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Knowledge-based expert system in manufacturing planning: state-of-the-art review

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In this paper, an effort has been made for intense review on Knowledge-Based Expert System (KB-ES) applications in manufacturing planning. Uniqueness of the present review work is addressed in terms of analysis on published review articles and their review gap. Research works exemplified between 1981 and 2016 were reviewed in terms of ES application in handling product variety, execution of process planning activities, machining, tool selection, tool design, welding, advanced manufacturing, product development. A statistical analysis was carried out in relation with number of publications, domain-specific area and their percentage contribution. It was inferred that, most of the work focused on ES applications related to tool design and machining apart from execution of various process planning activities. Future research can focus on the development frame-based, object oriented-based, ontology-based knowledge representation in order to develop robust system in decision-making for handling complex engineering problem. ES applications can be extended to field of micro fabrication, machine tool development and integrated system development from design to manufacturing.

Keywords: CAPP; artificial intelligence; manufacturing; knowledge-based system; expert system

1. Introduction

Knowledge-based expert system or Expert System (ES) deals with computer programme that possess own decision-making capability to solve a problem of interest. ES concerned with creation of computational system that imitates intelligent behaviour of human expertise. John McCarthy invented AI in 1956, explored a machine that could reason, solving problem and self improvement similar to human being. It possesses the key characteristics such as adaptive control, better handling and reusability of stored knowledge. According to the sophistication, ES system performs actions such as perception, interpretation, reasoning, learning, communication and decision-making in order to arrive at a solution for the given problem. From the inception ES system, various developments have been done, which broaden its application to include pattern recognition, automation, computer vision, virtual reality, diagnosis, image processing, non linear control, robotics, automated reasoning, data mining, process planning, intelligent agent and control, manufacturing (Xu, Wang, and Newman 2011; Yusof and Latif 2014).

Process Planning (PP) using computer automates the procedure of preparing a sequence of operations involved in manufacturing a product. CAPP plays vital role in integrating Computer-Aided Design (CAD) and Computer-aided Manufacturing (CAM) (Steudel 1984). Traditional approaches involve the use of experts in solving PP-related problem. The domain experts use their knowledge and skill to determine the processing steps required for manufacturing within the available resources. Problems associated with conventional PP include; expert's dependency, time consuming and inconsistent in nature. To overcome the bottleneck with traditional approach, Niebel extrapolated the use of computers in decision-making for PP in 1965. Over the period, various research works exemplified related to CAPP system (Alting and Zhang 1989). CAPP generally is divided into variant and generative approaches. Variant technique based on part similarity within a part family using Group Technology (GT) perception, it follows the mechanism that equivalent part necessitate-related plan (Xu, Wang, and Newman 2011). It requires expert to categorise a part, feature information input, recover comparable plan and makes essential alteration. In intelligent or generative type, process plan was developed in accordance with geometry information, decision logic and algorithms. It synthesises process plan for a new product, based on part shape, material and other variables that affect the manufacturing decision. Geometry description is the prime input to the system. It provides quick advice to the designers and closely joined with the product-modelling activities. KBS is the foremost development in Intelligent Process Planning (IPP) (Leo Kumar et al. 2014). Block diagram of KBS for IPP for micro parts is shown in Figure 1.

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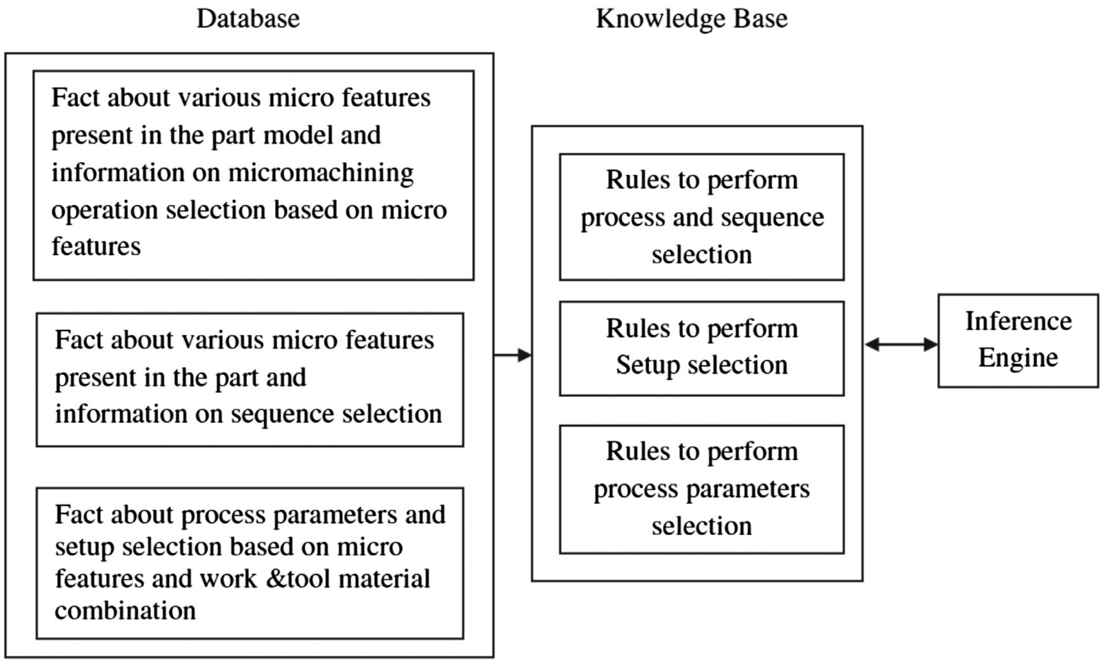

Figure 1. Block diagram of KBS for IPP of micro parts, Leo Kumar et al. (2014).

In this work, an attempt has been made to perform state-of-the-art review on ES applications in CAPP and manufacturing. The objective is to provide intense knowledge to the researcher from the origin to latest trend of research work exemplified in the field of PP and manufacturing. Research work carried out for the past three and half decades (1981–2016) were considered. Major part of the work was devoted to CAPP and also certain manufacturing application also presented.

2. Expert system

ES or KBS uses knowledge and deduction measures to resolve problems that necessitate significant human experts for the solution. KBS is a branch of AI invented by AI society in 1960s (Liao 2005). Fundamental principle behind KBS is based on expertise, a reservoir of specific task of interest. ES is an efficient tool for maintaining the knowledge crucial for manufacturing competitiveness and used for training and disseminating knowledge in an organisation. ES permits simplified transfer of knowledge with minimum cost. An imperative instruction learned by AI in 1960 states that, general purpose problem solver is weak and less efficient in solving complex problems. The power of ES comes from the knowledge rather than the specific inference. This new vision of AI systems manifests the development of more powerful problem solvers (Patterson 2011).

KBS receives expert knowledge coded into facts, rules, heuristics and procedures. ES comprises three elements include database, knowledge base and inference engine. The general architecture of KB-ES is shown in Figure 2. The database possesses information in terms of fact or heuristics based on user interest of specific problem domain. Knowledge base possesses domain knowledge expressed in terms of mathematical logic. Accordingly, it is classified as Rule-Based System (RBS), Frame-Based System (FBS), Object-Oriented System (OOS) and Case-Based Reasoning (CBR) system. RBS based on 'if- then' else condition and will execute certain task, once the condition is satisfied. FBS uses 'frame' as a structure for representation as a concept or a situation. OOS becomes more structured form of representing information in terms of hierarchy of classes, subclasses and behaviour of objects.

Inference engine acts as a controlling environment and interacts with the user. It receives input from the user about the problem and takes additional information as desired. It understands the knowledge base to formulate inferences and provides experts advice. Various research works are exemplified related to the various elements of ES in the past decades. In this work, it is divided into two broad categories; (1) Knowledge acquisition and validation, (2) Knowledge acquisition for process planning.

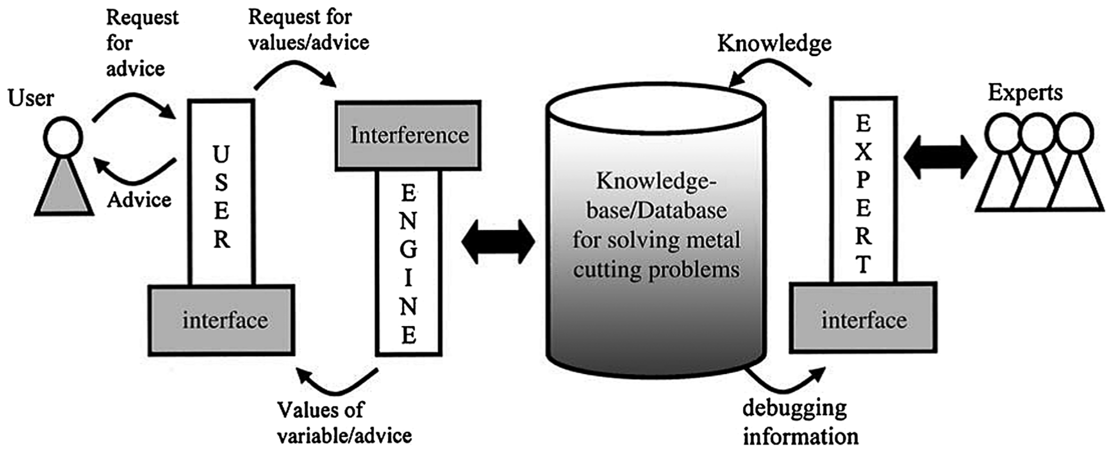

Figure 2. Knowledge-based expert system (Cakir and Cavdar 2006).

3. Preceding review work on expert system in manufacturing planning

From the inception of CAPP in 1960, various review works were exemplified related to ES in decision-making for manufacturing planning for a range of domain applications shown in Table 1. Weill, Spur, and Eversheim (1982) mentioned the areas of computer utilisation with typical examples and existing CAPP system and their characteristics. Austin (1984) performed review on AI planning, characteristics and addressed their research development. Steudel (1984) presented the use of computers in planning for the production of discrete product. Nau and Chang (1985) incorporated ES approach for generative PP. Eversheim and Schulz (1985) carried out a survey on CAPP system and addressed its current trends.

