CHAPTER-2

LITERATURE REVIEW

2.1 INTRODUCTION

The old adage says 'Knowing the past is the first step for preparing ourselves for the future'. As we enter the next century, it is beneficial to look back and review how technologies evolved through the years. Take sheet metal forming for example, in the past, it heavily depended on the skills of metal workers. Each piece was hammered artistically to provide a personal touch to the product. However, with increased production demands, this procedure was replaced by an automated stamping operation, which today is one of the most widely used manufacturing processes to plastically deform materials into desired shapes.

With the advancement in the area of computer graphics, CAD/CAM and Artificial Intelligence (AI), some researchers [Schaffer 1971, Nakahara 1978, Nee 1986, Shirai 1989, Duffy 1991, Prasad 1992, Park 1999, Choi 2001 etc.] started to exploit these techniques for the design of stamping tools, especially progressive dies. In this chapter, major published work on the use of CAD and knowledge-based systems in the area of checking of design features of sheet metal parts, strip-layout design, selection of progressive die components, material selection for components of progressive die and automatic modeling of progressive die components have been reviewed. Finally, based on conclusions drawn from literature review, the current research problem has been formulated.
2.2 CHECKING OF DESIGN FEATURES OF SHEET METAL PARTS

It is estimated that decisions made at the part design stage determine 70%-80% of the manufacturing productivity [Makinouchi 1996]. Therefore, as a first step in the planning for manufacture of a sheet metal part, it is useful to check its internal as well as external features for assessing its manufacturability on progressive die. Such checks are useful to avoid manufacturing defects, section weakness, and need of new dies, tools or machines. Over the years the industrial practices of checking of the internal and external features of sheet metal parts have not changed significantly. Traditional methods involve calculations and decisions, which have to be made on the basis of experience and practice codes without the computer aids. Trial and error methods are still being used in the process of checking of design features of sheet metal parts.

In 1978 Nakahara et al. [Nakahara 1978] introduced a progressive die design system that examines the part design data to decide whether it can be stamped by blanking or not. However, the system was not capable to check the external and internal features design features of sheet metal parts for assessing their manufacturability on a progressive die.

The Cold Press Die Design and Manufacturing system (CPDDMS) developed by Ying [Ying 1986] manipulates the digital representation of blanks stored in data files to perform technology check of the blank geometry. But the main limitation of this system is that it is implemented on a main frame computer with advanced data base support and thus it is beyond the reach of the small and medium sized tool and die industries.

Iliev et al. [Iliev 1989] developed a system, which mainly addresses the technical preparation in the production of flat parts by stamping. The system consists of separate sub-systems, each sub-system solving a certain number of problems associated with technical
preparation including technological check of the blank geometry. The major limitation of this system is that it involves large number of mathematical calculations of the geometrical characteristics of the sheet metal part just like the traditional methods being used in industries. Also the system is not capable of assisting the user for technological check of the blank geometry for manufacturing on a multi-operation die.

The Technology Check module of the Computer Aided Die Design System (CADDS) proposed by Prasad and Somasundaram [Prasad 1992] is capable of assessing the feasibility of the given sheet-metal blank for the blanking process. It checks whether the given blank profile can be easily produced by sheet metal stamping through a single operation die. This includes identification of those geometric regions that make the blank profile more complex, and that make it either difficult or impossible to produce it by sheet metal blanking. A checking algorithm has been implemented to prove the acceptability of the blank profile. The input required for the technology check module is the sheet thickness, sheet material properties and geometrical information about the blank. Once this information is available, the technology check module examines the acceptability of the blank profile according to the incorporated rules. In the case of an unacceptable blank profile, the algorithm identifies the unacceptable areas with necessary recommended values to match the requirements of the sheet metal blanking. It also suggests to the designer the possible changes in the blank profile for easier manufacturing. But the major limitation of this system is that it concerns with the checking of manufacturability of sheet metal parts only on single operation blanking and piercing dies.

Choi and Kim [Choi 2001] developed a CAD/CAM system for the blanking or piercing of irregular shaped-sheet metal products for progressive working. The system is capable of
checking the production feasibility of parts using AutoLISP and AutoCAD. But this system is limited to stator and rotor parts which require only blanking or piercing operations.

From the literature reviewed on the checking of design features of sheet metal parts, it has been observed that there is a very little research work has been done in the development of CAD and expert systems for this important activity. Worldwide researchers stressed on the development of computer aided knowledge-based system for checking of design features of sheet metal parts for assessing their manufacturability.

