwahati, Guwahati 781039*
*India*

## 1. Introduction

Expert system can be defined as an intelligent computer program, a repository of knowledge, a set of rules, like a human consultant, all aiming at delivering accurate solutions/suggestions to a problem at any level, say during plan, design, manufacture, and quality control. Some of the important definitions are quoted here.

"An expert system is a computer system used to distribute the expertise of a human or group of humans throughout a group of users" (Wang et al., 1991)

"Expert systems (ES) are a branch of applied artificial intelligence involving that expertise, which is the vast body of task-specific knowledge, is transferred from a human to a computer. This knowledge is then stored in the computer and users call upon the computer for specific advice as needed" (Liao, 2005)

"An expert system is one that has expert rules and avoids blind search, reasons by manipulating symbols, grasps fundamental domain principles, and has complete weaker reasoning methods to fall back on when expert rules fail and to use in producing explanations. It deals with difficult problems in a complex domain, can take a problem description in lay terms and convert it to an internal representation appropriate for processing with its expert rules, and it can reason about its own knowledge (or lack thereof), especially to reconstruct inference paths rationally for explanation and self-justification" (Dym, 1985)

The general structure of an expert system is shown in Fig. 1 (Dym, 1985; Tisza, 1995). The components of the expert system include - *input/output facilities*, which allow the user to communicate with the expert system and to use and create a database for a specific problem under investigation; *an inference engine*, which contains rules or reasoning methods, that acts upon the input query and knowledge base, data base, to provide solution and justification to the problem stated. This is like an executive that runs the expert system. It fires existing rules according to the problem stated that not only acts on the knowledge/data base to generate solution, but also updates the knowledge/data base by adding new knowledge/data to it; *a knowledge base*, containing the basic knowledge about the field including the facts, beliefs, procedures, expert opinion etc.; *a knowledge acquisition system*, which does the job of acquiring knowledge automatically from varied resources like libraries, experts, other data bases and so on; *a data base*, which is similar to knowledge base, where in quantified data (e.g., material properties, tool conditions, forming machine parameters etc.) pertaining to that field are located that will be used by the inference engine

during solution generation; *a data base generation system*, which collects the input given by expert and from other resources so that data base can be developed and updated at any stage of expert system. Both the expert and user are linked to each other so that data, knowledge can be easily updated at the development stage of expert system itself. The inference engine and knowledge/data base are not considered always as entirely separate components and there is a lot of overlap between the concepts of both the components (Dym, 1985). *A knowledge engineer*, expert in artificial intelligent techniques, is the one who structures the expert's knowledge, which will be shared by the user. Sometimes the expert himself acts as a knowledge engineer. However in this case, there are two practical dangers worth noting. One is that the domain experts developing their own expert system must learn a lot about knowledge/data representation. This will become clearer in due course, and should not underestimate the immensity of the task. On the other hand, though knowledge engineers learn a lot about the field on which the expert system is built, they should remember that they are not field experts and hence should remain as talented amateur in that field and efficient knowledge base builders (Dym, 1985).
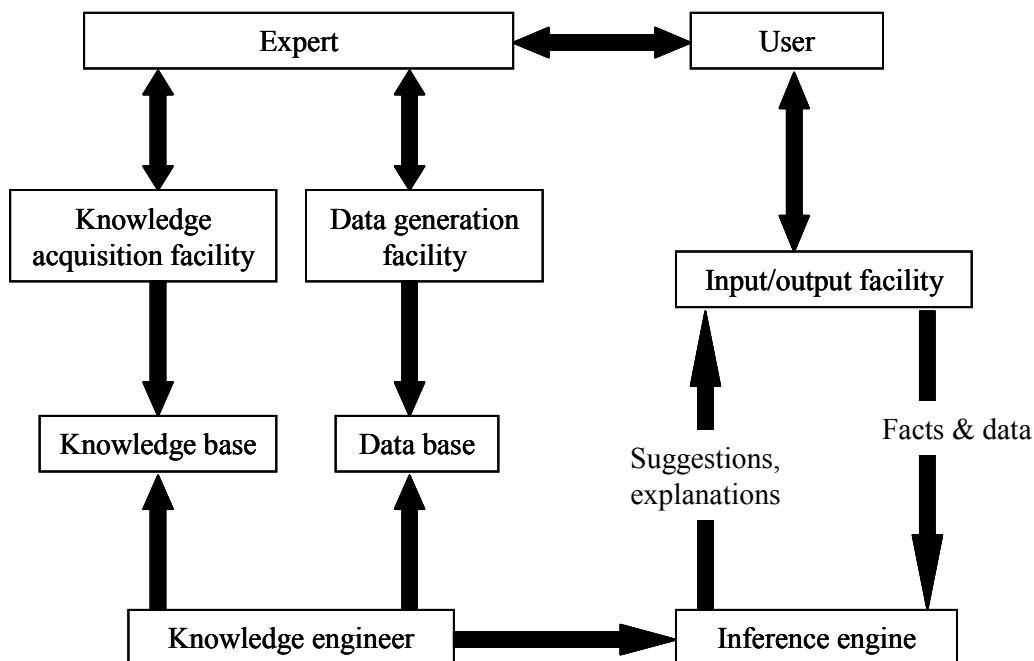


Fig. 1. Basic structure of an expert system (Dym, 1985; Tisza, 1995)

Expert system incorporates three types of knowledge: factual or data oriented knowledge, rule based knowledge, and procedural knowledge (Wang et al., 1991) embodied within a model base. The trend at present is to exploit the convergence of all the three kinds of knowledge representation in a single system. The knowledge base is contained in a set of rules or conditions and a secondary data base. Each production rule represents knowledge about a field, expressed in antecedent-consequent form and a knowledge base may contain hundreds of rules. For example, typical knowledge base can have some 700 rules on maximum load required for forming, press requirements and material properties. There are other ways of knowledge base representation like semantic networks, frame system etc. (Dym, 1985). In semantic network, there are set of *nodes* that represent objects, concepts, events etc. (say engines, hydraulic presses, die, burning) and *links* that connect the nodes

and represent their interrelation (say function of, subset of, part of, in process). Frames are data structures where in, instead of symbols, declarative statements about the objects are included in pre-defined slots. The information can include material properties, engine names, manufacture name, applicable names etc. One can exploit the advantage of each of the representation ideas to have an efficient expert system (Dym, 1985). For instance, production rules, simplify the generation of explanation and prompts the user as it is easy to change antecedent-consequent "IF-THEN" form or rules into a questionnaire. In a rule that states "IF the effective strain rate in the notch to bulk is greater than or equal to 4 THEN the sheet material fails" can be seen as an explanation – "The effective strain rate in the notch to bulk greater than or equal to 4 indicates sheet material failure" or as a question – "Is the effective strain rate in the notch to bulk greater than 4?". Thus an expert system might combine semantic network to relate objects to each other, a frame system that exposes the features of individual objects, and production rules to uncover the properties of individual objects.

Inference engine basically work on inference rules that tries to derive answers from a knowledge base. Backward chaining and forward chaining are the two main methods of reasoning when using inference rules. Forward chaining is data driven, and backward chaining is goal driven. An inference engine using forward chaining searches the inference rules until it finds one in which the 'IF' clause is 'true'. It then concludes the 'THEN' clause and adds this information to its data. It would continue to perform this operation until a goal is attained. An inference engine using backward chaining would search the inference rules until it finds one which has a 'THEN' clause that closely matches a prescribed goal. If the 'IF' clause of that inference rule is not true, then it is added to the list of goals. The selection of inference engine is important and is coupled to the nature of task the system is intended to perform. The selection of inference engine depends mainly on memory allocation for solving the problem, solution space required, tentative reasoning about the domain, and whether or not the data are noisy and varying with time. Initially LISP, the list processing language; Prolog, a logic oriented language are used, but an important trend in the expert system market is the evolution of systems towards more performance oriented programming languages like C, Pascal, Fortran etc. The reason for such a shift is two fold. Not only the inference engines run faster (100 times faster than older LISP based), but also promote ease of integration with other software applications. Nowadays various methodologies are available to construct expert systems in any chosen field. Expert systems can be developed based on rules, knowledge systems, neural networks, fuzzy system, object oriented methodology, case based reasoning, system modeling, intelligent agents, database methodology etc. (Liao, 2005).