Gupta and Ghosh (1989) carried out a review on ES application in PP and manufacturing. The key focus is on problem definition, implementation scheme, special features and enduring efforts for design and development of ES for manufacturing. CAPP performs vital role in developing Computer-Integrated Manufacturing (CIM) system. Alting and Zhang (1989) carried out review based on 14 well-known CAPP system. Future research trends include interfacing, integration, database system, workstation and software relocation strategy are presented. Gupta (1990) performed a review on ES for Automated Process Planning (APP). Need for ES technique, important features and limitations were addressed. Representation of knowledge base, control policy and suggestions were made for possible future direction. Shah, Sreevalsan, and Mathew (1991) performed survey on different elements of APP programming include part definition, reasoning and search techniques, traditional and Al-based methods and PP languages. Also Numerical Control (NC) programming techniques categorised into cell decomposition, volume decomposition, sectioning and geometric reasoning.

CAPP has received strong research attention from practitioners and researchers. One of the key benefits includes reduced throughput time and improved quality. Marri, Gunasekaran, and Grieve (1998) performed review with focus on insight into design and realisation of CAPP system. The review between 1989 and 1996 related to different PP systems are considered and future research direction are presented. Tu, Chu, and Yang (2000) proposed a CAPP framework for virtual production corporation. The problems involved in customised products, product development approach, network, part and production data, capturing of opportunities and response to customer's demands, customer influence, partners selection and synthesis are addressed. Ahmad, Haque, and Hasin (2001) performed a summary of current development of research work in CAPP includes design by solid modelling, Object-Oriented Programming (OOP), database, ES and AI. Recent research areas include feature extraction, AI techniques like Genetic Algorithm (GA), Artificial Neural Network (ANN) and Fuzzy Logic (FL) were presented.

Liao (2003) performed analysis on Knowledge Management (KM) technologies and its applications. Future research directions are presented in terms of expert orientation, suggestion for different social methodologies to implement KM technology. Duflou, Váncza, and Aerens (2005) performed a review on research connected with PP for sheet metal bending operation. Modelling of bending operation, in-process observation, adaptive control techniques, part demonstration and feature categorisation methods are discussed. Bottlenecks in PP for sheet metal forming are presented and ergonomic study for process plan assessment also carried out. Tisza (2007) proposed integrated simulation and knowledge based approach for PP and die design for sheet metal forming processes. Finite element based analysis was carried out

Table 1. Review articles on ES in process planning.

Author and year	Title	Key focus
Weill, Spur, and Eversheim (1982)	Survey of Computer Aided Process Planning System	Computer utilisation and their issues
Steudel (1984)	Computer-aided process planning: past, present and future	AI in process and their characteristics
Davies and Darbyshire (1984)	The use of expert systems in process-planning	Discrete manufacturing
Kastner and Hong (1984)	A review of expert systems	Expert system application
Shaw and Whinston (1985)	Automatic planning and flexible scheduling: A knowledge-based approach	Process planning and scheduling
Eversheim and Schulz (1985)	Survey of computer aided process planning systems	Process planning
Ham and Lu (1988)	Computer-aided process planning: the present and the future	CAPP
Kusiak and Chen (1988)	Expert systems for planning and scheduling manufacturing systems	Process planning and scheduling
Gupta and Ghosh (1989)	A survey of expert systems in manufacturing and process planning	Process planning and manufacturing
Alting and Zhang (1989)	Computer aided process planning: the state-of-the-art survey	CAPP characteristics
Gupta (1990)	An expert system approach in process planning: current development and its future	Automated process planning
Zlatareva and Preece (1994)	State of the art in automated validation of knowledge-based systems	KBS Validation
Kiritsis (1995)	A review of knowledge-based expert systems for process planning. Methods and problems	KBS characteristics
Marri, Gunasekaran, and Grieve (1998)	Computer-aided process planning: a state of art	CAPP elements and issues
Tu, Chu, and Yang (2000)	Computer-aided process planning in virtual one-of-a-kind production	Process planning
Ahmad and Anwarul Haque (2001)	Current trend in computer aided process planning	AI in process planning
Metaxiotis, Askounis, and Psarras (2002)	Expert systems in production planning and scheduling: A state-of-the-art survey	Production planning and scheduling
Liao (2005)	Expert system methodologies and applications – a decade review from 1995 to 2004	Expert system characteristics
Duflou, Váncza, and Aerens (2005)	Computer aided process planning for sheet metal bending: A state of the art	Sheet metal bending
Tripathi (2011)	A Review on Knowledge-based Expert System: Concept and Architecture	Human resource
Xu, Wang, and Newman (2011)	Computer-aided process planning – A critical review of recent developments and future trends	Variant and generative approach characteristics
Sahin, Tolun, and Hassanpour (2012)	Hybrid expert systems: A survey of current approaches and applications	Hybrid expert system
Yusof and Latif (2014)	Survey on Computer-Aided Process Planning	AI techniques
Isnaini and Shirase (2014)	Review of Computer-Aided Process Planning Systems for Machining Operation: Future Development of a Computer-Aided Process Planning System	CAPP in machining

to minimise stamping defect and redesign exemplified to shorten lead time and development cost. Quotation preparation for competitive pricing is a critical process for companies and it is a complex task due to huge quantity of variation.

García-Crespo et al. (2009) highlighted cost and price fixation methods in which KBS can be implemented. Recommendations on future requirements of KBS for price estimation of also presented. Fixtures used for production have direct influence on part quality, productivity and cost. Wang et al. (2010) performed a review on use of computer in fixture design and their automation for the decade between 2000 and 2010. Fixtures types and their applications, various approaches include intelligent and automatic fixture design methods, fixture configuration layouts and verification procedure are highlighted. Statistical analysis and future research direction also presented. Li, Xie, and Xu (2011) performed review on recent development of KBS. Knowledge acquisition techniques, rule- and case-based system approaches for developing the knowledge base, software tools are presented. Real-time application in manufacturing and future research direction are also presented. Tripathi (2011) discussed about the architecture, characteristics, life style, knowledge representation techniques and applications of KB-ES in Human Resource.

Xu, Wang, and Newman (2011) performed review on CAPP for the period between 2000 and 2010. CAPP approaches include feature-based technologies, KBS, AI techniques such as ANN, GA, Fuzzy Set (FS) theories, Petri Nets (PN), Agent Based (AB) and Standards for Exchange of Product Model Data (STEP) compliant approaches are presented. Sahin, Tolun, and Hassanpour (2012) carried out a review on hybrid ES approaches in connection with neuro-fuzzy system. Published articles between 1988 and 2010 were analysed and observed that, neuro-fuzzy and rough neural ES-based industrial applications are developed recently. Isnaini and Shirase (2014) performed review on CAPP in material removal process. Various elements include model convention, operation, resource, cutting condition, tool path and setup selections were described and future expansions are presented. Yusof and Latif (2014) performed a comprehensive survey on KBS, ANNs, GA, FS and FL, PN, ABS, Internet, STEP-compliant and functional blocks method for the period between 2002 and 2013.

3.1 *Review gap*

From the review, it was observed that quantum of research works exemplified related to CAPP based on variant and generative approaches. Most of the review work focused on CAPP system applications. It is observed that, very few work addressed about ES for PP and manufacturing and no review work was carried out since 2014. ES seems to be an inevitable tool to support decision-making in manufacturing planning, scheduling, machining, inspection, etc. Hence, in this work, an attempt has been made to perform review ES applications in PP and manufacturing for the past three and half decades 1981–2016. The main objective is to provide through idea to the researcher for the existing development from the origin to the present scenario. It will provide a clear representation on research gap and the need for providing unique solutions to the current problem for the benefit of engineering society.

4. Expert system in decision-making

ES provides major application in intelligent decision-making for solving specific problem of interest and its applications are widespread due its unique domain independent characteristics. In this work, ES applications are categorised into three broad areas; (1) Execution of process planning activities, (2) Manufacturing planning and (3) Diverse applications. CAPP and manufacturing applications are focused mainly on mechanical engineering domain. Also some miscellaneous applications are taken into the consideration and addressed as follows:

4.1 *Manufacturing planning*

ES is helpful in autonomous decision-making in broad domain spectrum. In general, a typical process plan consist of information related to process and sequence selection, equipment, tool and setup selection, etc., in order to transform raw material into finished product (Scallan 2003). In the mid-1980s due to lack of expert in manufacturing planning, there is a need for automation of PP functions. Various research works exemplified in order to extrapolate the ES applications. In this work, ES application for manufacturing planning are classified into broad categories; (a) Part variety, (b) Process planning activities, (c) Machining, (d) Tool Selection, (e) Tool design, (f) Welding, (e) Advanced manufacturing and (f) Product development.

4.2 *Part variety*

Sackett and Evans (1981) carried out implementation of CAPP in small- and medium-scale manufacturing industries. Implementation methods and their benefits are addressed. Davies and Darbyshire (1984) developed EXCAP system for manufacturing planning and addressed various implementation issues. Descotte and Latombe (1984) developed ES for PP of mechanical parts. Rule-Based System (RBS) approach was incorporated for advice generation. Individual process related with feature include faces, slots, bores, notches grooves and the rules were developed in accordance with the machining features.

Freedman and Frail (1986) developed ‘OPGEN’ operation sheets generator to perform assembly of Printed Circuit Boards. List in Processing (LISP) language incorporated for rules development. Obstacles involved during development, integration and reposting were also presented. Wang and Wysk (1987) developed ‘TURBO-CAPP’ system for symmetrical parts. Rahman and Narayanan (1987) incorporated structural data and rule based approach for PP generation. Design and PP system integration is a challenging task in development stages. Tsatsoulis and Kashyap (1988a) developed prototype KBS that uses high-level, Memory Organisation Packages (MOPs), meta-MOPs and thematic organisation packets to modify its knowledge. TOLTEC representation language was designed to represent dynamic change of knowledge and a novel planning method was proposed to solve planning problems.

Joshi, Vissa, and Chang (1988) presented a hierarchical integrated framework for design and PP system integration through AI techniques. CAD interface for Feature Recognition (FR), Tool Approach Direction (TAD) determination and precedence relationship was discussed and case study implementation were presented. Pande and Walvekar (1989) also developed PC-CAPP system for prismatic components used for electric tools. Giusti, Santochi, and Dini (1989) proposed generative type 'KAPLAN' system for PP of axis symmetry parts. If-Then rules logic was incorporated characterisation of knowledge and the system capability demonstrated with case study. Part feature information is an input for CAPP system.