2.3 STRIP-LAYOUT DESIGN

Design of strip-layout has an extreme importance during the planning stage of progressive die design as the productivity, accuracy, cost, and quality of a progressive die mainly depend on the strip layout. In conventional progressive die design, strip-layout is performed manually, and the quality of the die design depends heavily on the experience of die designer. Type of sheet metal operations required on the part, their proper sequencing, number of stations required and the operations to be accomplished at each station of progressive die have to be decided by the die designers. The sequence of operations on a strip and the details of each operation must be carefully developed to ensure that the design will produce good parts without production or maintenance problems. To improve productivity and to build a computer integrated manufacturing environment, intelligent modeling of the strip-layout is essential.

Four decades earlier strip-layout problems were solved manually. The blanks cutting from cardboard were manipulated to obtain a good strip-layout. This trial and error procedure of obtaining suitable strip layout with maximum material utilization is still being used in most of
the small scale and even in some medium scale stamping industries worldwide. The quality of strip-layout achieved by using traditional methods depends on the experience and knowledge of designers.

On the advent of CAD systems around three decades earlier, the process of strip-layout design was somewhat made easier and the design lead-time was reduced from days to hours. However, well-trained and experienced die designers were still required to operate these CAD systems. Most of the applications of CAD in strip layout are aimed mainly at achieving better material utilization by rotating and placing the blanks as close as possible in the strip. However, the strip-layout with maximum material saving may not be the best strip-layout, indeed the die construction may become more complex, which could offset the savings due to material economy unless a large number of parts are to be produced. The modeling of a right strip-layout for needed stamping operations is clearly a decision-making situation based largely on the experience of progressive die designers.

The system developed by George Schaffer [Schaffer 1971] in 1971 reported to calculate the stresses due to bending moment on cantilevered die projections and if the system finds that the stress level is above the yield stress of die steel material, then the system distributes the cutting operations over several stages in order to keep the stresses within the reasonable limit. One of the limitations of the system is that it does not give any importance to the complexity of die and punches during staging of operations.

The system developed by Nakahara et al. [Nakahara 1978] is capable of fixing the positions of punches and dies on the strip layout. But there is no report about the implementation of the system to prove its capability in real life.
Adachi et al. [Adachi 1983] developed an integrated CAD system for design of progressive die. The system outputs also include generation of strip-layout for progressive die. But the user has to specify the sequence of operations himself to obtain the strip-layout.

Nee [Nee 1984a, 1984b, 1985] developed some experimental packages for analysis on press capacity, the use of coiled or strip stock and cost factors in order to solve for near-optimum layout and nesting problems for both sheet metal and metal stamping blanks. He also reported to develop a system [Nee 1986, 1989] for production of sheet metal components, in which he described the phases involved in developing PC-based computer aids for sheet metal work. All of his work focused on the general strip-layout design process and the expert rules involved do not tackle other stamping operations such as piercing, bending, forming etc.

The system developed by Duffy and Sun [Duffy 1991] used knowledge base system approach to generate strip-layout for progressive stamping dies. The system was implemented in IDL, which is a knowledge-based language. The system has the capability to generate strip-layout; however it has not been implemented and its capabilities in real life have not been tested.

The Computer Aided Die Design System (CADDS) developed by Prasad and Somasundaram [Prasad 1992] also has one module for the strip-layout for progressive die. In this module, the die type is selected, depending on the input parameters such as sheet thickness, accuracy, production requirements and the complexity of the blank geometry. If the selected die is progressive, strip development is subsequently carried out according to the rules incorporated in the strip-layout module. But the major limitation of the system is that it supports mainly blanking and piercing operations.
Shpitalni [Shpitalni 1993] introduced a system for determination of bending sequence of stampings. In this system, the bending sequence determination is formulated as a graph search problem.

Singh and Sekhon [Singh 1996] developed a CAD system for evaluation of metal stamping layouts. The diagraph and matrix approach is used in this system. Later on, they also developed a low cost modeller [Singh 2001] for two-dimensional metal stamping layouts. The software is based on AutoCAD and AutoLISP. The system is capable of modelling circular, polygonal and components having curved segments. Alternative strip layouts are also generated and tested for optimality. The main limitation of the system is that it deals with single operation stamping dies.

Kim et al. [Kim 2002] developed a system using AutoLISP language. The system decides the sequencing process of electric products with intricate piercing and bending operations by considering several factors on bending and adopting fuzzy set theory. It constructs fuzzy matrix for calculating fuzzy relationship value and determines the optimum bend by combining several rules with fuzzy reasoning. The strip-layout module of the system is able to carry out bending and piercing operations of 3D electric product. The main limitation of this system is that it deals with only bending and piercing operations on progressive die.