Sheet metal forming is one of the important manufacturing processes used predominantly in automotive, aerospace, electronics, electrical, house-hold appliances, and building sectors. This process involves plastic deformation of metallic sheet materials to make sheet metal components for any application. Typical applications can be seen in cars, washing machines, air plane wings, house-hold appliances like gas cylinders, beverage cans, and building roofs. The sheet metal forming processes include deep drawing, stamping, bending, rolling, spinning, cutting, and blanking. Generally the sheet components are made by any one of the mentioned process or combination of processes. Most of the sheet forming processes requires a sheet material to be formed; tools like die, punch, sheet holder, draw bead, mandrel and machines to perform the operation. The material properties like chemical composition, microstructure, texture; mechanical properties viz., yield strength, ultimate

tensile strength, elongation; formability factors like strain hardening exponent, anisotropy index, strain path; process parameters like friction conditions between sheet and tools, working temperature, strain rate, blank holding force, draw bead restraining force; and finally tool (die, punch) geometry influence the sheet forming behavior in a compounding fashion.

In industrial practice, the sheet forming engineer should be aware of the process sequence, tool design aspect, process parameter design, sheet material behavior, blank design, and machine usage for successful fabrication of sheet parts. For example, the process sequence required for single stage and multi-stage components are different. Similarly the tool design requirements for making a sheet product made of un-welded blank and tailor welded blanks (two or more sheets of different thickness, grades etc. welded before forming) are not same because of the presence of different thickness, grade sheets, and weld line movement. The properties and behavior of the sheet material play a vital role in deciding its applicability in making a sheet part. The material behavior requirement will differ from product to product and hence knowledge on materials used is essential.

It is known that the parameters mentioned above determine the sheet formability in a synergistic manner. Designing sheet product for a typical application will be successful only by knowing the appropriate material behavior, process parameter design, process sequence, tool and machine design, and specific issues pertaining to advances in material and forming technology. Predicting these sheet stamping parameters in advance will be helpful in determining the formability of any sheet part. In order to fulfill this requirement, one has to perform lot of simulation trials and experiments separately for each of the cases which is time consuming and resource intensive. Automotive sheet forming designers will greatly benefit if 'expert systems' are available for sheet stamping that can deliver its forming behavior for varied material, process and tool conditions. Developing an expert system or knowledge based system, especially in fields like material forming and deformation behavior, die design, casting design, machining processes, metallurgy etc. is of interest to manufacturing and design engineers. In this chapter, the expert system and its application to predict the sheet metal formability in terms of tool, process and material design will be discussed through published literature. The expert system based analyses in sheet process design, process planning, strip layout design, tool design, material forming will be focused. The various techniques used to develop expert systems will be presented. The available expert systems and their applicability in sheet forming field will be highlighted. Finally an expert system research scheme that is being developed to predict the formability of Tailor Welded Blanks (TWB) will be discussed with case study results.

## 2. Process design

The sheet forming process includes operations like cup drawing, stamping, stretching, bending, ironing, spinning etc. that can be performed by many forming techniques using die, punch, blank holder and other tools. The purpose of process design is to predict and design the sheet forming process at the 'design stage' of a component manufacturing. For instance, the number of stages required and amount of cup drawing that is possible in each stage of a multi stage deep drawing process can be predicted at the design stage itself for successful completion of the sheet product. Similarly an intelligent process design would include closed loop control of blank holding force for changing friction conditions during forming. There are many expert systems (ES)/knowledge based systems (KBS) available for

sheet process design. The sheet forming processes and techniques by which process design is performed is described here.

Mostly bending, deep drawing, and general stamping (say industrial sheet parts) are concerned for ES development. The applicability of expert system in enhancing the bending process design was demonstrated by Lin and Peing (Lin & Peing, 1994). In this, a prototype of sheet metal bending expert system is developed. This ES is capable of predicting the pressure, width of die shoulder, minimum flange length and product inner radius for a given set of bending and material input. With this data, the punch and die numbers are inferred and their drawings are given as result using the graphic mechanism in the ES. This is presented with an example of V-bending (Lin & Peing, 1994), where the bend angle and material of the sheet were given as input. The predictions are based on 'IF-THEN' rules within the ES that are constructed with the help of lot of qualitative data base and experience based knowledge base. Here PC/AT was chosen as the computer hardware and artificial intelligence language LISP (LISt Processing), which has a powerful symbol processing ability, was used as system construction language. Like wise, an Intelligent Design Environment (IDE) which is a knowledge based system, was developed (Palani et al., 1994) that provides a method of integration, automation and optimization of sheet metal forming. IDE integrates knowledge base, finite element analysis and geometric modelers in AI framework. For the inputs like geometry of the sheet and material, process constraints given to the system, the outputs like optimized die geometry, material and process parameters for successful forming operation will be delivered. This was demonstrated in their work (Palani et al., 1994) by analyzing automotive inner panel. In this, 'IF-THEN' rules like "IF strain distributions should be uniform, THEN increase the critical radius, AND change the lubrication; OR change the blank size and shape" were used and their IDE can diagnose 'splitting' failure. It can effect changes in material properties including thickness, friction, BHF, drawbead geometry, blank size for evaluating the optimum forming operation. In the case of automotive inner panel, the final decision on modifying sharp corners improved the strain distribution and die geometry. A knowledge based process layout system (CAPP) based on decision tables (Sing & Rao, 1997) was constructed for axi-symmetrical deep drawn cup which can deliver a set of highest feasible process parameters for die design purpose for which the final deep drawn product is required as input. In this CAPP system, the knowledge base is represented by 'production rules' and 'frames'. The production rules are based on popular 'IF-THEN' rules like "IF First Draw of mild steels THEN the maximum drawing ratio is 2.2". These rules are represented as decision tables, which makes it very different from other KBS, where in the user can suggest 'Yes', 'No' or 'Don't care' for many rules corresponding to 'condition stubs' entries. The condition stub mainly includes the final cup description like Horizontal elements included, Vertical elements more than one, Concave elements included and many more. Similarly the 'action stub' contains different types of drawn cups like flanged cup, hemispherical cup etc. for which once again 'Yes', 'No' or 'Don't care' entries are suggested for various rules. This system has fuzzy inference like "R1: IF thickness is $T_i$ THEN drawability is $M_i$, for i = 1…n" which relates drawability and thickness range. Here 'R1' is a fuzzy relation mapping thickness ($T_i$) and drawability ($M_i$). '$T_i$' and '$M_i$' are subsets of sets A (thickness range) and B (drawability) on U and V universe, respectively. These fuzzy inferences are also represented as decision tables containing 'condition stubs' like thickness range, cup without flange and 'action stubs' like drawing rate. These decision tables are made from 'frames', having

drawing rates for different types of cups. This system is tested with a 'flanged cup' that is given as input. The system basically evaluates, through analytical models and rules, the blank development, blank layout design, number of draws, clearance, air vent hole, tool radii, and BHF and delivers as output (Sing & Rao, 1997). A component check KBS was made (Shailendra Kumar et al., 2006) which is once again based on 'IF-THEN' rules made from details available with designers, manufacturers, and hand books that can suggest the feature based outputs based on inputs registered about the sheet material and product. This system makes use of Auto LISP and Auto CAD for data representation. An intelligent design system for multi stage deep drawing is also available (Choi et al., 2002). The capability of the system was illustrated with the help of single stage deep drawing, three step deep drawing, and deep drawing with embossing. A user friendly, menu driven decision support system (DSS) was also developed by Faura et al. for sheet metal blanking operation (Faura et al., 2001). The DSS consists of relational database having technical-economic information and collection of processing algorithms created to apply the know-how to the model. The technical knowledge is based on many experiments relating empirically the blanking clearance with edge draw-in, the penetration depth of cracks, and burr height. By providing dialog boxes to facilitate data input and display of output results, it is possible to predict the impact of blanking parameters on the cost and quality (Faura et al., 2001).