Younis and Wahab (1997) framed ES for axis symmetry parts and the knowledge base was framed by the advice from different ES classes, realisation from existing work and heuristic programming and a prototype system was developed successfully. Kim et al. (1997) proposed geometric reasoning system for part modelling and PP for mill-turn parts. Convex decomposition and mapping method were used for FR and to relate feature volumes. Jiang, Lau, and Chan (1998) introduced generative system for prismatic components based on flexible digit coding scheme. GT-based scheme combined with RBS to develop process plan for operation sequence, machines, cutting tools and process parameters selection. The structure of modules aimed at interfacing PP functions and manufacturing system. A prototype was developed and tested successfully.

Ciurana et al. (2000) proposed information system to determine optimal sequence for minimisation of non-cutting time. An Object-Oriented Programming (OOP) was incorporated to obtain all workable sequencing. Information system transfers the relationship among operations to generate sequencing. Proposed system effectiveness verified through implementation for axis symmetry parts. CBR is an intelligent problem solving technique, performs searching through database for similarity to the current problem.

Chang, Lu, and Liu (2002) performed PP for prismatic part using holes, pockets and slots features. Proposed system composed of elements which include feature indexer, modifier, simulator and repairer. The developed system can formulate a typical process plan and implemented using geometric modeller in OOP environment.

Siva Sankar et al. (2008) developed a CAPP framework for rotational components shown in Figure 3. Parameters optimisation for minimisation of machining time and cost. AI tool Particle Swarm Optimisation (PSO) was incorporated for the determination of best sequence using machine tool data, parameters and their constrains. Vamsikrishna, Shankar, and Surendra Babu (2011) developed a system to create process plan based on FBM and integrated modelling approach. It comprises three modules include FBM, information storage and process plan preparation. KBS approach was incorporated to formulate process plan based on feature information and production rules and validated for symmetric components.

System performance validated with case study. Expert system handling part variety is shown in Table 2.

4.3 *Process planning activities*

Pande and Palsule (1988) developed generative 'GCAPPS' system possesses modules for geometry representation, machine, tool selection, sequencing of operation, parameter selection, time and cost computation and report generation. Developed package was tested for a group of turned components. Tsatsoulis and Kashyap (1988b) developed TOLTEC KBS with the emphasis on process plan design, design errors detection, manufacturing errors recovery, planning errors recovery, handling branching solutions and performance improvement through the learning techniques. Decision-making in process plan generation depends on part feature information.

Kusiak (1991) mentioned the problems and possible solutions for various PP phases include sequence, tool and fixture selection. Qualitative planning problems were solved using KBS approach and quantitative problems were solved using optimisation approach. Implemented concepts are presented with a case study. Dong and Hu (1991) presented a methodology for optimal sequence selection using KBS. Manufacturing knowledge embedded into KBS in terms of production rules. Optimal sequence was determined by combining knowledge deduction and quantitative optimisation. Abdou (1992) presented an integrated approach for process plan generation using ES. KBS was designed to automate the process plan development and developed system application illustrated with case study.

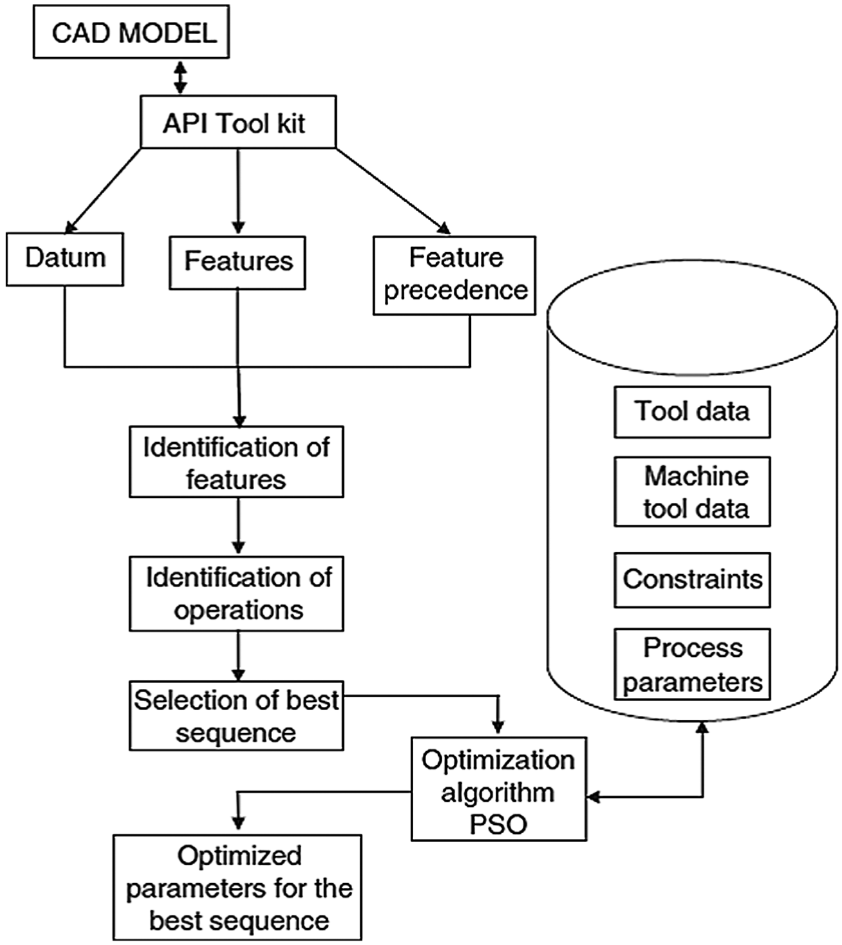

Figure 3. CAPP framework for rotational components (Siva Sankar et al. 2008).

Table 2. Expert system in handling part variety.

Author and year	Typical KBS	Application domain
Sackett and Evans (1981)		Small and medium scale industries
Davies and Darbyshire (1984)	EXCAP	Mechanical parts
Descotte and Latombe (1984)		Mechanical parts
Shaw and Whinston (1985)		Flexible manufacturing System
Freedman and Frail (1986) developed	OPGEN	Printed Circuit Board Assembly
Wang and Wysk (1987)	TURBO – CAPP	Axis symmetry parts
Brooks, Hummel, and Wolf (1987)	XCut	2 and ½ D machining of prismatic and rotational parts
Tsatsoulis and Kashyap (1988a)	TOLEC	
Pande and Walvekar (1989)	PC-CAPP	Electrical tools
Giusti, Santochi, and Dini (1989)	KAPLAN	Axis symmetry parts
Younis and Wahab (1997)		Axis symmetry parts
Kim et al. (1997)		Mill-Turn parts
Jiang, Lau, and Chan (1998)	Generative	Prismatic components
Ciurana et al. (2000)		Sequence determination
Chang, Lu, and Liu (2002)		Prismatic part
Siva Sankar et al. (2008)	CAPP	Rotational components
Vamsikrishna, Shankar, and Surendra Babu (2011)		Symmetric components

Kiritsis (1995) performed a review on ES for PP and their connected approaches. Various components of ES and problems related to the part and product description, FR and PP activities are discussed. List of 52 prototype systems were presented and their uniqueness were summarised. Kojima et al. (2000) developed a system with reference to machining instance data acquired through examination of tool catalogues; related standards and handbooks. World Wide Web (WWW) technology and Java language were used for system development. Prototype system for end milling cutting conditions selection was developed and their performance was validated through case study.

Shehab and Abdalla (2002) developed a KBS for the selection of material, machining process and parameters based on set of design and production parameters and product cost. Hybrid knowledge representation scheme includes production rules, frame based and Object oriented were used for the representation of manufacturing knowledge. Advanced manufacturing industries possess dynamic planning capabilities, since it produce variety of products in batches. Wang, Feng, and Cai (2003) framed a methodology for dynamic and distributed PP with the help of function blocks. Two-layer structure include supervisory and operation planning were used and inferred that, the proposed architecture enhances system function in a dynamic production environment.

Deb and Ghosh (2007) incorporated CLIP RB-ES shell to automate setup planning activities for axis symmetry components. It is capable of formulating setup plans automatically by taking input data including part information, TAD and geometric tolerance relationship for machining of features. Set of rules were developed for precedence sequence based on heuristics knowledge. It is inferred that, the developed system minimises execution time, cost effective and provides practical use for industrial applications. Oba, Ishida, and Takeuchi (2008) initiated decision support system to assist tool posture in multi-axis micromachining. Date, Krishnaswami, and Motipalli (2009) proposed an approach for manufacturing planning and tool path generation for machining of free-form features in mill-turn centre. Machining of part with β-spline protrusion was carried out by rough machining, followed by finish profile cutting. The developed system supports convex and concave profiles. Algorithm was tested on mill-turn centre and inferred that, the produced part met the desired dimensional specifications.

Wang and Gong (2009) developed an approach for PP of 3D microstructures used in Bio-MEMS application. It automatically formulates data for process plan along with mask based on model defined using B-representation. A prototype process planner was implemented in order to validate the system performance. Deb, Parra-Castillo, and Ghosh (2011) developed an integrated IPP for symmetric parts. Machining operations sequencing and setup planning were automated. ANN was incorporated for operation selection by acquiring specific knowledge in terms of thumb rules. CLIPS-RBS used for set-up creation, sequencing of operation and datum selection. The developed system validated with a case study. The machining cost is based on IPP and collection of process parameters. Problem associated with machining parameter received huge attention and many methodologies were developed. Gupta et al. (2011) developed ES 'ExIMPro' for machining to represent operation sequence, tools and parameters for cost minimisation.

Helgoson and Kalhori (2012) introduced a model for distribution and amalgamation of knowledge for process planning. Customised software tools were incorporated for combining process and data related to the information. Cutting tool data management and tool selection system are presented. Sun et al. (2012) developed a new integrated setup/fixture planning approach to identify the optimal and practical plan. The planning was conducted under four steps. (a) The dissimilarity degree matrix, operation precedence graph and hybrid graph were used to describe the requirements and constraints (b) A setup precedence graph was used to describe precedence constraints between setups. (c) Suitable locating surfaces were selected for each setup. (d) All the plans were evaluated based on the number of setups and recalculation of dimensions. Effectiveness of the developed system demonstrated with a case study.