Rao [Rao 2004] presented a strip-layout selection procedure pertaining to metal die stamping work. The procedure is based on analytic hierarchy process (AHP). But, the developed procedure is applicable only for simple blanking and piercing dies.

Chu et al. [Chu 2004] proposed a mathematical technique capable of generating a stamping sequence automatically in the design of progressive stamping dies. A graph is used to represent a stamping part and define the relationships between its stamping features. The graph is partitioned into sets of mutually independent vertices using a clustering algorithm.
Finally, the clustered sets are ordered to give the final sequence of workstations. Completion and development of a software prototype of the system is still in progress and has to be tested against real industrial sheet metal parts having different shapes.

The foregoing literature review reveals that only a few research and development work has been carried out in the area of modeling of strip-layout for progressive dies. Most of the works are concentrated on process planning for sheet metal blanking and piercing operations.

2.4 COMPUTER AIDED PROGRESSIVE DIE DESIGN

Traditionally, research in sheet metal processing has been focused on using experimental and numerical techniques to solve problems related to the design of press tools. However, press tools are still being designed manually. With the introduction of computer graphics and CAD/CAM systems, some researchers have started to exploit the advances in interactive computer graphics and CNC technology for the design and manufacture of metal stamping tooling, especially progressive dies.

In 1971, Schaffer [Schaffer 1971] laid down the applications of CAD in sheet metal work through the development of a system called Progressive Die Design by Computer (PDDC). This system is capable to identify the projections of the part, which may subject the die to undue stresses during cutting. The system also calculates the stresses due to bending moment on cantilevered die projections. Some limitations of this system are its inability to perform technology check of the blank geometry, automated selection of various die elements and generation of bill of materials.

Fogg and Jaimeson [Fogg 1974] improved the PDDC system by considering various factors, which influence the die design. This system consists of different modules, each would
perform a specific task for designer like stock layout, die layout etc. The major limitations of this system are its inability to select materials for die components, model die components and die assembly etc. It takes long design time due its semi-automatic nature of design process.

Nakahara et al. [Nakahara 1978] developed the MEL (Mechanical Engineering Laboratory, Japan) system in which the design work is divided into ten steps. Each step can be used independently. The main steps of this system are input, check, type selection, process planning, strip-layout and die layout. The user inputs the geometry of the component as well as other associated information such as tolerances, thickness of the sheet etc during input stage. The system examines the geometrical data to decide whether it can be realized by blanking or not. Then the system selects suitable die block such as solid type and insert type by using the data such as availability of press and tolerance required. To decide the positions of punches and dies, the relationship between blank profile and the standard punches is determined during the process planning stage. The limitation of this system is the inability to nest two different blanks for blanking. Also there is no report about the tests carried out to prove its capabilities in real life.

Murakami et al. [Murakami 1980] and Shirai [Shirai 1985, 1989] of the Hitachi Production Engineering Research Laboratory reported to develop a CAD/CAM system for progressive dies. Initially they developed a CAD system for progressive dies [Murakami 1980], subsequently it was integrated with the CAM system [Shirai 1985, 1989]. This system is divided into three modules namely Pre-processor, Main-processor and Post-processor. The die designer coded the shape of the developed component in APT language, which is input to the Pre-processor. The Pre-processor module generates a blank layout with maximum stock utilization. Using the blank layout, the die designer has to design the approximate strip and die
of sharp corners, use of standard punches and punch mounting arrangements and so on. The
design of die plate is done by the system by considering the working area of the die, the die
block thickness and the exterior of the die. The limitations of the Nee's system are use of
empirical rules for the calculation of bend allowance for flat pattern development and the
designer is expected to generate the assembly views and bill of materials interactively. In his
recent publication with Li and Cheok [Li 2002], an integrated feature-based modelling and
process planning system for bending operations in progressive die design has been proposed. The
system has been implemented in C++ using ObjectARX SDK using AutoCAD R14 platform.
The bend and part features have been developed as custom AutoCAD entities.

Around mid 1980s, some commercial CAD/CAM systems were also developed such as
Auto-trol's Progressive Die System, Fanuc Progressive Die CAD/CAM System, the ADMS
Die Master System, the U-Graph Assisted Die Design System etc. Auto-trol Progressive Die
System [P-DIE 1987] combines automatic nesting capability with interactive user
modification to optimize material usage. The part geometry definition used by the system is
the APT-formatted tool path defining the part profile. This APT file can be created
automatically in Auto-trol's numerical control software or can be created by other APT-
formatted systems. In addition to material utilization, the system also considers material cost,
machine cutting time, inventory control, and scheduling. The automatic nesting system is
specifically used in the production of components whose manufacture begins with numerically
controlled plasma or oxy-fuel cutting of plate stock. Output of the system includes standard
NC programs such as milling, drilling and wire EDM. The major limitation of this system is
that its interactive die design approach expects the user to be conversant with the tool design
The system also needs expensive workstations and works only with the basic software of Auto-trol, which is beyond the reach of small-scale industries.