Other than the ES described above, there are expert systems that are helpful for web based manufacturing. These ES are generated and used through World Wide Web (WWW) for part and process design. The user can virtually sit in a remote place performing simulations and analyses and finally design the process and part as per their requirement. A virtual design system (VDS) for sheet forming was developed by Hindman and Ousterhout (Hindman & Ousterhout, 1998). This system has web based interface in 'fill out forms' where the user can input the details of forming like material properties, bend allowance, bend radius etc. The forms are framed by html programming and submitted by the user for further processing. The user can also transfer a part to remote shop through file transfer protocol (FTP) for fabrication with worry-free transfer of sensitive data indicating standard security. The VDS is not only demonstrated for 'bending' where final die design is performed, but also for spring back and deep drawing. The system works not only on equations, but also has space for real time simulations of the manufacturing processes. An interesting and efficient Distributed Multi Agent expert System (DMAS) was developed for sheet forming by Karayel and Ozkan (Karayel & Ozkan, 2006). DMAS is a system that operates in an integrated manner with all agents to realize a common objective. Each agent is an expert system containing rules and knowledge base that are at distant places connected through internet. The model proposed consists of knowledge management agent (KMA), product description agent (PDA), calculating and dimensioning agent (CDA), artificial intelligence agent (AIA), die design agent (DDA), assembly and disassembly agent (ADA), operation planning and cost agent (OPCA), validation and verification agent (VVA) and design mediator (DM), all are connected and have specific tasks. For example, the job of PDA is to describe sheet metal component geometry when the design is realized using multi agent system. The sheet metal parts are represented and stored as complete geometric and topological solid in 3D. Such a representation is suitable for display and any engineering analyses and simulation can be performed. The PDA also takes care of feature representation like holes, curvatures, bends, flanges, notches etc. Similarly the purpose of

VVA is to observe any faults and discrepancies in the manufacturing lot and notifies them to KMA. This agent prepares a global report on all faults and their degrees as well. Similarly all other agents are meant for specific purpose. This system will be implemented fully for efficient running of the sheet metal expert system (Karayel & Ozkan, 2006).

There are expert systems/knowledge based systems based on neural network that control the sheet forming processes. One best example would be the adaptive control system developed for controlling the deep drawing process (Manabe et al., 1998) where in neural network is used for initial process parameter identification. In this, chosen input parameters are trained with optimized network architecture and output material properties like strain hardening exponent (n), plastic coefficient (F), anisotropy coefficient (R) are identified. The predicted n, F, R values is used to evaluate the friction coefficient, fracture/wrinkle limit Blank Holder Forces (BHFs) using available equations.. The BHF is optimized for varying friction conditions during the drawing process by in-process sensing information. Corresponding to the current frictional condition, the fracture and wrinkle limit BHFs are modified and the BHF path scheme can be optimized accordingly. This adaptive system, where the BHF is updated continuously with changing friction conditions, was demonstrated by monitoring thinning distribution of wall region of the cup and comparing it with the constant BHF case. The thinning behavior is found to be improved in the case of adaptive deep drawing system (Manabe et al., 1998). Summing up one can say that, deep drawing, bending and stamping of industrial sheet parts are generally modeled using expert system for planning and controlling the sheet forming process. Also the expert systems used for process design are mainly based on production rules (IF-THEN rules), web based process control strategies, and neural network based data modeling and process control or a combination of different techniques. In the case of ES based on rules, predominantly AutoLISP is used for data handling, in conjunction with AutoCAD for graphics representation. One can also refer the state of the art report by Duflou et al. (Duflou et al., 2005) on computer aided process planning for sheet bending.

## 3. Process planning and process sequence design

Table 1 shows the details of process planning and sequence design in sheet forming. Most of the literature suggests that 'IF-THEN' variety is used for knowledge base implementation, while few of them are based on specified algorithms, design rules, fuzzy set theory etc. The sheet operations considered are axi-symmetric forming (like drawing), blanking, bending, general stamping sequence, and specific sheet parts like rotor and stator. The KBS developed are validated with industrial shop floor trials having simple to complex geometries.

## 4. Strip layout design

The strip layout design exercise is like a tailor's job. Here the tailor maps the different parts of the shirt and makes a layout as per the customer's choice, efficient cloth utilization and fashion. Later the layout is used for stitching shirts. Similarly strip layout involves laying out the material strip that is passed through the press in order to produce stamping, exactly as it will appear after all operations have been performed on its parts (Ann & Kai, 1994). The strip layout design is an art by itself, wherein the experience and practice in the light of reality decides the quality of the stamped sheet product. In early days, the strip layout was done manually. The trial and error method followed resulted in maximum material

| S. No. | Publication details | Process details in expert system | Purpose of expert system | Technique used for developing expert system | Knowledge generation modes | Syste delive |
|--------|--------------------|----------------------------------|--------------------------|---------------------------------------------|----------------------------|--------------|
| 1 | Ong et al., 1997 | Brake forming; tools having punch, flat sheet, bend sheet, die, finger stops | CAPP system for process sequence design | Fuzzy set theory | -- | Bendi seque |
| 2 | Sitaraman et al., 1991 | Axi-symmetric sheet forming | Knowledge based system for process sequence design | IF-THEN rules variety like "If the input object geometry is axi-symmetric, then the blank is circular"; Knowledge base & inference engine in Prolog, Analysis module in Fortran | Literature, industrial brochure, industrial visits, experts opinion etc. | Proce with i produ |
| 3 | Uzsoy et al., 1991 | General sheet parts giving importance to bending & hole punching | Process planning for sheet forming operations – binding & hole making | Rule based KBS, IF-THEN variety like "If there is a hole on a bent edge, then do the hole before the bend"; implemented using Turbo prolog | Discussion with die designers & process planners, die design & forming handbooks | Bendi makin with o in wh proce |
| 4 | Gupta et al., 1998 | Bending operations | Automated process planning for robotic sheet metal bending press brakes; system contains central operation planner, tooling & set up planner, grasping planner, motion planner | State-space search formulation based on A* algorithm; sequence decision is based on cheapest total time (total time = execution time + repositioning time + set up time); specific modules are based on rules & constraints; Implemented using C++ | -- | Opera seque robot neede layou positi robot plans makin |

Table 1. Details of expert systems for process sequence and planning design in sheet forming

| 5 | Park et al., 1998 | Axi-symmetric deep-drawing products based on G&TR strategy | Computer aided process planning design system – Pro_Deep, having four modules – input, geometrical design, test & rectification & user modification | IF-THEN rules based system; Implemented in AutoLISP on the AutoCAD | Plasticity theories, handbooks, experimental results & knowledge of field experts | Pro with obje pro - dr BHI cup coe |
|---|---|---|---|---|---|---|
| 6 | Choi & Kim, 2001 | Making rotor and stator parts with blanking operation | CAD/CAM system having nine modules – input and shape treatment, flat pattern layout, production feasibility check, blank layout, strip layout, die layout, data conversion, modeling, post processing | Design rules for blanking or piercing like 'If holes to be pierced are close to each other or are not related to function, the holes are distributed for many processes' and formulae like $P_{face} = F_d / L_{Shear}\, t\, BLR$ | Plasticity theories, experimental results & knowledge of field experts | Ger auto data tool requ che dim acc dra lay |
| 7 | Rajender Singh & Sekhon, 2005 | Sheet metal operations like piercing, blanking, notching, forming, cropping, shearing, trimming, clipping, parting, slitting, perforating, bending & drawing | Process planning for small and medium scale sheet metal industries based on rules (150 nos.) implemented in AutoLISP on AutoCAD | IF-THEN rules like 'If, 0.01 < minimum accuracy needed on part in mm< 2.0; and feature required on part = Line cut then, required operation=slitting' | Knowledge of process planners, die designers, Handbooks, monographs, journals, & industrial brochures | Opt plan met |
| 8 | Ciurana et al., 2006 | Meant for drawing operations in sheet forming | Computer aided process planning in sheet forming based on activity model | Based on design rules implemented in visual basic with GUI, & application development environment | Discussion wit process planners, scientific community, enterprises | Dra step of s sele die |