Assembly sequence planning plays an indispensable role in the manufacturing industry and gathering of assembly knowledge is a challenging task. Wu, Zhao, and Wang (2013) proposed a novel approach for assembly sequence planning that offers a way to articulate geometric information and knowledge. Assembly connection graph was built according to the knowledge in design and manufacturing fields. Finally, assembly planning example was presented to display the effectiveness of the projected approach. Leo Kumar et al. (2014) proposed a KBS for automatic process plan generation for micromachining of turn-mill parts. Machine tool capability and part feature information were fused into knowledge base in terms of production rules in Visual Studio environment. Hence, in relation with part feature information, KBS generates process plan. Kashkoush and ElMaraghy (2015) proposed a novel knowledge-based mixed-integer programming model for generating the assembly sequence of a product based on available assembly sequence data. The model finds the optimal assembly sequence tree for an existing product family based on the assembly sequence trees of individual product family members. The developed model was demonstrated using a family of pilot valves. Summary of ES application in execution of process planning activities are shown in shown in Table 3.

Table 3. Expert system in execution of process planning activities.

Author and year	Typical activities	Application domain
Pande and Palsule (1988)	GCAPPS	Turned components
Tsatsoulis and Kashyap (1988b)	TOLEC	
Lee, Lee, and Lee (1989)	FEXCAPP	Prismatic parts
Kusiak (1991)	Process Sequence and tool selection	
Dong and Hu (1991)	Sequence selection	
Abdou (1992)	Process plan automation	
Kiritsis (1995)	Process planning	
Kojima et al. (2000)	Tool selection	End milling
Shehab and Abdalla (2002)	Machine, process parameters and tool selection	
Wang, Feng, and Cai (2003)	Operation planning	
Deb and Ghosh (2007)	Setup planning	
Oba, Ishida, and Takeuchi (2008)	Tool posture selection	Micromachining
Date, Krishnaswami, and Motipalli (2009)	Tool path generation	
Wang and Gong (2009)	Planning for 3D micro structures	
Deb, Parra-Castillo, and Ghosh (2011)	Operation sequencing and setup planning	Symmetry components
Gupta et al. (2011)	Sequence, tools and parameters optimization	
Helgoson and Kalhori (2012)	Tool selection	
Sun et al. (2012)	Setup/fixture planning	
Wu, Zhao, and Wang (2013)	Assembly sequence planning	
Leo Kumar et al. (2014)	Sequence, tool and fixture selection	
Kashkoush and ElMaraghy (2015)	Assembly sequence planning	

4.4 *Machining*

Machining is a material removal process in order to produce a part/product from the raw material with desirable quality. Quality of the finished product depends on expert working with the system and the type of tooling involved it. ES replaces the need of human expertise in decision-making on machining process selection, cutting conditions, tooling requirements etc. Volume of research works were accomplished related to the use of KBS for machining in the past decades. Eshel, Barash, and Johnson (1986) developed RBS for PP of symmetry components. Proposed system concerned with formatting the possibility of metal flow and rules are organised as design, test, rectify and compute categories. Automated reasoning programme manipulates the rules in order to formulate a process plan. Brooks, Hummel, and Wolf (1987) developed a RBS 'XCut' that formulates process plan for the production of prismatic components from geometric description. About 300 rules were generated for 2 and ½ D machining. Also various issues are addressed. Joshi, Vissa, and Chang (1988) presented an integrated hierarchical framework of PP with a CAD interface. The development of CAD interface was discussed with automated feature recognition, determination of tool approach direction and the precedence relationship between the features. PP module was described with the part representation, knowledge base and the plan generation procedure. The developed ES demonstrated with case study.

Lee, Lee, and Lee (1989) incorporated pattern recognition technique for feature extraction and generative CAPP system 'FEXCAPP' for machining of prismatic parts. Feature extraction was carried out by utilising directed data structure and adjacency graph methods. Tree search approach was used for machining sequence formulation, TAD and tool radius based on feature information. Axiomatic approach was used for the determination of machining conditions. There is lack of complete integration between CAD and NC systems due to complexity involved in PP. Joseph and Davies (1990) proposed EXCAP system for axis symmetry parts using ES and the integration of CAD and NC machine tool was made through IGES file. Customised algorithms were used for automatic generation of NC programme for simple turned components. Cho, Lee, and Ahn (1991) proposed a system for the integration of PP and monitoring for CNC turning operation. The integration of data and knowledge processing were carried out and validated for the accuracy. Luong and Spedding (1995) demonstrated KBS for PP and cost assessment for hole making. Implementation study shows that, there is consistency output in planning and cost estimation. Khoshnevis and Tan (1995) also developed a system for automated PP of hole making operation.

Jain, Batra, and Garg (1995) developed an interactive generative PP system for die-sinking operation. The system comprise modules for tool management, component representation and process plan generation in accordance with feature information. The developed system minimises process plan generation time considerably and reduces the need for skilled operators. Tiwari, Kotaiah, and Bhatnagar (2001) incorporated CBR system that comprise part representation, case retrieval and adoption module. Developed system validated with industrial case study. Vidal et al. (2005) designed a system to support parameters selection for milling operation. An algorithm was developed to optimise the operation cost. Process variables include geometry factors, machine and tool were taken into the consideration and variety of parts are evaluated and verified. Based on real-time experiment, it was observed that, reduction of 35% processing time was achieved.

Cakir and Cavdar (2006) developed a KB-ES 'COROSolve' to investigate the problems encountered in drilling, milling, turning and related processes. Proposed system suggests recommendation through Graphical User Interface (GUI) and possible research directions are addressed. Li, Gao, and Liu (2007) developed PP system for 'MEMS' components produced by surface micromachining. Feature semantics are observed and process models are built for every layer concurrent with production layer. Prototype system developed for demonstration purpose. It automatically decides tool posture for 5 axis control machining. Giannakakis and Vosniakos (2008) developed ES for PP for sheet metal operations. Knowledge acquired from handbooks and catalogues are represented as 'Crude' rules and coded into CLIPS ES environment and the output was tested for real-time sheet metal components.

In end milling of pockets, the radial depth and feed rate will fluctuate during movement of cutter along the corner. It leads to unstable cutting force and poor accuracy. Gao, Xue, and Wu (2012) proposed cutting force model for CNC end milling of pocket features using process knowledge. Optimum milling parameters intended in terms of dynamic cutting force model and work material characteristics. Real-time experiment proves the usefulness of the optimisation results. Lee et al. (2013) proposed a hole machining PP system for marine engines. Industrial requirements are converted in terms of rule and it can be edited based on the requirements. System comprise hole manager, sequence definition and operation manager. Strategic procedure was established for efficient coordination and case study implementation for engine block and engine cylinder were carried out. Wang (2013) developed web-based architecture for machine accessibility monitoring and PP. Function blocks were used for prototype implementation. Integration of proposed system with a shop floor framework enables real-time monitoring for metal cutting operations.

Singh and Deb (2014) developed an intelligent CAPP methodology based on KBS for generation of process plan for machining. Based on part feature information, KBS performs decision-making in operations sequence, setup selection, locating and clamping for fixturing and setup sequence. A set of rules were developed using ES Shell and its performance validated through example component. Newman et al. (2015) proposed a framework 'iActive' for PP of additive and subtractive manufacturing. It is also combined with inspection process. Modified plans were developed using combined processes and discussed with case studies. Leo Kumar, Jerald, and Kumanan (2015) developed a KBS for parameters selection for machining of prismatic micro parts. Industrial catalogues, real-time experimentation and handbooks were considered in developing the knowledge base and their performance validated with case study. Summary of ES typical applications in machining is shown in Table 4.

Table 4. Expert system applications in machining.

Author and year	Typical KBS	Application domain
Eshel, Barash, and Johnson (1986)		Rotational parts
Brooks, Hummel, and Wolf (1987)	XCut	Prismatic components
(Joshi, Vissa, and Chang 1988)		Machining
Lee, Lee, and Lee (1989)	FEXCAPP	Prismatic parts
Joseph and Davies (1990)	EXCAP	Axis symmetry parts
Cho, Lee, and Ahn (1991)		CNC Turning
Luong and Spedding (1995)		Hole making
Khoshnevis and Tan (1995)		Hole making
Jain, Batra, and Garg (1995)		Die sinking
Kulkarni, Marsan, and Dutta (2000)		Layered manufacturing
Tu, Chu, and Yang (2000)		Virtual Production
Tiwari, Kotaiah, and Bhatnagar (2001)		Machining
Vidal et al. (2005)		Milling
Cakir and Cavdar (2006)	COROSolve	Problem in Drilling, Milling and Turning
Li, Gao, and Liu (2007)		Surface micromachining
Gao, Xue, and Wu (2012)		CNC end milling
Lee et al. (2013)		Hole making
Wang (2013)		Metal cutting
Singh and Deb (2014)		Machining
Newman et al. (2015)		Additive and subtractive manufacturing

4.5 *Tool selection*

Arezoo, Ridgway, and Al-Ahmari (2000) developed an ES for cutting tool and cutting conditions selection named 'EXCATS' for turning operation. Proposed system consists of inference engine, explanation facility and knowledge base. Part feature is the primary input to the system and it optimise tool and cutting parameters automatically. Carpenter and Maropoulos (2000) proposed a system 'OPTIMUM' for preparation of tooling and evaluation of machinability for milling operation. RBS approach and regression techniques were incorporated for tool and cutting data selection for a range of work materials. It was inferred that, developed approach provides flexible support for planning of milling operation. Mezgár et al. (2000) described the use of hybrid system combined with simulation techniques in handling complex problem. Various classifications and the scope for the integration with simulation tools for design and control of dynamic, stochastic and complex systems are presented. Chan, Ip, and Lau (2001) proposed an advisor 'MHESA' for selection of material handling equipment. It comprises database, KB-ES to assist equipment selection and Analytic Hierarchy Process (AHP) model to decision-making. It is inferred that, proposed approach minimises decision-making time.