The Fanuc Progressive Die CAD/CAM system [F-PDIE 1988] uses FAPT language of "System P-Model G" to define product shape and to design dies by conversational mode with the graphic display screen using a fully custom-built menu. The system is not fully automated, as user input is required for a number of design decisions. A skilled die designer is also required to operate the system. Design output from the system is fully compatible with FAPT MILL and FAPT CUT and automatic programming for CNC milling and wire-EDM machines can be produced.

The ADMS (Automatic Die Design and Manufacturing System) DIE MASTER System [ADAMS 1988] consists of two systems, the ADMS Tool Master and ADMS Design Master. The former is concerned with the general purpose machining and the later is developed for die design. The system runs on HP platform. ADMS Designer Master System enables the user to design stamping dies. The modules include: Arrange Design, Flat Pattern Design, Blank Layout and Bits Design, Strip Layout and Unit Design. Most of the design modules are interactive in nature. This system assists a designer by providing efficient drafting aids, calculations and good graphics for visualization. The designer, however, has to use his knowledge and expertise to achieve most of the die design requirements.

The U-Graph Assisted Press Die Design System [U-GRAPH 1989] follows the typical progressive die design approach, i.e. with product 2-D and 3-D drawings as input, followed by modules such as flat pattern development, blank layout, stage layout, overlapping of punches, decision of die structure, assembly drawings, design of non-standard punches and finally
generation of NC tapes. Although certain functions allow easy computation of punch force, material yield, etc., much of the final layout is still dependent on the user.

Almost all the systems discussed above are of interactive or semi-automatic type, in which the need for user interaction in many stages like blank development, strip-layout and die layout is essential. This requirement forces the user of the system to be knowledgeable tool designer. Even though all the systems discussed above have their own advantages, there is no single system, which can completely automate the die design procedure starting from the blank layout stage to the final stages of generation of bill of materials. It has been concluded that most of the CAD system for die design discussed above have been developed for a pre-defined manufacturing setups. Though lot of research has taken place in this field of computer aided die design, the commercial development has not kept in pace with the research. Most of the commercial systems are the customization of existing CAD/CAM systems such as Fanuc, Auto-trol, Pro/ENGINEER, IDEAS, CATIA and AutoCAD to provide the added functionalities required specifically by die designers. They are basically interactive in nature and can only be viewed as productivity enhancement aids for the die designer [Liu 2004]. This is because considerable human expertise is still needed to use these systems to arrive at the final design.

2.5 KNOWLEDGE-BASED PROGRESSIVE DIE DESIGN SYSTEMS

Research and development of progressive die design automation systems was given a new dimension in the late 1980s and early 1990s, when the applications of AI techniques in engineering design started to take off [Chryssolouris 1986, Boyle 1989, Tong 1992 etc.] One
area of the research that has attracted a considerable amount of researchers is development of knowledge-based die design systems.

Karima and Richardson [Karima 1987] introduced a framework for describing the domain related knowledge as facts, procedures, judgments and controls, which can be acquired from relevant sources.

Sitaraman et al. [Sitaraman 1991] proposed a knowledge-based system for process-sequence design in axisymmetric sheet metal forming. The system first generates an initial-guess process sequence based on experience-based die-design guidelines, and then this process sequence is tested using the analysis module. He pointed out that domain knowledge for development of KBS could be acquired from human experts, journals, handbooks, and industrial brochures.

Lin et al. [Lin 1989, 1994, 1996] developed a PC-based expert prototypes for the design of shearing cut (blanking and piercing) progressive dies. ESSCP [Lin 1989] is a prototype developed using FORTRAN, Micro Expert (the inference engine) and AutoCAD to plan and develop the progressive dies for the blanking and piercing of 2D parts with very simple geometrical profiles. Further the researcher also investigated that how uncertainties in design parameters can be processed using fuzzy mathematics for the design of particular component in the die structure [Lin 1994], and developed a knowledge-based system that uses a pattern recognition approach to develop the blank and a matching combination learning method for press procedures to determine the number of stations in the die [Lin 1996]. It is not clear whether they have integrated these AI techniques into an integrated system for the design of blanking and piercing progressive dies.
Kumar et al. [Kumar 1990] developed a knowledge-based system for the design of progressive dies. The system has been coded in AutoLISP language and loaded through AutoCAD interface. The input to the system is the polygon enclosing the part profile. The system consists of a database of "standard" orientations for selected shapes. The user has to select the actual part profile from a data consisting of standard orientations for selected shapes. The system tilts the input polygon optimally and then strip development follows. The system is also capable to display the die block layout. The main limitations of the system are that it does not have KBS modules for checking of part design features, automatic modeling of strip-layout, selection of progressive die components and selection of die materials.