utilization and is still followed in many small and medium scale industries. Nowadays there are many computer aided systems that takes care of the strip layout design even in complex parts. A knowledge based system for strip layout design was presented by Ann and Kai (Ann & Kai, 1994), includes two important modules viz., part orientation module and sequence of operation module. The part orientation module is meant for providing recommendations about the appropriate 'part orientation' in the parent strip, while the sequence of operation module is mainly to suggest the proper design in terms of strip layout in each of the four operations of the progressive die – piercing, blanking, bending and trimming. The 'part orientation module' has few sub-modules like *customer's specification*, where the user can opt for any strip orientation; *material optimization*, in which the KBS will decide the appropriate orientation, part-to-part and part-to-edge distances, space for pilot hole and their locations; *type of end product removal method*, where the rules are meant for checking the type of end-product removal methods employed to remove the final stamped part from the scrap strip; *smooth strip movement through the die*, contains rules to check whether the strip is rigid enough to move through the die smoothly without any obstruction due to collapsing of the strip. Subsequently, it will inform the user to orientate the strip in a compromised orientation. In such cases, the part-to-part and part-to-edge gaps will have to be increased for more strip rigidity at the cost of increased material wastage. The four forming operations in the 'sequence of operation module' contain many phases in each of them. In the case of 'blanking', the phases – shape of blanking portion, location tolerance of two blanking portions, distance between nearer edges of two blanking portions, dimension tolerance, and strip movement through the die are present. The other forming operations also contain similar phases. Both the modules work as per the rules framed through 'decision tables' (Ann & Kai, 1994). Finally the applicability of the knowledge based system is demonstrated with an example. A strip layout design for sheet metal on progressive die (Kumar & Singh, 2008) is also based on 'IF-THEN' rules. In this, many rules for strip layout design and conditions for piloting operations are listed. The rules are coded in AutoLISP and interfaced with AutoCAD for layout modeling. Finally the expert system is tested for brass sheet metal for its validity. An interesting work was conducted (Nye, 2000) which is aimed to design strip layout for optimal raw material utilization based on the '*Minkowski sum*'. According to this concept, if two blanks are considered, 'A' and 'B', they will overlap only if A⊕(-B) contains the origin. To avoid overlapping between blanks, they need to be translated relative to each other. This relative translation causes a similar translation of the Minkowski sum, and when the Minkowski sum no longer contains the origin, the blank overlap is eliminated. This property leads to the mapping of '*strip pitch*' – distance to the edge of the Minkowski sum, and '*strip width*' - maximum perpendicular distance between the strip longitudinal axis (through the origin) and the perimeter of A⊕(-B). The material utilization can be easily calculated as a function of blank orientation, once the Minkowski sum is generated (Nye, 2000). The strip orientation in the parent sheet is represented by 'sweepline' vector, which sweeps through a range of orientations and is anchored at the origin. The raw material utilization, strip width and pitch were evaluated with the help of expressions derived. This concept of strip layout design is demonstrated by T-shaped blank, for which the optimal blank orientation occurs at $\theta$ = 18.43° and 161.56°, with a corresponding material utilization of 53.3% (Nye, 2000). The metal stamping layouts using analytic hierarchy process method is also an important contribution for strip nesting design (Rao, 2004). To explain briefly, this method necessitates the decision makers to develop a

hierarchical structure for the factors and to provide judgments about the relative significance of each of these factors and specifying a preference for each decision alternative with respect to each factor. It provides a ranking order indicating the overall preference for each of the decision alternatives (Rao, 2004). This method is helpful in selecting suitable strip layout from a large number of available strip-layouts for a given metal stamping operation. From the above references, it can be said that 'IF-THEN' rules based strip layout design system are predominantly used, while stand alone efficient algorithms for strip nesting are also developed to improve the skill set of stamping designers.

## 5. Tool design

This section focuses on the development of expert system or knowledge based system for designing the press tools (like punch, die etc.) used for sheet stamping operation. Emphasis is given on the input-output details of the system, structure and design methodology used in the system and case study illustrations. It is observed from the selected references that progressive die design involving varied forming operations, tool design for bending, drawing die design and specific applications like industrial parts, roll forming etc. are dealt with extensively. An attempt has been made to automate the progressive metal stamping die design through knowledge base approach (Cheok et al., 1994). The main input to the system is the 3D representation of a product and the system delivers the die to transform the strip into the stamped (or final) product. Some of the crucial issues to be addressed while automating the die design are work shape representation, die components representation, punch shape recognition and decomposition, staging and assembly of die components, operation simulation of various die operations. In the work shape representation, using existing CAD/CAM system, a 2D drawing of the strip layout can be obtained. In order to convert this data into useful information like detailing the topological relations of the various features of the work shape, semantic network based Constructive Solid Geometry (CSG) representation of the workpiece is considered in the KBES. In CSG, the external profile and internal features of the workpiece are represented as 'nodes' where the geometry details about the work shape is stored. There are other decisions pertaining to die design like holes that can be punched in same or different stations are registered as 'slots' like Box515, Cyl516 etc. It can be understood that the CSG tree of a workpiece provides a wealth of topological information that can be processed by declarative knowledge statements in a KBES to guide the synthesis of a die. In the case of punch profile recognition, the KBES contains twelve different geometric features that are used to select the usable punch profiles for internal profiles. If a suitable match cannot be achieved, the system will decompose the profile of the internal feature into a combination of the pre-defined shapes using a 'divide and match' approach. This is achieved by dividing the original punch profiles into a combination of smaller profiles of standard dimensions that can be included in the twelve punch shapes available in the KBES. The 'divide and match' approach is guided by number of condition statements in the KBES. Similarly the selection of punches for external profiles is also governed by few rules and procedures. In order to represent the die components, model based reasoning (MBR) approach is followed. MBR requires die components to be represented in such a way that their geometrical modeling information, their parametric dimensions – stored in database, and the algorithmic mathematical functions for design can interact with declarative knowledge statements governing the synthesis of these components. The standard die components can be represented by part identification and

parametric dimensions. The data on its location and orientation is also provided when inserting into the die assembly. The non-standard die components are complex and hence need more information to describe them that depends on other components in the sub-assembly too. As an example, the topology of a punch plate depends on the size and location of the punches it carries, their mounting arrangements, and the size and location of the fasteners and dowels. In this, rules and functions are defined that require resolution of conflict and that do not require resolution of conflict (Cheok et al., 1994). The staging of punch operations and selection of pilot holes are based on IF-THEN rules. Finally all the different components of the KBES are implemented on a PC that uses AutoCAD extension modeling for solid modeling and Kappa PC to provide the object oriented programming capabilities. The routines that convert geometries into features are written in C++ for efficient working. Similarly 'logic programming' has been used to plan the process in sheet forming with progressive dies (George-Christoper et al., 2005). The product category targeted is U-shaped with bending and cutting operation predominantly. This expert system consists of three modules like *part design, process planning, and tool design*. The data gathered is introduced into the system in the form of IF-THEN rules. Questions are posed to the customer to obtain all necessary information, related to geometry, machine tool characteristics, etc. Clarifications, explanations, intermediate results and prompts for corrections are in a textual format, and the user is also supported by information from files and figures in order to answer system questions. The code is developed in Amzi Prolog and consists of about 3000 lines. The logic programming using Prolog is a declarative language. A program consists of Predicates, each containing a functor (name) and a number of components (arguments). Each predicate is defined by a clause which can be a fact or a rule. A Prolog program is initiated by a high-level question, which triggers some predicates, which in turn may trigger more, thus propagating the question to deeper levels. In order to obtain a solution to the question asked, a path leading from deeper levels to the highest level should be proven to be valid. This path spans several predicates involved in providing the high level solution. The process of finding a solution is a searching process, which needs to be conducted efficiently and smartly. In part design module, there are about 16 main rules that govern the design process. These generic rules are used to evaluate the important parameters like part thickness, type of material, bending tolerance, flanged hole characteristics etc. that determine the manufacturability. A clause reads 'If the actual distance is above 3 mm and greater than 1.5 times the sheet thickness, then there is no problem' for steel material in the case of minimum distance between any features. In process planning module, there are similar rules that guide the entire process. The knowledge representation is based on predicates that contain information about the part state and the list of processes that have to be performed. Similar to part design, tool design module also functions with the help of rules like 'For processes executed on the vertical plane, side cam mechanisms should be used'. They are executed by 'facts' which contains the query like 'How large is the die?' with choices of 'small, medium, or large' (George-Christoper et al., 2005). This system is illustrated with an industrial example of forming strip in progressive die and the design correlates well with the actual design.