Zhao, Ridgway, and Al-Ahmari (2002) proposed 'EXACTS' for amalgamation of CAD and KBS for cutting tool selection. The integral system capable of extracting the data from the CAD model using FR. KBS was developed for set-up, geometry detection, FR and the system performance validated with step turned components. Wong and Hamouda (2003) developed online KBS for machinability data selection using FL inference mechanism. OOP, dynamic link library and active control was employed for KBS development and verified for local and wide area network environment. FMS are intricate in nature, if there is large volume of information flows. Özbayrak and Bell (2003) proposed three KBSs include production scheduling, tool management and fault diagnosis systems to simplify decision-making process. More than 400 production rules were incorporated in a structural manner and observed that, ES shell ensures satisfactory results. Many cutting tools are involved to form die and mould, ranges from deep hole drills to micro ball end-mills. An expertise is always desirable to incorporate specific production rules. Chtourou, Masmoudi, and Maalej (2005) presented ES based on simulation approach to formulate solution search mechanism, architecture is shown in Figure 4. A prototype was developed and observed that, rule based and OOP tool provides satisfactory results.

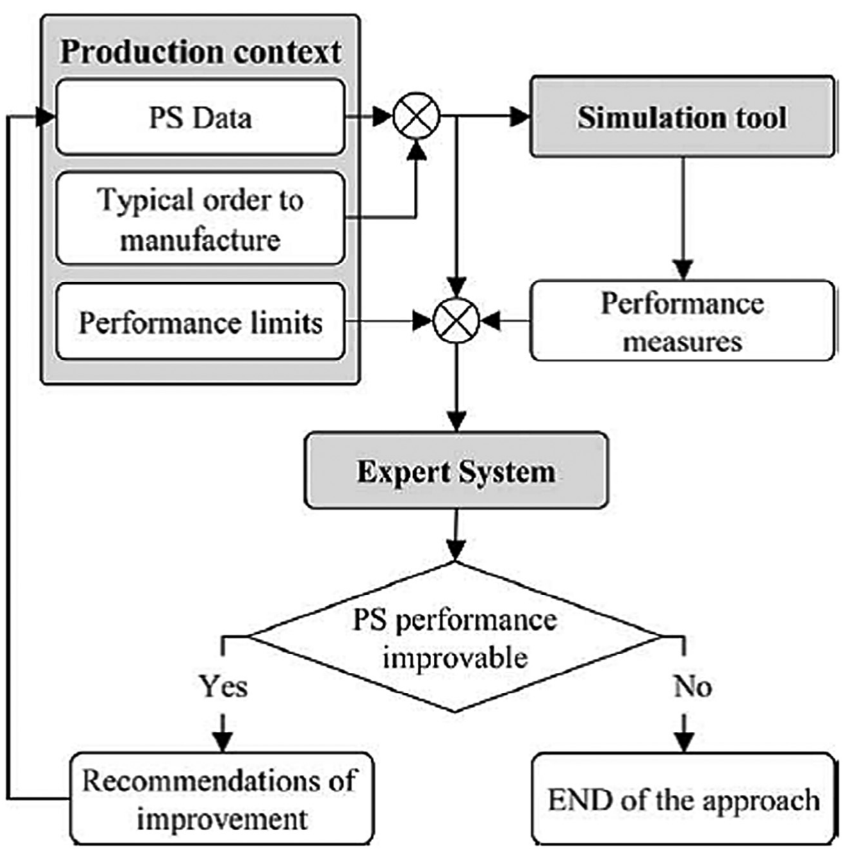

Figure 4. ES for manufacturing systems machine selection (Chtourou, Masmoudi, and Maalej 2005).

Table 5. Expert system applications in tool selection.

Author and year	Typical KBS	Application domain
Arezoo, Ridgway, and Al-Ahmari (2000)	EXCATS	Cutting tool and conditions selection
Carpenter and Maropoulos (2000)	OPTIMUM	Machinability evaluation for milling
Mezgár et al. (2000)		Hybrid system
Chan, Ip, and Lau (2001)	MHESA	Material handling equipment selection
Zhao, Ridgway, and Al-Ahmari (2002)	EXCATS	Cutting tool selection
Wong and Hamouda (2003)		Machininability data selection
Özbayrak and Bell (2003)		Tool management
Chtourou, Masmoudi, and Maalej (2005)		Machine tool selection
Alberti et al. (2011)		Milling tool Selection
Khan, Hussain, and Noor (2011)		Flexible manufacturing system
Wang, Li, and Huang (2016)		Tool path minimisation
Prasad and Chakraborty (2016)		End mill tool selection

Complete analysis of problem in metal cutting plays noteworthy effect on quality and overall manufacturing cost. Alberti et al. (2011) proposed a system to assist milling machine tool selection. System developed according to the product dimension accuracy, process variables, interpolation method and cost. Experimental data were obtained from profile machining with various geometrical zone and ANN models were utilised for prediction. Khan, Hussain, and Noor (2011) presented an integrated approach for planning and designing of number of machining centres, material handling system selection, layout and networking architecture and cost analysis for FMS. System performance was validated and observed that, proposed methodology capable of considering design inputs and assist in design and selection of practical FMS.

Cutting tool selection is an imperative task in PP for efficient production and cost effectiveness. Wang, Li, and Huang (2016) proposed branch and bound algorithm for machining of complex parts. It is divided into sub-machining features with a single machining operation. Proposed algorithm sequence minimises the non cutting tool path. Case study implementation for aircraft manufacturing was carried out. Prasad and Chakraborty (2016) developed a KBS in Visual Studio environment for end-mill selection. KBS narrow down the end-mill based on preset parameters. Weight criteria were set to keep away from improper judgments. The developed system assist the planner to obtain proper cutting conditions. Summary of ES application in tool selection along with respective KBS is shown in Table 5.

4.6 *Welding*

Welding is an assembly processes used for physical joining of materials, Groover (2010). ES assist in decision-making for physical joining of parts with desired quality. Taylor (1986) developed a KBS for planning of arc welding process in which, the rules were framed for specimen preparation and parameters selection based on work material properties. Wang et al. (2006) incorporated ES to ensure quality of welding projects. The activity includes construction of ES repository, knowledge acquisition, application of reasoning mechanism and realisation for welding process qualification. Proposed system has theoretical and practical value for intelligence of welding design. Laser additive manufacturing technologies integrated to CAPP in order to achieve best performance. Arntz, Wegener, and Liu (2015) implemented CAPP for laser deposited welding, which is focused on individual geometries and to offer solution for complex manufacturing and repairing task. Control of process parameters were considered within the CAM system. Hence, the machining strategies can be fitted to the part's geometry. Summary of ES application in welding along with respective KBS is shown in Table 6.

Table 6. Expert system applications in welding.

Author and year	Application domain
Taylor (1986)	Welding parameters selection
Wang et al. (2006)	Weld quality prediction
Arntz, Wegener, and Liu (2015)	Laser assisted welding

4.7 *Tool design*

Siddique (1990) developed 'KBS-SETUPP' system for PP of steel tube production process. It is competent enough to develop process plans, production schedules and capabilities to support PP. Generated process plans compared with the actual plans for their accuracy. Lee, Lim, and Nee (1991) developed 'IKOOPP' KBS for the production of plate for progressive dies. Die assembly components are modelled and feature information along with geometrical properties are extracted and their attributes are converted into Object-oriented representation. Functional knowledge permits automatic deduction of PP information and tooling knowledge formulated in terms of production rules for cutting tools, machining allowances and operations sequence. Smith et al. (1992) described a relational database system for PP of sheet metal parts that integrates a feature-based relational database for the parts. A forward chaining rule-based strategy for machine selection and feature-specific execution of the rules and a graph theoretic cost optimisation model for optimal process plan selection were incorporated. It was inferred that, with the expertise of shop floor personnel, an efficient integration of PP and ES strategies can be accomplished.

The design of the press tool and its PP functions are particular and knowledge-intensive activities. Lee, Lim, and Nee (1993) also developed an intelligent Knowledge-based Object-Oriented PP System for progressive die plates. The Object-oriented schema, production rules and heuristic representations are effectively integrated to represent the complex relationships in die design, process planning, heat treatment and fixture design. The developed system validated with a case study. Lim, Rho, and Cho (1994) developed KB-PP system for injection mould design. Part features are designed using FBD approach and attribute information used as input. Design rules were acquired through empirical knowledge and shop floor data. Proposed system performance validated through design of split cavity plate. Britton, Tor, and Li (1996) addressed the research work related to PP of mould for plastic products. Industrial requirements of PP and the use of Object oriented model in process plan generation are presented.

Kong, Hodgson, and Nahavandi (2000) developed a system to integrate expert knowledge, empirical models, process analysis, etc., and observed that, the proposed system reduce cost, improve quality and increases competitiveness for metal forming process by the selection of necessary setting for the current industry practices. Mok, Chin, and Ho (2001) proposed 'IKMOULD' KBS for injection mould design. KB graphic module integrated within CAD framework and accessed through interactive programme. The developed approach facilitates design standardisation and minimise manufacturing time considerably.

Chan et al. (2003) developed KBS 'IKB-MOULD' to assist the design off injection mould for polymer part production and it integrates design and knowledge management modelling environment. Tor, Britton, and Zhang (2005) presented KB blackboard architecture for stamping PP. Object oriented feature modelling was incorporated for part modelling and stamping operation mapped with feature objects. Graph-based approach incorporated for process plan generation. Prototype system was developed through 'CLIP' ES cell and the effectiveness of the system validated through case study. Jin, Luo, and Fang (2001) proposed KBS to assist decision-making in tube bending process. Object oriented concept and goal driven search mechanism featured by graphical user interface were applied for the development of KBS. It is inferred that, proposed system minimises the inaccuracy in tube bending process. Kim, Kim, and Choi (2001) proposed a system for hot forging and blanking operations. CAPP system written on Auto-LISP and drafting language were used for implementation. Blank complexity, punch and die profiles, press availability and standards parts were taken into consideration for KBS development. Observed results enable the forging and blanking die designer and manufacturer to produce defect free components.

Kang and Park (2002) investigated process sequence design and constructed CAPP system for deep drawn parts. Proposed system comprise modelling module to determine surface area, blank design module to fashion oval-shaped blank and PP module. Production rules related to drawing coefficient, punch and die radii are formulated by interaction with field engineers. Validation was carried out through case study implementation. Kumar, Shanker, and Lal (2003) proposed 'GIFTEP' system for PP of cold extrusion of complex shape products through single hole dies. Based on the component layout, feature recognition module provides necessary data to carry out the die design process. The process parameter module performs optimisation and calculates the optimal process parameters. Finally, an optimal process plan corresponding to the chosen criteria were generated.