Li et al. [Li 1990, Li 1992, Lin 1993] developed knowledge-based CAD/CAM packages of progressive dies for small-sized sheet metal parts. Using features, a user can design a product in 3D wire-frame; thereafter the system will unfold it. After manually developing the blank layout, the user can use interactive commands to develop the strip-layout. The user can then proceed to design the die structure interactively. Another feature of their research is the use of the directed and weighted graph approach for the automatic splitting of complicated die cavities [Li 1990]. The system was developed on a Micro VAX mini-computer. But the major limitation of the system is its inability to model the strip-layout automatically. The system is also not capable of assisting the user in the selection of suitable materials for die components and accessories.

Raggenbass and Reissner [Raggenbass 1991a, 1991b] developed an expert system, which generates a complete NC production plan for stamping, laser cutting and for the process combination. The system is designed mainly to use on NC punching machines. The limitation of this system is that the actual factors relevant to die design are not considered.
Duffy and Sun [Duffy 1996] sought to develop a knowledge-based system for design of progressive stamping dies. The system uses both physical principles and often-complex "rule-of-thumb" knowledge of tool designers. This is achieved by data representations of both the part die geometry as well as database of standard die components, machine capabilities and other reference information. In this system the die assembly is represented with a four level tree hierarchy structure in which each node of the tree can be one of primitive geometry entities, primitive features, components and sub-assemblies. The system is implemented in IDL (Icad Design Language), which is a knowledge-based language used for modeling.

Researchers from the Department of Industrial Studies, University of Liverpool have also applied efforts for the development of expert systems for progressive piercing and blanking die design [Huang 1996, Ismail 1995, Ismail 1996]. Their research concentrated on shape-coding and recognition techniques for the decomposing of the bridge scrap into smaller shapes. However, their techniques are limited to straightedge workpieces only. They also developed a UNIX-based expert system for the planning and the design of progressive piercing and blanking dies. The system was developed by integrating Auto-CAD with Kappa and some C programs. They stressed for the development of knowledge-based system for selection of die components.

Researchers at the Department of Mechanical and Production Engineering, National University of Singapore developed algorithms for die design automation [Nee 1984, 1989]. Initially, they applied research efforts for developing heuristics for nesting, automating the staging and punch shape selection and de-composition process. Later, it was extended to the use of a variety of knowledge-based approaches to extend the capabilities to include bending and forming, automatic punch shape selection and 3D die configuration [Cheok 1994, 1995].
But the research efforts have not been applied for development of knowledge base system modules for assisting the user in the selection of suitable type of die and press, selection of proper die materials and checking of part design features.

Some researchers [Lee 1991, Lee 1993, Lee 1995, Tiza 1995, Esche 1996, Choi 1998, Choi 1999, Park 1999, Choi 2001, Shi 2002] applied their efforts to reduce the size of the problem by developing systems that concentrate on specific product types or on specific tasks. For example, Lee et al. [Lee 1991, Lee 1993] developed IKOOPP, a knowledge-based process planning system for the manufacture of progressive die plates. IKOOPP is able to automatically recognize the machining features from 3D die plate modeled in Auto-Trol and proceed to automatically plan the set up sequences, select the required machine tools, cutting tools, heat treatment, fixturing elements and sequence of operations. Lee et al. [Lee 1995] developed an assessment system consisting of a knowledge-based geometric-analysis module, a finite-element method (FEM) module and a formability analysis module. This software is suitable for assessing the formability of deeply formed parts such as automobile panels.

Tiza [Tiza 1995] applied the principles of group technology to the process planning of multi-stage forming processes for the development of Metal Forming Expert System (METEX). It uses AutoCAD and AutoLISP to provide an expert system to generate possible forming solutions for deeply formed or drawn shapes, and adopts a hybrid classification utilizing both geometric features and manufacturing characteristics for the coding of components to form part families for automatic process planning.