Bending tool design is another important issue to be discussed. There are expert systems based on 'rules' for bending tool design. There are few based on neural network too. Neural network based bending tool design (Lin & Chang, 1996) based on back propagation network requiring machine inputs like pressure capacity of the bending machine, the bending length of the product, the open height of the die, and the punch stroke, is efficient in designing the

final tooling for bending using pattern classification capability of the BP neural network. The ANN modeling is performed under digital and conditional attributes mode. For the inputs specified, the output of the system is the bending machine code containing information like pressure capacity, maximum stroke, bending speed, motor power, number of cylinders. Esche (Esche et al., 1996) developed a process and die design methodology for multi step forming (say deep drawing) of round cups. ASFEX – Axisymmetric Sequence Forming Expert System was developed initially in MPROLOG. Later this was transferred to C/C++ environment on UNIX platform. The main aim of the system is to develop the process sequence, especially for multi step forming operation, and tool configuration for the whole forming process. In process sequence design, both geometry and formability based decisions will be taken. The process is then analyzed by finite element simulation to check the feasibility of the production. Later tooling for each stage of forming operation will be decided. There are standard steps and rules to evaluate the forming sequence in the system. The system is demonstrated through a sample simulation of round cup made of Aluminium alloy material and compared with experiments. The radial strain and thickness are also compared with experiments and the results are found to be satisfactory (Esche et al., 1996). Similar expert system for drawing dies is seen in (Lin et al., 2008) also, except that the design is based on parametric design system. The efficiency of the system to improve the design quality is demonstrated through inner wheel housing part.

Roll forming is a continuous bending operation, in which the ductile sheets are passed through consecutive set of rolls, or stands, each performing only incremental, prescribed bending operation, till the actual cross-section profile is obtained. This process is particularly suitable for long strips of large quantities, with minimum material handling. Expert systems are available for roll forming pass design that are based on neural network and shape element idea. In the case of neural network based ES (Downes & Hartley, 2006), Radial Basis Function (RBF) is used for training the input data. The example taken for study has four bends and three parallel surfaces connected by slanting sides. The four bends are quantified by four angles $\varphi_1$, $\varphi_2$, $\varphi_3$, and $\varphi_4$ that forms input for ANN. The ANN system predicts the output which is the location of the design data. There are almost 63 different locations for the design data that are present with the industrial collaborator. Classification of the data depends on a number of section parameters, such as the total number of bends, sheet thickness and sheet width prior to forming. The system developed in this project searches the 63 storage locations to find integral shapes. If a similar shape is identified it will have the same number of bends, and each corresponding bend angle $\varphi_1$, $\varphi_2$, $\varphi_3$, and $\varphi_4$ will have a similar value (Downes & Hartley, 2006). In the case of shape element idea (Shen et al., 2003), the roll formed part is visualized as combination of forming of each part. The relationship of space geometry is relatively fixed and the forming steps of these parts are almost same. These parts are called as 'shape element'. The validity of the system is presented with few examples like roll forming with symmetrical section, non-symmetrical section, welded pipe, and complex shape of steel window section (Shen et al., 2003). There are expert systems for press selection (Singh & Sekhon, 1999) also. The press selection expert system belongs to IF-THEN variety following forward chaining method. The rules are based on information obtained from experienced designers, shop floor engineers, handbooks, journals, monographs and industrial brochures. This system suggests the press tonnage, recommended presses, optimum press and unit manufacturing cost for the posed inputs or queries (Singh & Sekhon, 1999). There are expert systems for specific applications like die design for automotive parts (Lin & Kuo, 2008), progressive die design for electron gun grid

parts (Park, 1999) etc. A fully integrated CAD/CAM/CAE system was developed (Lin & Kuo, 2008) for stamping dies of automotive sheet parts that functions with the help of high end softwares like CATIA for layout diagram design and die structure analysis, STRIM software for die face design, DYNAFORM for formability analysis and CADCEUS for tooling path generation and simulation. Finally the stamping die development is illustrated for the 'trunk lid outer panel' (Lin & Kuo, 2008).

## 6. Material forming

Table 2 details the expert/knowledge base system (or models) to predict the material forming behavior like flow stress, shear strength, material failure, mechanical properties, residual stress etc. The materials considered are steel, Al alloys, Zircaloy, welds, and processes like rolling practice, shot peening are modeled. Most of the techniques used are ANN based and few others are based on design rules, specific theories and algorithms. ANN is found to reproduce the results with maximum accuracy showing its efficiency over rule based systems. The material behavior thus predicted is of academic importance and industrial practice as well. TENSALUM, an expert system used to predict the stress-strain data of Al alloys, implemented in industries, shortened the testing time by approximately 300-400% in comparison with other programs in market (Emri & Kovacic, 1997). Similarly the KBS for materials management developed by Trethewey et al. (Trethewey et al., 1998) which is demonstrated for the selection of coating for marine applications is of practical importance. More details on the KBS for material forming are given in table 2.

## 7. Expert system for tailor welded blanks (TWB) forming

Tailor Welded Blanks (TWB) are blanks of similar or dissimilar thicknesses, materials, coatings etc. welded in a single plane before forming. This welded blank is then formed like un-welded blanks to manufacture automotive components, with appropriate tooling and forming conditions. Applications of TWB include car door inner panel, deck lids, bumper, side frame rails etc. in the automotive sector.

Some of the advantages of using TWBs in the automotive sector are: (1) weight reduction and hence savings in fuel consumption, (2) distribution of material thickness and properties resulting in part consolidation which results in cost reduction and better quality, stiffness and tolerances, (3) greater flexibility in component design, (4) re-usage of scrap materials to have new stamped products and, (5) improved corrosion resistance and product quality. (Ganesh & Narasimhan, 2008). The forming behavior of TWBs is critically influenced by thickness and material combinations of the blanks welded; weld conditions like weld orientation, weld location, and weld properties in a synergistic fashion. Designing TWB for a typical application will be successful only by knowing the appropriate thickness, strength combinations, weld line location and profile, number of welds, weld orientation and weld zone properties. Predicting these TWB parameters in advance will be helpful in determining the formability of TWB part in comparison to that of un-welded base materials. In order to fulfill this requirement, one has to perform lot of simulation, experimental trials separately for each of the cases which are time consuming and resource intensive. This can be avoided if an 'expert system' is available for TWBs that can deliver its forming behavior for varied weld and blank conditions.

| S. No. | Publication details | Purpose of expert/knowledge base system | Material details | Technique used | Testing method & base details |
|---|---|---|---|---|---|
| 1 | Emri & Kovacic, 1997 | To test the mechanical properties of Al and Al alloys. The ES is called as TENSALUM | Mainly for Al and Al alloy sheets; Can be updated for materials like polymers, wood, textile fabrics & leather | -- | Tensile testing is pe based on the data b including test condi material, product fo elongation, temper condition, mechanio property limits mad various resources |
| 2 | Qiang et al, 2006 | ES named as IndBASEweb-HT is an intelligent database web tool system of simulation for heat treatment process. This system is capable of performing Metallo-thermo-mechanical coupled analyses. | Meant for metallic materials suitable for heat treating conditions | Data mining technology is used to analyze the data from different aspects and finding correlations or patterns among dozens of fields in large relational database. | Database is develop through technical re & experiments |
| 3 | Trethewey et al., 1998 | Generic model of the knowledge structure of materials performance, viz., materials selection and failure analysis, has been developed | -- | Certainty theory is used to judge exact inferences. Certainty factor is defined as a measure of belief and disbelief based on evidence is used as decision making index. Visual Basic is used to create inference engine and microsoft Access for the database. | Data base contains performance knowl corrosion details. Th retrieval is done thr case based reasonin data generated is ob from domain exper knowledge enginee transferred to comp through expertise e shell. |

Table 2. Details of expert systems in material forming

| | | | | | |
|---|---|---|---|---|---|
| 4 | Calcaterra et al., 2000 | Prediction of mechanical properties of spheroidal cast iron | Spheroidal cast iron was made for different chemical composition and other casting parameters that has become input for the model | Neural network is used to build the model. The NN with different hidden layers and neurons were evaluated for investigation. | Many test samp made using var composition an parameters and for UTS evaluat forms the data f the ANN model |
| 5 | Rao & Prasad, 1995 | Flow stress prediction during hot deformation | Medium carbon steels tested under different strain, strain-rate and temperatures | ANN based on back propagation network with two hidden layers and 40 hidden neurons | Experimental da to train the netw strain-rate & ter were input para predicting the fl |
| 6 | Shashi Kumar et al., 2007 | Flow stress prediction during hot deformation | Different carbon steels with varying carbon equivalent at different strain, strain-rate and temperature | ANN based on recurrent self-organizing neuro fuzzy networks | Experimental ru the range of 100 Strain, strain-rat temperature we parameters for flow stress (σ) |
| 7 | Karatas et al., 2009 | Study the impact of shot peening on residual stresses and predicting the same | Shot peened steel sample of C-1020 material | ANN based on back propagation learning algorithm with one hidden layer having four neurons; | Experimental re used as training Shot peening ar surface as input stress as output |
| 8 | Vasudeva n et al., 2005 | Predicting the shear strength of stainless steel & Zr-2 welds | Austenitic stainless steel welds and Zr-4 welds | Multilayer preceptron based ANN is adopted to model the system; 6-20-2 architecture with 20 neurons in hidden layer | AE signals gene the spacer pad v used as input fo |

The main objective of the present research work is to develop an 'expert system' for welded blanks that can predict their tensile, deep drawing, forming behavior under varied base material and weld conditions using different formability tests, material models, and formability criteria. It is decided to develop the expert system in conjunction with Artificial Neural Network (ANN). The data required for the expert system development is obtained through simulations only. PAM STAMP 2G a finite element code is used to generate data for varied base material and TWB conditions. The proposed expert system design for TWB forming is shown in Fig. 2 (Veera Babu et al., 2009). This expert system is expected to involve three different phases. All the three phases have a design mode of operation where an initial expert system is created and put in place. The created expert system is then operated in use and update mode.