Cakir, Irfan, and Cavdar (2005) developed 'DieEX' ES to assist mould and die making operations. The geometry, work and tool material and type of operation are considered as input. It provides recommendations on tool and its specifications, work holding, machining operation, feed and offset values. ES performance was validated with case study implementation. Kumar, Singh, and Sekhon (2006) described a KBS for assisting manufacturability of sheet metal parts. Knowledge representation was carried out using rule and frame-based system approach and integrated with CAD environment. System performance validated for small-scale industry. Pan and Rao (2009) proposed CAD/CAM-based ES for sheet metal parts. It comprise modelling, nesting, PP, NC programming, simulation and reporting modules, integrated through OOP data structure to ensure seamless data processing. System performance was demonstrated through case-study. Naranje and Kumar (2010) performed comprehensive review on AI techniques applications in manufacturability evaluation of sheet metal parts. Salient features of present research works and future research scopes are presented.

Automotive body panels are complex in nature than common stamped parts, since it is composed of group of free-form surfaces. Tsai et al. (2010) automates PP and die design for automotive panel using Knowledge-Based Engineering (KBE) methodology shown in Figure 5. CBR approach integrated into traditional process planning for the development of hybrid KBE system. It is inferred that, CBR approach ensures reuse of existing knowledge to create new design and their performance demonstrated with a case study. Die component selection is an important step in drawing die design and requires empirical knowledge. Naranje and Kumar (2012) developed a KBS for die components selection. RBS approach was utilised and modules are coded using commercial Auto-LISP. It is inferred that, KBS provides recommendations on die block, stripper, die gauges, punch plate, die set, fasteners, etc., and validation was carried out through industrial sheet metal part.

Potočnik, Ulbin, and Dolšak (2012) presented KBS to provide quality support to the designer, while making decision on plate-press. The developed system provides an opportunity to attain crucial decision and inferred that, there is reduction of design time and design quality improvement. Lin and Sheu (2012) developed a methodology for planning strip layout for shearing process in progressive dies. Die design rules classified into prior, posterior, compatible, sequential and simultaneous uses. Factors are coupled with weightings and it supports the designers to achieve better results. Naranje and Kumar (2014b) also developed KBS for deep drawing die design for symmetric components. RBS approach utilised for construction of the knowledge base, comprise 27 modules coded in Auto-LISP. Proposed system

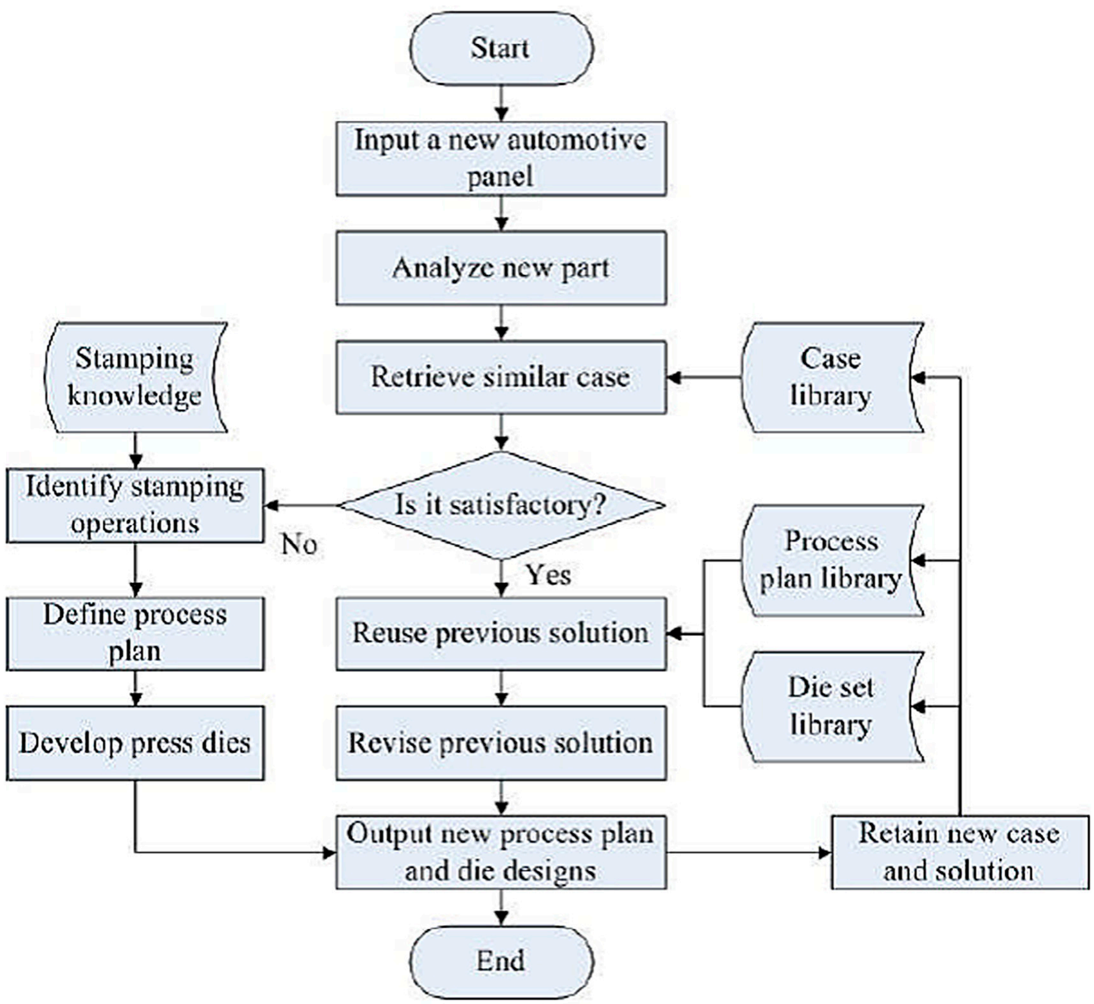

Figure 5. KBE framework for automotive body panel die design (Tsai et al. 2010).

Table 7. Expert system applications in tool design.

Author and year	Typical KBS	Application domain
Siddique (1990)	KBS-SETUPP	Steel tube production
Lee, Lim, and Nee (1991)	IKOOPP	Progressive die plate production
Smith et al. (1992)		Sheet metal parts
Lee, Lim, and Nee (1993)		Forming die
Lim, Rho, and Cho (1994)		Injection mould design
Britton, Tor, and Li (1996)		Mould for plastic parts
Kong, Hodgson, and Nahavandi (2000)		Metal forming
Jin, Luo, and Fang (2001)		Tube bending
Kim, Kim, and Choi (2001)		Hot forging and blanking
Mok, Chin, and Ho (2001)	IKMOULD	Injection mould design
Chan et al. (2003)	IKB-MOULD	
Kang and Park (2002)		Deep drawn parts
Kumar, Shanker, and Lal (2003)	GIFTEP	Cold extrusion
Cakir, Irfan, and Cavdar (2005)	DieEX	Die making
Tor, Britton, and Zhang (2005)	CLIPS-ES	Stamping process
Tor, Britton, and Zhang (2005)		Stamping
Kumar, Singh, and Sekhon (2006)		Sheet metal parts
Pan and Rao (2009)		Sheet metal parts
Naranje and Kumar (2010)		Sheet metal parts
Tsai et al. (2010)		Automotive panel die design
Tepi et al. (2011)		Injection mould
Chen, Yau, and Lin (2012)		Complex shoe mould
Naranje and Kumar (2012)		Die component selection
Potočnik, Ulbin, and Dolšak (2012)		Plate press
Lin and Sheu (2012)		Strip layout planning for progressive die
Naranje and Kumar (2014a)		Deep drawing die design
Yurdakul et al. (2014)	PROSEL	Net shape manufacturing

capable of performing activities include manufacturability evaluation, strip layout design, PP, die components selection, modelling and assembly. Yurdakul et al. (2014) presented a decision support system for net-shape primary manufacturing process selection termed PROSEL. The developed system eliminates the unsuitable processes by checking part's material, production quantity, specified shape, thickness and presents the most economical process after a final cost analysis. The developed system was written in Visual Studio and tested with real-life examples.

Automation of design and manufacturing planning are the best method to improve polymer mould production process. Tepi et al. (2011) performed a review on dedicated PP system for injection moulding through CAD/CAPP/CAM technologies. Knowledge base growth for mould parts, material selection, software solutions and their related case studies are demonstrated and future research scope are presented. Chen, Yau, and Lin (2012) developed a CAPP system for complex shoe mould. Auxiliary boundary curve generation and machining strategies were incorporated and the domain knowledge embedded into knowledge base. System performance validated through automation of different complex, several shoe moulds and compared with traditional system. Naranje and Kumar (2014a) incorporated frame based system approach for the selection of process parameters and strip layout in sheet metal industries. System performance was validated for deep drawn parts. Summary of ES applications in tool design is shown in Table 7.

4.8 *Advanced manufacturing*

Layered manufacturing (LM) is a promising manufacturing technology that enhances manufacturing scope and PP is indispensable task in LM. Kulkarni, Marsan, and Dutta (2000) carried out review on LM and presented possible future research directions. Tu, Chu, and Yang (2000) proposed CAPP framework for virtual production organisation. The issues involved in customised products, concurrent PD approach, network-based production, reply to customer's demands and customer influence were addressed. Chang and Wee (1985) developed KB planning system for mechanical assembly using robots. Two novel approaches include problem analysis and hierarchical representation was incorporated and analysis was performed with the help of heuristic rules. Fung (1989) proposed ES framework 'XBAK' for diagnosis of microchip manufacturing tool. Methodology, features, execution and problem-solving structure are described and inferred that, the developed architecture can be used for solving similar machine diagnostics problems.

Linn and Wysk (1990) demonstrated an ES-based Automated Storage/Retrieval System controller ‘ECSSIM’ that plans a control strategy based on system characteristics. It was inferred that, system performance was well at high demand levels and demonstrated with real-time application. Coordinate Measuring Machine (CMM) is an efficient tool for geometry inspection. Gu (1994) developed knowledge based inspection planner to integrate CAD and CMM system. Based on task decomposition, it is designed with modules include knowledge base, control operator and interface. Interfacing of modules is realised by accessing procedures in order to transfer activities and decisions.