Esche et al. [Esche 1996] developed an Axisymmetric Sequence Forming Expert System (ASFEX) that uses design rules to generate process sequences for multi-stage drawing of round cups and tool geometry for each station of the sequence.
Researchers from the Department of Mechanical Design Engineering, at Pusan National University, South Korea developed a compact and practical CAD/CAM system for the blanking or piercing of irregular shaped-sheet metal products for progressive working [Choi 1998, 1999, 2001]. This CAD/CAM system is based on knowledge-based rules. Knowledge for the system is formulated from plasticity theories, experimental results and empirical knowledge of field experts. The program for the system has been written in AutoLISP on the AutoCAD for strip- and die-layout and in customer tool kit on the SmartCAM software for modeling and post processing with a personal computer. Based on knowledge-based rules, the system is designed by considering several factors, such as the material and thickness of product, the complexities of blank geometry and punch profile, the diameter and material of a wire, the working conditions, and the availability of a press. It is capable of generating automatically NC data to match tooling requirements by checking dimensions according to the drawings of the die-layout module. But this system is concerned only with stator and rotor parts with bending and piercing operations.

Park [Park 1999] from Dongeui, Institute of Technology, South Korea developed an expert system for electron gun-grid parts. To develop this system, C-language has been used under the HP-UNIX system and CIS customer language of the EXCESS CAD/CAM system.

Researchers [Shi 2002] in the Department of Plasticity Technology, Shanghai Jiaotong University, Shanghai, proposed a knowledge-based process planning system (KBPPDS) for auto panel. The process planning system is able to provide process planning and main process models by using design rules and the case base effectively. The system has been developed specifically for dealing with auto panels only.
Now, AI techniques are being used increasingly in pattern recognition, production rules and frame-based inferencing and reasoning, fuzzy reasoning, feature-based design, etc., to design systems for the production of metal stampings. However, because of the complexity of the die-design process, most of the 'intelligent' die design automation prototypes are rather restrictive in their applications.

2.6 MATERIAL SELECTION FOR PROGRESSIVE DIE COMPONENTS

The selection of a proper material is one of the important aspects of Engineering Design. But most of the times, material selection is still done manually using handbooks, thumb-rules and heuristics. Traditional methods of selection of materials of progressive die components involve numerous calculations and decisions based on experience and practice codes. Selection of materials for progressive die components is still dependent on the designer's vast experience and involves trials and errors to obtain the desired results.

Over the past, some efforts have been dedicated to the problem of material selection. Most of the selection methods were based on analytical models. For example, Tang [Tang 1988] proposed a model of material selection based on material cost and material quality in analytical format. Chen et al. [Chen 1993] presented an economic model for raw material selection. They considered two decision factors in the model, i.e. raw material cost and additional material cost incurred due to the inappropriateness of raw material quality. However, often, the characteristics of different materials stated in the engineering design handbooks [e.g. Bralla 1986, Suchy 1997] are multi-dimensional and qualitative. The assessments of these attributes by experts are given in linguistic terms such as poor, fair, good,
excellent, and etc. Based on the provided information, it is rather difficult to make a suitable tool material selection by conducting the conventional quantitative analysis.

Wang and Cheng [Wang 1995] proposed an algorithm for tool steel materials selection under fuzzy environment. A fuzzy set multiple criteria decision making approach is proposed for the selection of the most suitable tool steel materials for a specific manufacturing application such as die design, jig and fixture design. The important weights of different criteria and the material suitability ratings of various alternatives under different criteria are given in linguistic terms. Subsequently, they are represented in fuzzy linguistic values and fuzzy numbers. Five levels of linguistic values are designated in the rating and weighting scales of this system, based on the needs of cognitive perspectives and the available data characteristics. Through aggregation and ranking of fuzzy numbers, the most suitable tool steel material is determined. A hypothetical example is illustrated. One of the major limitations of the proposed algorithm is that it is not computerized. Researchers [Wang and Chang] stressed for the construction of a material database consists of experts' assessment data and knowledge of various materials available in the design handbook. Further they stressed on the need of developing a decision support system for material selection incorporating menu-driven user-friendly interface design.

Goel and Chen [Goel 1996] used an expert network approach for development of a system of material selection in engineering design. The expert network is comprised of an expert system integrated with a neural network. The neural network was developed using C++. The neural network is used in conjunction with an expert system. PDC Prolog has been used for developing the expert system. The expert system has two main modules: Material Analyzer module and Inventory Check module. The Material Analyzer module takes the desired
properties of a material required for a job, the relative importance of these properties and the
time span under which that material should become available, as input. The module then
prepares a priority list of the materials that are suitable for that job. The Material Analyzer
module takes a list of applicable materials and produces a normalized weightage list of the
materials based on their closeness to desired properties and degree of importance of the
various properties. The Inventory Check module checks the lead-time for the procurement and
quantity of the selected material available in the stock. The system is capable of assisting the
users in the selection of materials for general engineering products only.