In Phase 1, while the expert system is designed, a range of material properties and TWB conditions are defined within which ANN models are developed to predict the results as discussed in the earlier sections. The same phase while operated in the usage mode, the user selects base material properties and TWB conditions within the chosen range for application and prediction of formability. In this phase, user can select different material models viz., strain hardening laws and yield theories to predict the forming behavior. There is no single strain hardening law and yield theory that can predict the forming behavior of TWBs made of varied sheet materials accurately. Hence in the design mode, ANN models will be developed to predict the forming behavior using different material models. As a result, in the usage mode of the expert system, the user can opt for desired material models to predict the forming characteristics.

Phase 2 involves selecting the forming behavior to be predicted for chosen base material and weld conditions. In the design mode, tensile behavior, formability characteristics, deep drawability of welded blanks will be simulated by standard formability tests. Different category of industrial sheet parts will be simulated and expert system will be developed to predict their forming behavior. The global tensile behavior of TWB viz., stress-strain curve, yield strength, ultimate tensile strength, elongation, strain hardening exponent and strength co-efficient will be monitored. Formability properties like forming limit curve, percentage thinning, dome height at failure, failure location will be predicted by Limit Dome Height (LDH) test and in-plane stretching tests using different limit strain criteria (say M-K analysis, thickness gradient based necking criterion, effective strain rate criterion, semi empirical approach etc.). Cup deep drawability response like draw depth, weld line movement, punch force, failure location, earing and draw-in profile can be predicted. Also it is planned to develop ANN model and expert system for predicting the formability of application (or industry) specific sheet parts made of welded blanks. In the usage mode, the user selects the type of test results that is required to be predicted.

In phase 3 the training, testing, usage and updating the ANN predictions with simulation results will be performed. In the design mode operation, various ANNs are created and validated for predicting the forming behavior (enumerated in Phase 2) for various combination of material properties and TWB conditions and constitutive behavior (enumerated in Phase 1). In the usage mode, the user predicts the required forming behavior for an initially chosen material, TWB condition and constitutive behavior. If the forming behavior predicted is not indicative of a good stamped product, the user changes the above said conditions till he gets satisfactory results. In the absence of this expert system, the user will have to run time consuming and resource intensive simulation for this iterative stage. In
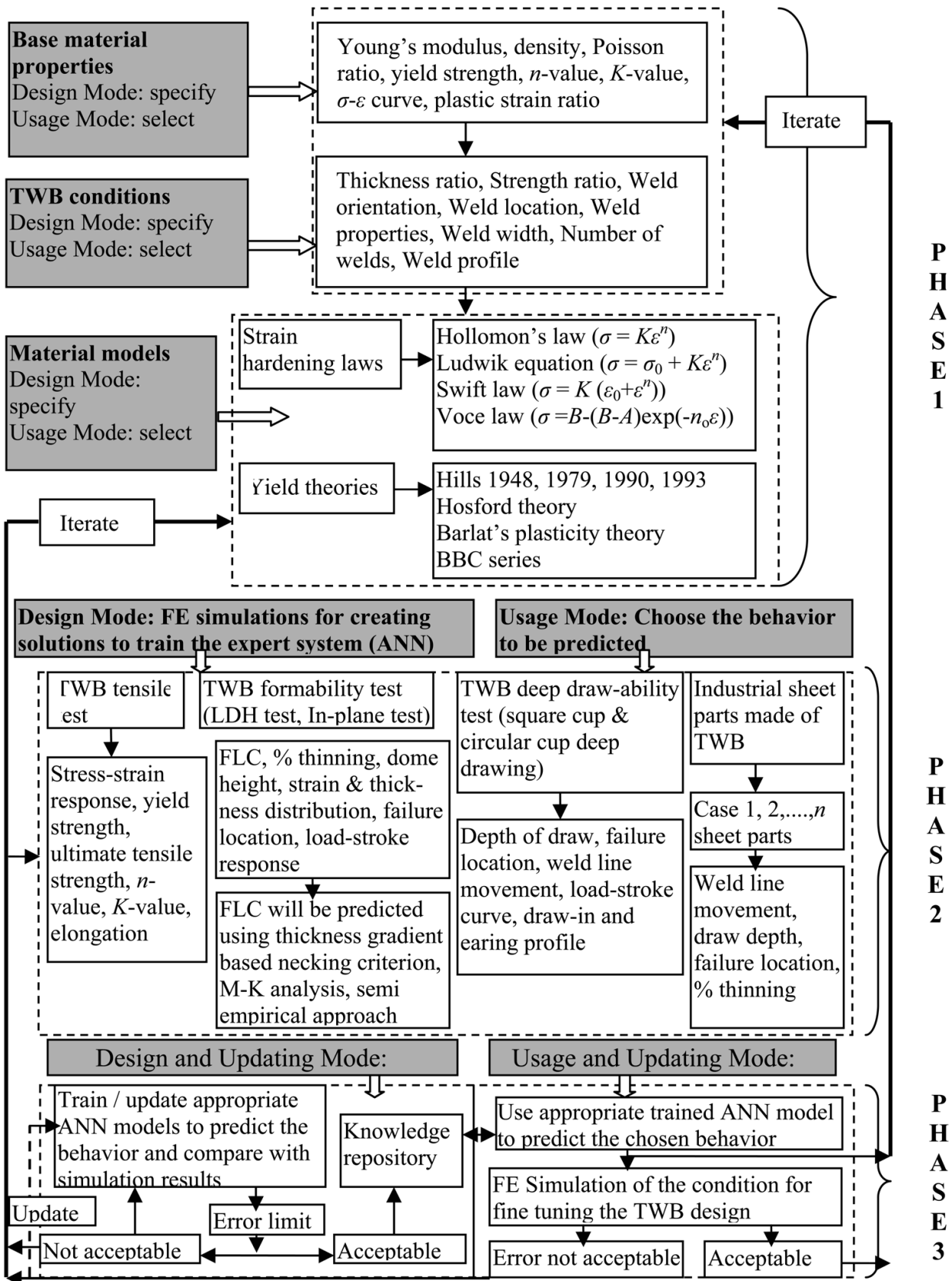
Fig. 2. Expert system proposed for TWB forming (Veera Babu et al., 2009)

the usage mode, if the results are not with in the expected error limit, the user will have the choice of selecting different material models for predicting the required forming behavior as described earlier and/or the expert system is updated with the specific case by updating the ANN models to predict the case within acceptable error limits. In this way, the expert system also learns form the application cases, enhancing the range and success rate of predictions.

In this chapter, some representative expert system prediction like the stress-strain behavior, draw-in profile during cup deep drawing, and forming limit curve are presented. The tools required for tensile test, deep drawing test, Limit dome height test simulation and modeling details can be obtained from (Veera Babu et al., 2009; Siva Krishna, 2009). The six different input parameters are varied at three different levels (decided from literature) and simulation trials were conducted as per L27 Taguchi's orthogonal array. The various ANN parameters like number of hidden layers, neurons, and transfer functions are optimized based on many trials to predict the outputs within the normalized error limit of $10^{-4}$. Various network structures with one and two hidden layers with varying number of neurons in each layer are examined. Finally the architecture which yielded better performance is used for modeling. In all the cases, a feed forward back propagation algorithm is selected to train the network in Matlab programming environment. Here the scaled conjugate gradient algorithm is used to minimize the error. From the available simulation data sets, 27 data sets are used to train and two intermediate data sets are utilized for testing the ANN model/expert system. The comparison between ANN predicted true stress-strain behavior and simulation results are shown in Fig. 3. The strain hardening exponent ($n$) and strength co-efficient ($K$) values obtained from ANN models are incorporated into Hollomon's equation ($\sigma = K \, \varepsilon^n$) for TWB made of steel and aluminium alloy base materials and true stress-strain curves are obtained.