Computerisation of Small- and Medium-Sized Enterprises (SME) leads to improvement of business capabilities. Huin, Luong, and Abhary (2003) presented requirements of multi-stage SMEs and proposed KB resource planning model using AI techniques. It ensures more amount of knowledge in the electronics and precision engineering sectors. Lan, Ding, and Hong (2005) presented a new approach for the selection of appropriate rapid prototyping process according to user’s specific requirements using the ES and fuzzy synthetic evaluation. The selection process is divided into two stages include the generation of feasible alternatives and formulation of ranking order to finalise most crucial prototyping system. Two examples of rapid prototyping process selection were designed to demonstrate the application of the system.

Chakraborty and Dey (2007) incorporated Quality Function Deployment (QFD) approach for Non-Traditional Machining (NTM) selection. It is inferred that, QFD-based ES automate the decision-making process using GUI and visual aids. High-Speed Machining (HSM) used to produce contour surface accurately with desirable surface finish. Reconfigurable Manufacturing Systems (RMS) provides flexible, challengeable and dynamic manufacturing platforms. Based on customer requirements, the manufacturing systems need to be reconfigured. Mpofu, Kumile, and Tlale (2008) performed a review on software package and their characteristics in building KBS for RMS.

Liu, Khan, and Oh (2010) developed KBS ‘FASTCUT’ to acquire technological information for HSM. KBS provides specific knowledge of various aspects of HSM include cutting parameters, tool materials, etc. A sequential structure was proposed for the knowledge base and inferred that, it provides insight into stability analysis during HSM for the manufacturing of products. Zhang, Xu, and Shou (2011) proposed a prototype KBS for autonomous generation of production processes. XML-based knowledge demonstration was used to minimise the complexities in product modelling, process data and planning of knowledge. A mechanism was designed for the formulation of production rules and implemented for truck family. Mohamed and Khan (2011) implemented hybrid KBS in lean process for low-volume automotive manufacturing. The KBS analyses the difference between existing and the benchmark standards for lean process for implementation through gauging absences of pre-requisites. Developed system provides valuable information for decision-makers to implement low-volume manufacturing process.

Machining centre configuration is an imperative activity in FMS design. Chowdary and Muthineni (2012) proposed ES to automate machining centre selection while design FMS. ES ‘kbFMC’ was developed, which comprises database, knowledge base and an deduction engine. System performance was demonstrated with a case study. Azaryoon, Hamidon, and Radwan (2015) developed a KBS for NTM process selection using analytic network techniques and Vikor

Table 8. ES applications in advanced manufacturing.

Author and year	Typical KBS	Application domain
Chang and Wee (1985)		Mechanical assembly using robots
Fung (1989)	XBAK	Microchip diagnostic tool
Linn and Wysk (1990)	ECSSIM	Automated Storage/Retrieval System
Gu (1994)		Coordinate measuring machine
Kulkarni, Marsan, and Dutta (2000)		Layered manufacturing
Jones (1988)	ART	Front end scheduling
Fähnrich, Groh, and Thines (1989)		Production application
Tu, Chu, and Yang (2000)		Virtual production
Huin, Luong, and Abhary (2003)		Small- and medium-sized manufacturing
Lan, Ding, and Hong (2005)		Rapid prototyping process
Chakraborty and Dey (2007)		Non-traditional machining
Mpofu, Kumile, and Tlale (2008)		Reconfigurable manufacturing system
Liu, Khan, and Oh (2010)	FASTCUT	High speed machining
Zhang, Xu, and Shou (2011)		Production process automation
Mohamed and Khan (2011)		Lean implementation in automotive manufacturing
Chowdary and Muthineni (2012)	kbFMC	Machining centre selection
Azaryoon, Hamidon, and Radwan (2015)		Non-traditional machining process selection

tool. It assess dissimilar performance types, financial factors and presents set of processes and inferred that, the developed system provides satisfactory performance. Summary of expert system applications in advanced manufacturing is shown in Table 8.

4.9 *Product development*

Assembly is the most significant stages in Product Development (PD). Design for assembly involves the use of certain tools to assist the designer in planning and analysis of assembly process. Zha, Du, and Qiu (2001) proposed KB-ES to assist top-down design approach for product assembly, its structure is shown in Figure 6. It involves connection of product design, assimilability study, evaluation and economical analysis. Chin and Wong (1996) explored the usefulness of KBS in the design and development of plastic product at the conceptual stage. Frame-based representation was used for the creation of EIMPPLAN-1 that assist in the selection of appropriate plastic material and mould injection design features were presented.

Collaborative Product Development (CPD) can ensure information required for manufacturing. Rodriguez and Al-Ashaab (2005) developed knowledge-based CPD system that, facilitate knowledge fusion in product development. System architecture description and implementation was carried out for injection mould product. Harik, Derigent, and Ris (2008) carried out PP for structural components using USIQUICK package. System performance was validated through commercial software package in Product Life Cycle Management environment and future research scope are presented. Tseng and El-Ganzoury (2012) developed an intelligent system based on concurrent engineering phenomenon for innovative product development. Conceptual design stage is considered and frame based system approach was used for knowledge representation.

Gleadall et al. (2016) presented a framework for the transformation of a product concept to exhaustive process chain in hybrid manufacturing domain. KBS was developed to enable manufacturing expertise integrated with sequence for design and process chain selection. Feature-based design approach was incorporated to guide the designer during embodiment phase and implemented for electronic products. Summary of expert system applications in product development is shown in Table 9.

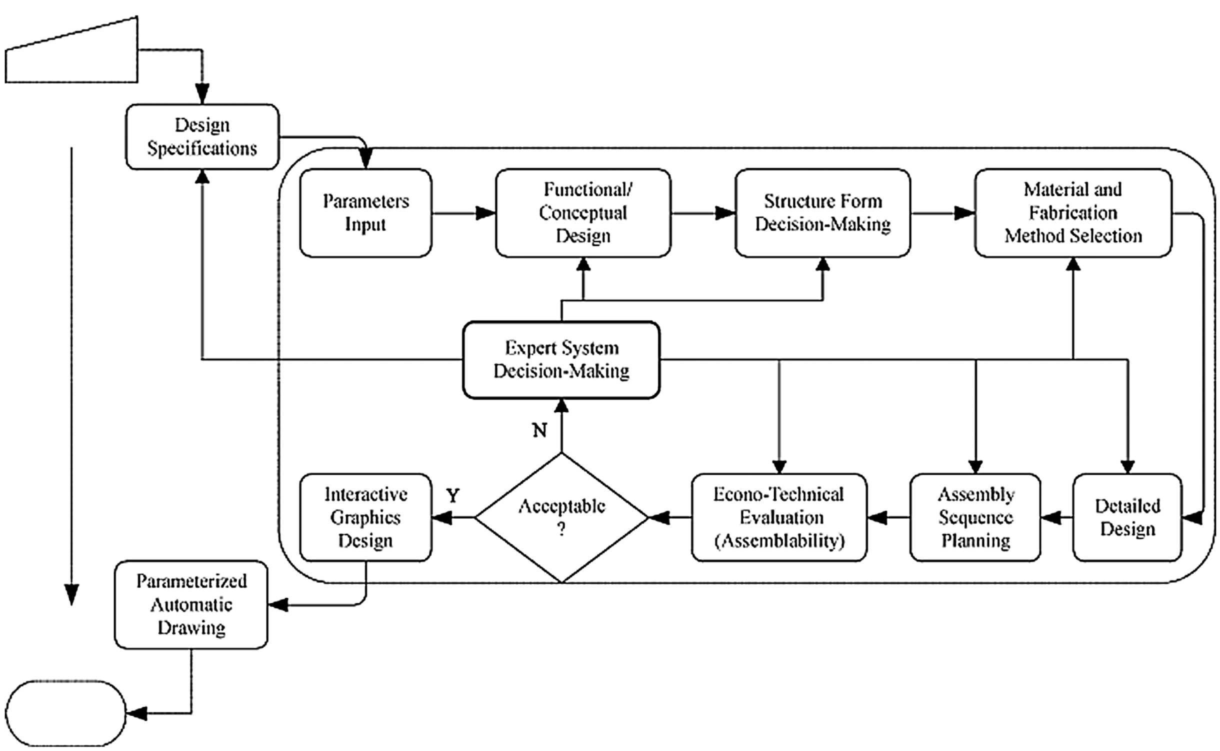

Figure 6. Knowledge-based approach for assembly oriented design (Zha, Du, and Qiu 2001).

Table 9. ES applications in product development.

Author and year	Typical KBS	Application domain
Chin and Wong (1996)	EIMPPLAN-1	Plastic product
Zha, Du, and Qiu (2001)		Product assembly
Rodriguez and Al-Ashaab (2005)		Collaborative product development
Harik, Derigent, and Ris (2008)	USIQUICK	Product life cycle management
Tseng and El-Ganzoury (2012)		Concurrent engineering
Gleadall et al. (2016)		Hybrid manufacturing

5. Statistical analysis

ES applications in PP and manufacturing are considered in this work for the review. The research work exemplified in the past 35 years 1981–2016 are taken into the contemplation. Publications referred in this work are mainly from Elsevier, Taylor & Francis and Springer publications. Articles with focus on mechanical manufacturing are alone taken into the consideration for review. Since the inception of CAPP by Niebel in 1965, various review works were carried out related to CAPP system in order to extrapolate its applications across domains. There are 24 review articles related to CAPP and ES since 1981, shown in Table 1. It is observed that, nearly 11 articles are published related to ES system applications in PP and manufacturing since 1981 and no review work has been carried out related to ES in PP and manufacturing since 2011. Number of articles between the period 1981 and 2016 is shown in Figure 7 and domain specific details are shown in Figure 8.

Summary of ES development related to part variety, execution of process planning activities, machining, tool selection, tool design, welding, advanced manufacturing and product development are in Table 2–9. It is observed that, most of the work focused on customised ES development for specific application. More number of research works accomplished in the field of tool design. Quantum of work related to execution of various process planning activities were also carried out. Machining related activities are also exemplified with the considerable numbers. Advanced manufacturing field also strengthened to the maximum extent with the applications of an expert system. Very limited work on welding and product development related works are exemplified within the scope of domain applications. It is also observed that more number of works are exemplified related to rule-based knowledge representation. Considerable number of works related to frame-based system approach.