Jiang et al. [Jiang 1999] developed an automatic process planning system (APPS), which
is capable of selecting the tool materials based on the raw stock material. Suggested tool
materials are taken from reference handbooks. In APPS, high-speed steel (HSS) and carbide
materials are used.

Buggy and Conlon [Buggy 2004] proposed a system for material selection in the design of
electrical connectors. The database was developed in Microsoft Access. This software is a
relational database management system (RDMBS). The software provides a database engine
called “Microsoft Jet” and a graphical user interface (GUI) for data definition and
manipulation with the power of the now standard structural query language (SQL). Users can
develop forms and reports for input/output operations in the database through the use of
Wizards, which are interactive programs that guide the user through a series of questions in a
dialog mode. An Expression Builder helps the user build syntactically correct expressions
when developing querying functions through reports. The definition of the forms and reports is
interactively accomplished when the user designs and links different fields on the form or
report to items in the database.
Existing computer-aided die design systems and knowledge-based systems have still not fully dealt with the core die design issue of material selection of progressive die components. Some existing CAD/CAM systems and knowledge-based systems for progressive dies are able to generate bill of materials automatically [Shirai 1985, Prasad 1992, Ismail 1995, Huang 1996]. However these systems do not take into account the availability of materials and choice of user for optimum results. Further, these systems do not have knowledge base comprising of experienced knowledge of domain experts for material selection of progressive die components. Worldwide researchers [Duffy 1991, Ismail 1993, Cheok 1994, Ficko 2005] stressed to apply research efforts for capturing and documenting the invaluable practical knowledge of experienced die designers and toolmakers through the applications of AI techniques.

2.7 CONCLUSION FROM LITERATURE REVIEW

A summery of the salient features of some important R&D work reviewed during the present investigation in terms of inputs, system details, outputs and remarks is given in Table 2.1. The reviewed literature on checking of design features of sheet metal parts, strip-layout design, computer aided progressive die design, knowledge-based progressive die design systems and material selection for progressive die components reveals the growing interests of worldwide researchers and technocrats in the area of computer aided die design for metal stampings.

Some researchers have developed special CAD/CAM systems. But most of these systems are applicable only to specialized parts or parts with relatively simple geometry. Commercially available CAD/CAM systems are providing some assistance in drafting and analysis in die design process, but human expertise is still needed to arrive at the final design.
Table 2.1 Salient Features of Important R&D Work in the Area of Computer Assisted Progressive Die Design

<table>
<thead>
<tr>
<th>Ref. (s)</th>
<th>Researcher (s)</th>
<th>Inputs</th>
<th>System Details</th>
<th>Outputs</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>[Nakahara 1978]</td>
<td>Nakahara, S. et al.</td>
<td>Shape description in APT language, tolerance details, burr side</td>
<td>Used the concept of basic pattern as per standard punches</td>
<td>Blank layout, Die layout</td>
<td>Not capable of checking the design features of sheet metal parts,</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Interactive strip-layout</td>
<td></td>
<td>No report about the implementation of the system to prove its capability in real life.</td>
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<tr>
<td>[Murakami 1980, Shirai 1985, 1989]</td>
<td>Murakami et al.</td>
<td>Part shape data in APT language</td>
<td>Used the concept called “Die Layout Area”, around which the standard layout pattern is constructed</td>
<td>Die assembly, Dimensioned part drawings, NC code generation</td>
<td>Strip and die layouts have to be done manually by the designer,</td>
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<td>Not capable of selection of die materials</td>
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<td>[Adachi 1983]</td>
<td>Adachi et al.</td>
<td>Blank Geom. data, material data, information about guiding &amp; fastening elements</td>
<td>Semi-automatic design, Integrated CAD-CAM design of progressive dies</td>
<td>Strip-layout, Die layout, NC code generation</td>
<td>User has to specify the sequence of operations himself to obtain the strip-layout,</td>
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<td>Needs designer assistance in order to design and select the guiding and fastening elements</td>
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<td>[Iliev 1989]</td>
<td>Iliev, V.I. et al.</td>
<td>Drawing details of part</td>
<td>Technical preparation for manufacturing of parts</td>
<td>Generation of CLDATA file</td>
<td>Involves large number of mathematical calculations of the geometrical characteristics of the sheet metal part just like the traditional methods being used in industries</td>
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<td>[Nee 1986, 1989, Li, 2002]</td>
<td>Nee et al.</td>
<td>Part Geometry data, Bend data, Material data</td>
<td>Punch design automation concept</td>
<td>Blank, Strip and Die Layouts</td>
<td>Not capable of checking the design features of sheet metal parts,</td>
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<td>Integrated System (FPD, Nesting)</td>
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<td>Designer is expected to generate the assembly views and bill of materials interactively</td>
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<td>Duffy and Sun</td>
<td>Lee et al.</td>
<td>Goel and Chen</td>
<td>Choi et al.</td>
<td>Shi et al.</td>
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<td>Part geometry data, standard die components data</td>
<td>Part definition data</td>
<td>Properties of materials, relative importance of these properties, list of applicable materials</td>
<td>Drawing, material and thickness of sheet metal part</td>
<td>Drawing of part and initial sequence of operations</td>
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<td>Concept of KBS to model die components and assemblies. Implemented in ICAD Design Language</td>
<td>Die assembly is designed using standardized components based on commercially available CAD system. Used Object-oriented schema together with production rules and heuristics.</td>
<td>Neural network is used in conjunction with an expert system, PDC Prolog is used for developing the expert system</td>
<td>Used knowledge-based system approach</td>
<td>Case-based and rule-based reasoning techniques are applied</td>
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<td>Strip-layout, Selection of some standard die components</td>
<td>Process plan for the manufacture of progressive die plates</td>
<td>Priority list of the materials that are suitable for the job</td>
<td>Process planning drawing and assembled drawings</td>
<td>Process planning and main process models</td>
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<td>Developed for design of door hinges only Requires an experienced die designer to operate the system</td>
<td>The system is limited to the planning of progressive die plates only. Limited to a small range of work holding methods and heat treatment procedures.</td>
<td>Capable of assisting the user in the selection of materials for general engineering products only</td>
<td>Supports mainly blanking or piercing and bending operations on irregular shaped sheet metal parts</td>
<td>Developed specifically for dealing with auto panels only</td>
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</table>