It should be noted that even though Hollomon's strain hardening law is not accurate to predict the tensile behavior of aluminium alloy base material, ANN predictions are quite accurate in predicting the same. Similarly, the comparison between ANN/expert system and simulation results of draw-in profile during square cup deep drawing is presented in Fig. 4. At different TWB conditions, the draw-in profile predicted by ANN model/expert system is well matched with the simulation results for both steel and Al alloy TWBs. In the case of LDH test, the FLC is predicted by thickness gradient based necking criterion
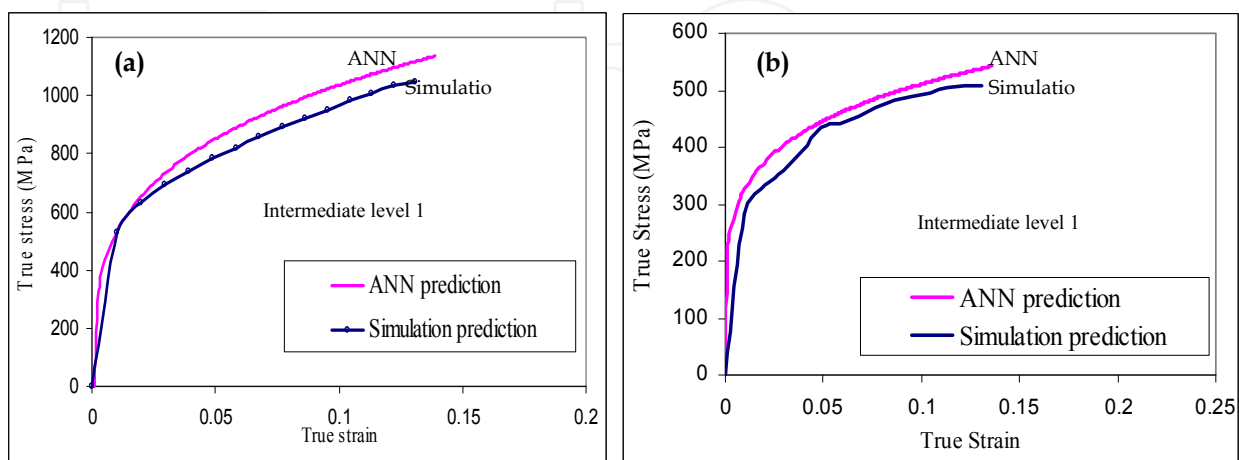


Fig. 3. Validating the true stress - strain behavior predicted by ANN/expert system with FE simulation; (a) Steel TWB, (b) Al alloy TWB (Veera Babu et al., 2009)
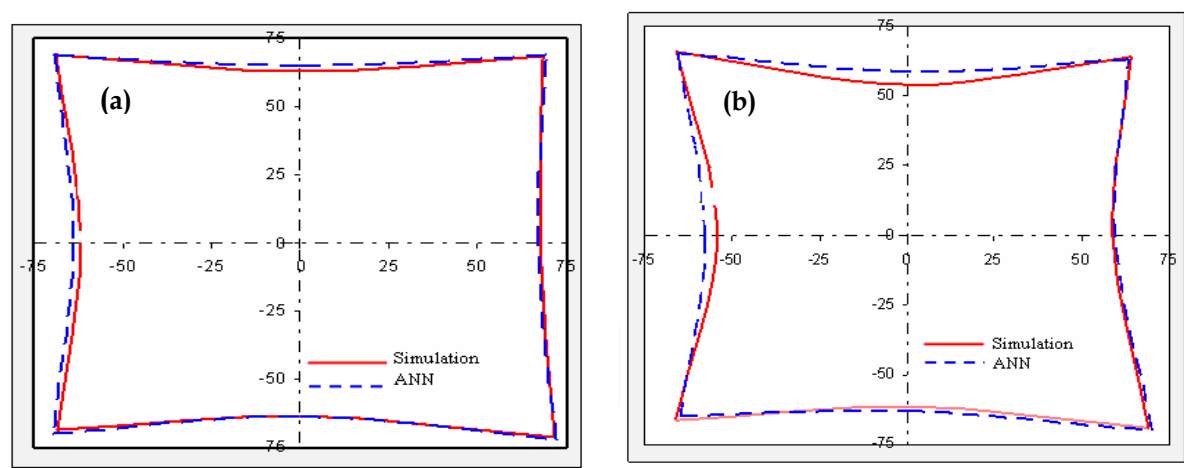
Fig. 4. Comparison of cup draw-in profile between ANN prediction and FE simulation; (a) Steel TWB, (b) Al alloy TWB (Veera Babu et al., 2009)

(TGNC). The ANN/expert system prediction is found to show excellent correlation with FLC from the criterion (Fig. 5 a-c) for steel TWB. It is also found (Siva Krishna, 2009) that the FLCs predicted from other failure criteria – effective strain rate, major strain rate based necking criteria, both the original and modified ones (Fig. 5 a-c), are comparing satisfactorily with the expert system results. A slight deviation in the plane strain and stretching modes of deformation is seen in both the intermediate TWB conditions.

The proposed ANN based expert system for TWB is in rudimentary stage of development. The suitability of the system is problem specific. A sheet forming engineer who wants to develop an expert system for some industrial TWB sheet part can just make it as part of
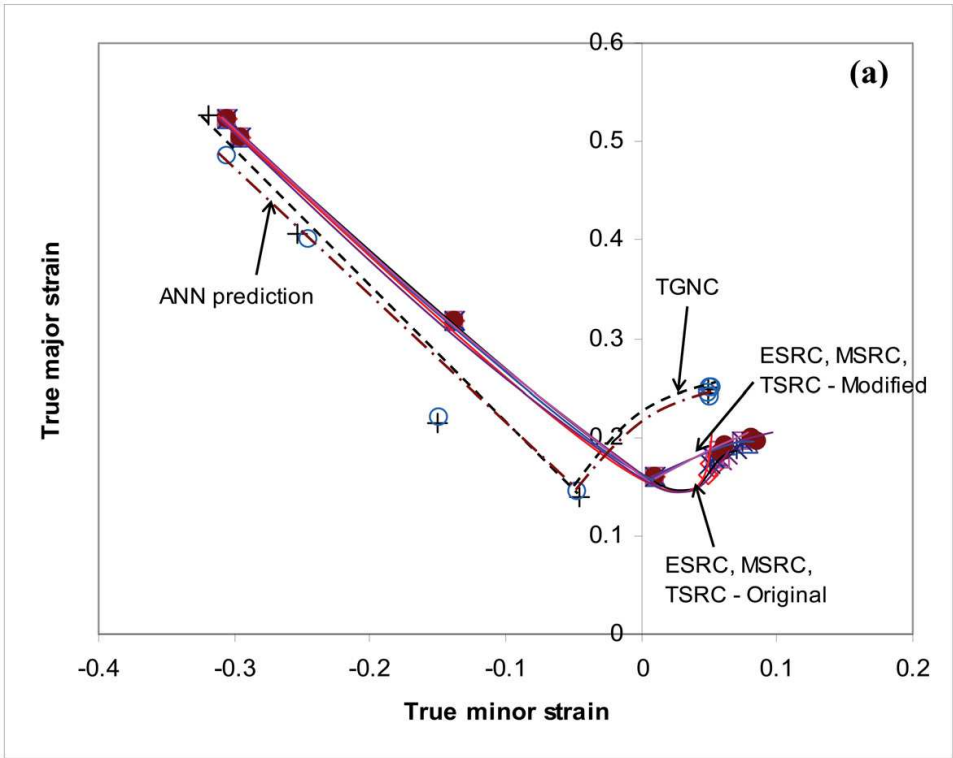