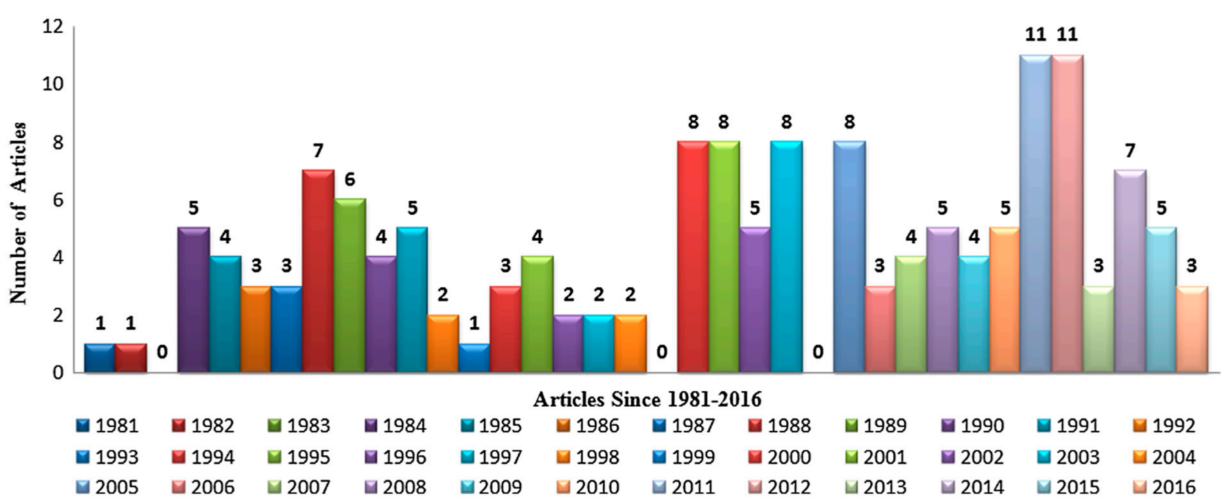

Figure 7. Number of published articles since 1981–2016.

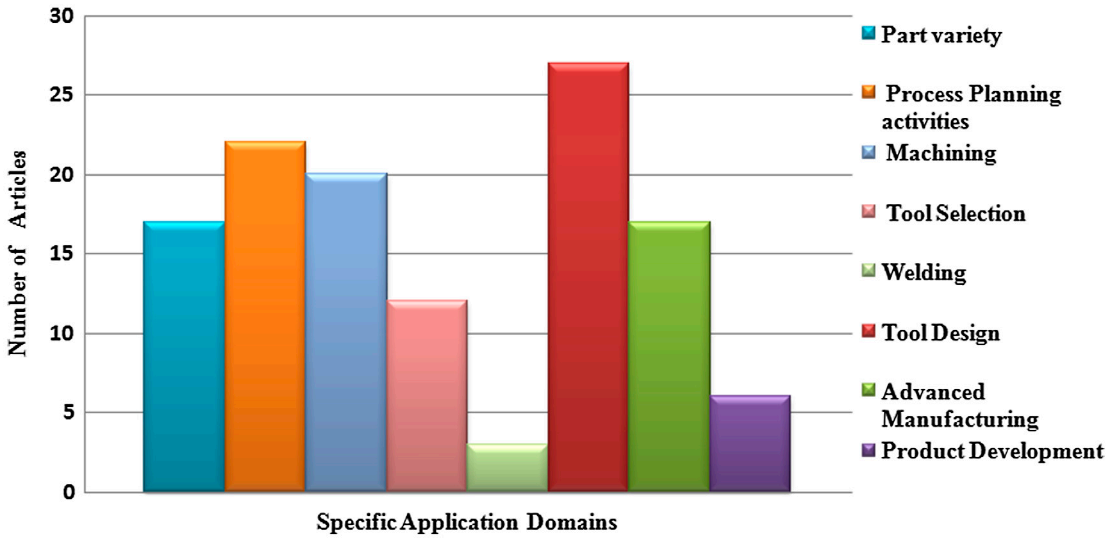

Figure 8. Published articles under domain specific areas.

6. Possible future research direction

Statistical analysis helps to predict the current research status of ES in manufacturing planning and it is a challenging task. Based on the review, possible future research directions are identified. Existing research work focused on ES elements includes knowledge representation, knowledge acquisition techniques, validation and implementation case studies. Customised KBS were developed for manufacturing applications. It includes automated PP for prismatic and rotational components, Bio-MEMS application, inspection planning, IPPS, steel production, production planning and control, pattern recognition, condition monitoring, machining and business PP, process parameters selection.

Apart from PP, various research work exemplified to extrapolate the manufacturing application include cutting tool selection, simulation, material handling equipment selection, machinability data selection, FMS design, die and mould making, machine selection, NTM process selection, sheet metal operations planning, HSM, web-based quotation development, characteristics study, deep drawing, welding process selection, additive and LM, stainless tube production, sheet metal forming, progressive and injection moulding die design. Various research work exemplified related to miscellaneous application includes protocol management, assembly using robots, machine diagnostic, strategic market planning, CMM for inspection, optimal crop planning, assembly oriented design, business process reengineering, cost estimation, risk evaluation, CPD, defence budget planning, bench marking, job shop scheduling, power generation, location planning, embodiment design, etc.

From the published work, it is inferred that quantum of research works carried out related to the use of ES. Most of the work focused on solving specific problem of interest. Future research can focus on developing a robust KBS, which has the capability to update its data and knowledge base based on user's interest. Conceptual representation of scope for future research direction is shown in Figure 9. Most of the published work focused on RBS approach of developing the knowledge base. RBS is complex in nature when the number of rules increases. Incorporation of other approaches include frame based, case based reasoning approach, object oriented, ontology based can handle such problem efficiently. Most of the published work focused on standalone KBS for typical application in one location. Fusion of KBS into web environment can ensure the benefits of KBS to the remote environment. It also eliminates the need of multiple experts for specific problem domain.

Application domain area have been divided into various categories include micro fabrication, machine tool development, process improvement, integrated system development, advanced welding and forming processes. The demand for micro and miniature parts are increasing nature. Micro fabrication by through conventional and advanced micromachining processes provide huge application in the recent decades. Incorporation of ES for micromachining processes, precision and ultra-precision machining can be carried out as future research scope. Leo Kumar et al. (2014) performed review on micromachining and addressed the need of KBS in micro fabrication. ES for decision-making in machine tool development, process improvement and online measurement having huge research scope in across domain application.

Limited amount of work focused on advanced welding, forming processes and the issues involved knowledge acquisition and validation. Hence, research can be strengthened by addressing solution to knowledge acquisition and ES for

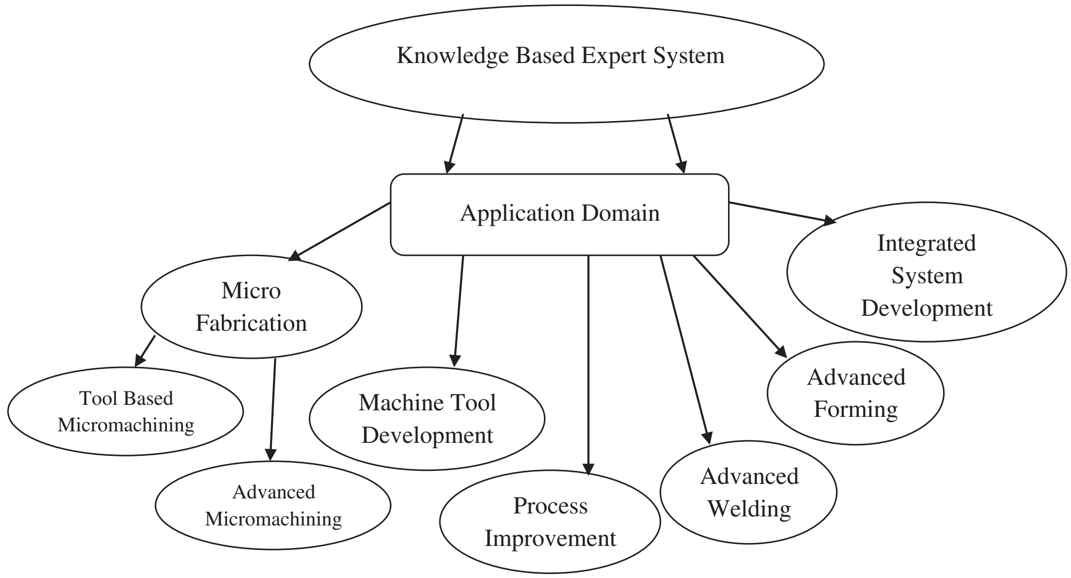

Figure 9. Conceptual representation for scope for future research in KB-ES development.

specific problem of interest. KBS development in digital environment that possess API with GUI capability can support customisation. Incorporation of adaptive control feature will ensure ES becomes more intelligent for autonomous decision-making in dynamic environment. Minimum number of work focused on integrated design, PP and manufacturing using ES. It is mandatory for the development of complete CAPP system for typical application and it ensures true CAD/CAPP/CAM integration. Future work can focus on providing key solution for integrated ES development for specific application domain.

7. Conclusions

In this work, an effort was made to perform review on ES applications in manufacturing planning. Role of KBS for PP and manufacturing applications were presented. The research carried out for the past 35 years (1981–2016) are considered and analysed. Apart from general consideration, future research can focus on strengthening the following area:

ES can be strengthened by enhancing the capability for dynamic update of database to accommodate future requirements. Development of user friendly KBS through API and GUI, incorporation of adaptive control, inclusion of ES for advanced machining processes, precision and ultra-precision machining, micromachining, machine tool and process development and to support online measurement can be taken as future research direction. Incorporation of ES in integrated CAD/CAPP/CAM system development will ensure realistic system to assist decision-making for manufacturing. Development of ES advanced forming and joining processes having huge research scope.

In the present study, ES in manufacturing planning are presented. Published work focused mainly on mechanical manufacturing. ES applications are widespread and it can be applied to any system that needs replacement of human expertise to provide useful solution. Review on domain application and their current research trend will help the researcher to identify the research gap and to minimise review time considerably.

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