Also, the high cost associated with setting up such systems is quite often beyond the reach of small-scale sheet metal industries. Further, Majority of the developed CAD/CAM systems for progressive die cannot perform many tasks such as checking of design features of sheet metal parts, design of strip-layout, selection of progressive die components and material selection of die components, which are highly dependent on the knowledge and experience of the designers. Therefore, it is most appropriate to use knowledge-based methods to establish CAD/CAM systems for the design of progressive dies. The advantages of using knowledge-based system approach include the utilization of the knowledge of domain experts, high efficiency and flexibility. Development of such systems for press tools can also promote systematization and standardization of the knowledge in sheet metal forming.

Some researchers have used knowledge-based system approach to conserve experienced based knowledge of die design experts. But the use of these systems is very limited. They can either handle only blanking and piercing operations or parts with relatively simple geometry. Thus, there is a stern need to develop a knowledge-based system for intelligent design of progressive dies using both CAD and AI approach collectively. The system should be capable of performing major activities of progressive die design such as checking of design features of sheet metal parts, design of strip-layout, selection of progressive die components and material selection for die components. Further, the system should be flexible enough to accommodate any future modifications on the advancement in technology. It should be interactive and have low cost, which can be easily affordable by small and medium scale sheet metal industries.

2.8 FORMULATION OF THE PROBLEM

The reviewed literature reveals the possibility of developing a knowledge-based system for tackling the problems of progressive die design intelligently. The above comprehensive
study has evolved to identify the following five problems in the intelligent design of progressive dies for sheet metal work –

- Checking of design features of sheet metal parts.
- Modeling of strip-layout for progressive dies
- Selection of type and dimensions of progressive die components
- Selection of suitable materials for progressive die components.
- Automatic modeling of progressive die components and die assembly.

In the present research work, a knowledge-based system has been developed for intelligent design of progressive dies. The knowledge-based system approach of Choi et al [Choi 1998, 1999, 2001] has been utilized for development of modules for checking of design features of sheet metal parts and intelligent design of strip-layout. Lee’s approach [Lee 1993] for selection of progressive die components and accessories, Duffy’s approach [Duffy 1991] for modeling of die components and die assembly, and expert system’s approach for selection of materials for progressive die components have been utilized in the present investigation. Efforts have been applied in the development of the system in such a way that the system is capable of checking the design features of sheet metal parts, selection of suitable die and press machine, modeling of strip-layout automatically, selection of die components and the selection of materials for progressive die components. The system is also capable of generating drawings of die components and die assembly of progressive die automatically. The system modules have been coded in AutoLISP language and designed to be loaded into the prompt area of AutoCAD. The system is developed in such a way that it can conveniently be used without in depth knowledge of tool design.