Fig. 5. Comparison of ANN prediction with TGNC and other failure prediction (continued)
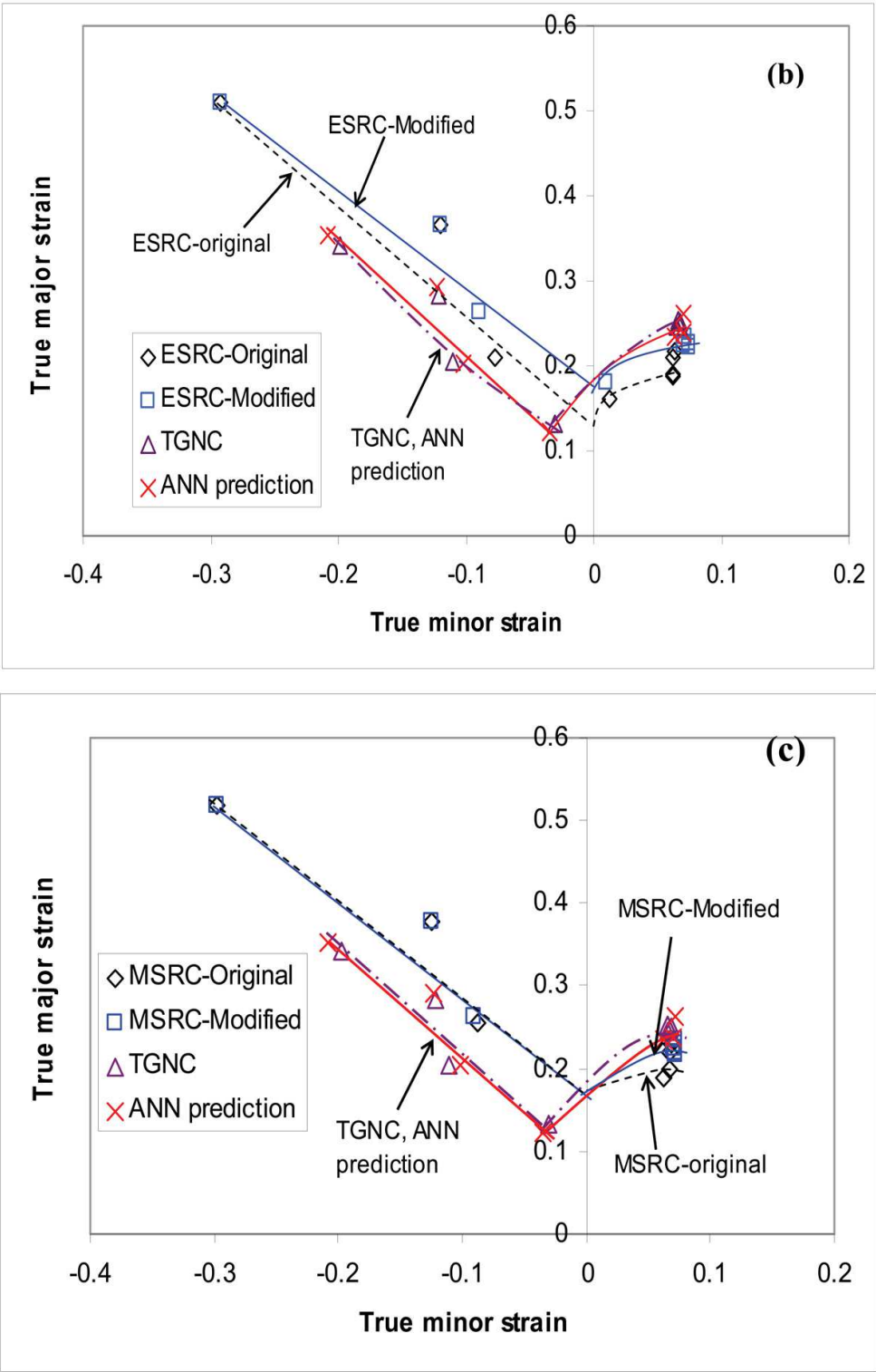
Fig. 5. Comparison of ANN prediction with TGNC and other failure prediction - (a) intermediate level 1, ESRC, MSRC, TSRC comparison; (b) intermediate level 2, ESRC; (c) intermediate level 2, MSRC (Siva Krishna, 2009)

existing system framework in the same line of thought, with out introducing new rules and conditions. This way the expert system is also expanded, becomes more efficient in solving realistic TWB forming conditions. The relations between TWB inputs and outputs are non-

linear in nature and hence it is complex to explicitly state rules for making expert system. But these complex relationships can be easily handled by ANN. In fact, it is not mandatory that the user should know about the input-output relations in TWB. Since this expert system is ANN based, it can potentially become a learning system as the problem solved by the system can also become a part of training examples for customers. Though the expert system can not reason out the decisions/results unlike rule based systems, one can interpret the results by comparing the outputs of two different input conditions quantitatively with minimum knowledge in TWB forming behavior. The ANN learning and fixing optimum architecture takes time and are problem specific, which can be sorted out by practice. The expert system developed in this work is applicable within the range of input and base material properties specified by Veera Babu et al. (Veera Babu et al., 2009). Though this is true, the range specified is large enough to include usable TWB conditions. It is worth to study the applicability of the present expert system outside the range and for many new sheet materials including high strength steels.

## 8. Summary

In this chapter, the expert system applications in designing, planning, and manufacturing of sheet parts is discussed. Emphasis is given for process design, process sequence and planning, strip layout plan, and tool design. The use of expert system in material forming is also highlighted. Finally an expert system that is being developed to predict the TWB forming behavior is presented. The expert systems play a vital role in designing the sheet forming processes and acts like a 'brain' in taking decisions and suggesting the optimum conditions for better sheet formability. In TWB, the expert system can predict the weld line movement for the given input properties, by which the blank holding force can be varied suitably to minimize the weld line movement. Most of the expert/knowledge based systems belong to IF-THEN variety which has interpretation power and updating ability. Some of the systems are neural network based that are capable of handling non-linear relationships in a better fashion and are independent of existing design rules. The only disadvantage is that they can not interpret the results, unlike IF-THEN rule based systems. The strength of ANN based system is that any new material, forming process, process parameter, and industrial parts can be included into the model without formalizing new rules, except that one needs to train and test the network whenever it is updated for new prediction work. The IF-THEN variety systems are based on data obtained from experts, industries, handbooks, journals etc. while ANN are based on data from experiments and simulations. Also it looks like most of the systems are developed as per industrial requirements, rather than for academic research. There are ES for deep drawability, bending, and blanking that are quantified by 'geometric parameters' like cup height, bending angles etc. and hardly any expert system is found to design the sheet forming based on 'forming limit diagram (FLD)' which is quantified by strain or stress developed during the forming operation. The ES based on FLDs will give more insight into the sheet design aspects. In this case, one has to follow some forming limit criteria to predict the limit strains under varied TWB conditions, as depicted earlier in TWB expert system.

In future, expert systems to design and predict, (a) the sheet formability of new materials like high strength steels, advanced high strength steels; new processes like hydro forming, micro forming etc.; (b) the ability of allied processes like friction stir welding, laser welding to manufacture sheet parts are expected. For instance, expert system can be developed for

tailor welded blanks made of dual phase steel, friction stir welded blanks made of Al alloy sheets, hydro forming of dual phase steel, spring back and bending of high strength steels that are of practical importance and can be used efficiently in industries. Efficient expert systems that can predict the microstructural, fatigue, and high temperature behavior of many automotive and constructional materials should be developed in future. ANN model developed by Hosseini et al. (Hosseini et al., 2004) to predict the tensile strength and elongation of TRIP steels is an example of this kind. One can also develop hybrid expert systems that integrate different methods of expert system development like ANN and Genetic Algorithm (GA) to predict the sheet forming behavior. The best example for this is the spring back prediction work done by Liu et al. (Liu et al., 2007) using integrated ANN and GA, in which GA is used to optimize the weights during ANN modeling.

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**Expert Systems**

Edited by Petrica Vizureanu

Expert systems represent a branch of artificial intelligence aiming to take the experience of human specialists and transfer it to a computer system. The knowledge is stored in the computer, which by an execution system (inference engine) is reasoning and derives specific conclusions for the problem. The purpose of expert systems is to help and support user's reasoning but not by replacing human judgement. In fact, expert systems offer to the inexperienced user a solution when human experts are not available. This book has 18 chapters and explains that the expert systems are products of artificial intelligence, branch of computer science that seeks to develop intelligent programs. What is remarkable for expert systems is the applicability area and solving of different issues in many fields of architecture, archeology, commerce, trade, education, medicine to engineering systems, production of goods and control/diagnosis problems in many industrial branches.

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