Feature clustering based approach for generation of reconfigurable machining process plan with kinematic configuration

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AUGUST, 2018

Declaration

I certify that this research work titled "Design of Universal Joint" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student

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Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Copyright Statement

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Dedicated to my parents, my teachers and friends for their patient support and not losing hope in me.

ABSTRACT

Reconfigurable manufacturing systems (RMS) found a novel manufacturing model of mass customization and co-evolution and are measured as the prospect of manufacturing because of their variable and adjustable nature. As the product of design and its manufacturing abilities are narrowly related, the manufacturing system is anticipated to be customizable to accommodate for all the design modifications at any granularity level from machining to product assembly.

This research work is based on mass customization and co-evolution concepts for RMS and generates a framework for reconfigurable process planning of the whole part family instead of single part variant. The part variety decomposition model (PVDM), developed by Qing's, is used with reconfigurable machining operation plans (RMOPs) developed in matlab by using the feature clustering from models and cutting tool charts data and precedence relationships (PRs) developed for part family.

To extract the configurations of part and RPP, for part variant of the same part family dynamic constraint satisfaction problem (DCSP) in constraint logic programming (CLP) language Eclipse is used. The data obtained from DCSP is then used to develop process plan and kinematic configurations for the required part variant of the part family.

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CHAPTER 01: Introduction

Worth addition is the very fundamental of, manufacturing industry. Manufacturing also dwell on economy by worth creation. Due to saturation of manufacturing market, world globalization along with global warming, trends is shifting to consumer satisfaction and environment friendly industries. Consumer satisfaction wants quality and change with time, so industries must focus on improving quality of products while sustaining worth within a scope that provides viable gain and is appealing for consumers. One challenge for companies today is to achieve the economies of scope without dropping too much on the economies of scale.

Manufacturing industries are in an incessant competition, concentrating headed for management techniques such as (TQM) and motivated to advance their products to get viable benefit. Developments such as these can be fetched from superior standard products and dropping price bearing quality in notice or by well-timed supply and new products. This creates the necessity for novel technologies and ideas for product design but as well as for the manufacturing structure and whole system.

Manufacturing structures stretching from devoted and permanent to completely involuntary and adjustable, from remote services or job workshops to computer integrated systems. The necessity of system is dogged by the type of requirements. Requirements like production volume, type of customer, demand govern whether it need job workshop, static, isolated or uninterrupted production system. Thus, for the selection of manufacturing systems these multiple factors have to be kept in notice.

The intention of selecting such a manufacturing system that consumes the ideal resources and provides reasonable gain in lowest capital investment provides managers and designers with a great contest as it is a multi-objective job with numerous contradictory goals in a manner that increasing one decreases the other. The aforesaid requirements are the reason due to which intelligent manufacturing systems are changing old-fashioned manufacturing systems in today’s world because of latent profits linked with them.

1.1 Motivation

Different type of manufacturing systems has been established over the years due to fluctuating environment and situations like fresh technologies developed, products and consumer desires.

These are the external factors but in addition to these there were internal factors too for instance to have the waste low and gain productivity, scrap negligible, shrink inventory and labor charges etc. These necessities were the key factors for evolved and integrated manufacturing systems which can be extra alert, and consumer centered.

1.2 Advance Manufacturing Systems

Models of manufacturing systems like ifactory for reconfigurable manufacturing system respond to the modern-day requirements in unusual ways. Systems like these can be quick to respond and can deliver essential conversions every time required at diverse level.

1.3 Changeability/Variations

"*The quality of manufacturing industries to be adaptable in a constantly evolving manufacturing environment can be described as changeability*". To compete in international market, manufacturing systems should be changeable in such a way that develops, products and facilities layout must be made flexible hence it can be altered due to differences in external or internal factors (requirements).

Responsiveness or variability is essential because of vagueness in a manufacturing system. It is compulsory at various stages in a manufacturing system.

- Factory stage
- Assembly stage
- Process planning stage
- Manufacturing stage

1.3.1 Factory Stage

Due to the product deviations, factory level changeability is required. Modifications are to be made at shop floor and design needs to be altered because of the fluctuating market. This create a necessity for a vibrant facility planning. Along with that it is desired to increase and decrease the manufacturing capacities in line with the loads, beside that inventory control would also have to be adjustable.

1.3.2 Assembly Stage

Owing to product variety variations are desirable at production lines or assembly lines which are retained flexible to achieve the compulsory responsiveness.

1.3.3 Process Planning and Control Stage

Due to part variety variations are desirable to be prepared at machine level. To handle such variations different types of machine structures are suggested in the literature, which are reconfigurable to variation for specific variety of part/product requirements. Part variety is classified in part families, for which there occur different kinematic configurations of machines and for each new part variant there occur optimized configuration of machines set ups and posts.

1.3.4 Manufacturing Stage

Manufacturing systems experience sluggish variation in present movement of industrialization. Players must target to fulfil present demands and adjust to be flexible to future demands. This method can augment the option of applying computer integrated manufacturing.

1.4 Manufacturing Systems

The customary manufacturing setups cannot be incorporated in the existing international market and the change is required. Since dedicated systems had the potential of manufacturing exclusive goods on the basis of their design. In (DML), each layout is mainly sketched to construct a specific product. Meanwhile the layout is exclusively oriented for the goal, it takes minimum period to manufacture and providing the part appeal is high so production capacity rise, unit price of the product will decrease and price for buying dedicated tools will be catered. Figure 1.1 shows a DML for a cement industry focused on the above discussed objective.

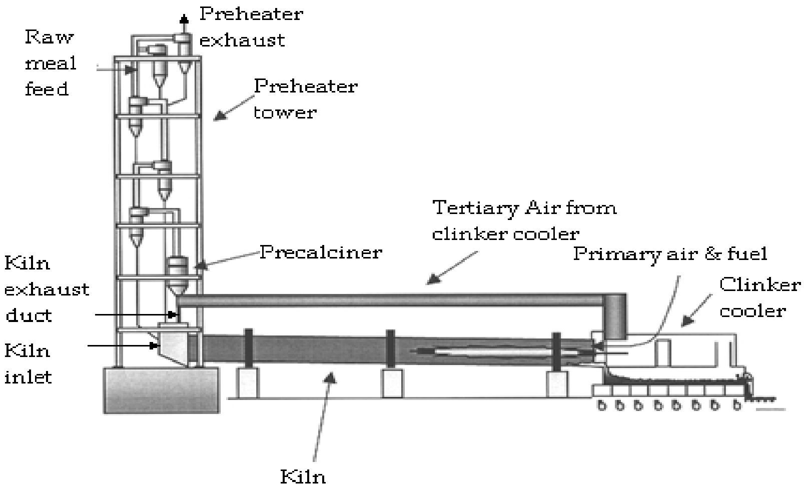


Figure 1. 1: Dedicated Manufacturing Line [3]

Consumers require change, flexible manufacturing systems (FMS) provides it to assist several requirements. The main goal of FMS is to increase part variety. For small manufacturing setups with high part variety, FMS was an ideal choice. FMS comprised of computerized numeric controlled machineries CNCs and manufacturing systems were automated. Flexibility was introduced at different stages in a manufacturing system. Figure 1.2 validates an FMS suggested by [1]. It is made up of various adjustable subsystems creating a complete FMS. Every circle shows an (FMC) which comprises of number of CNCs with automatic tool changer and pallet changer. Every cell has a robot for the parts movement. AGVs are there for transferring the job from the machine chambers and carrying them from the AS/RS.

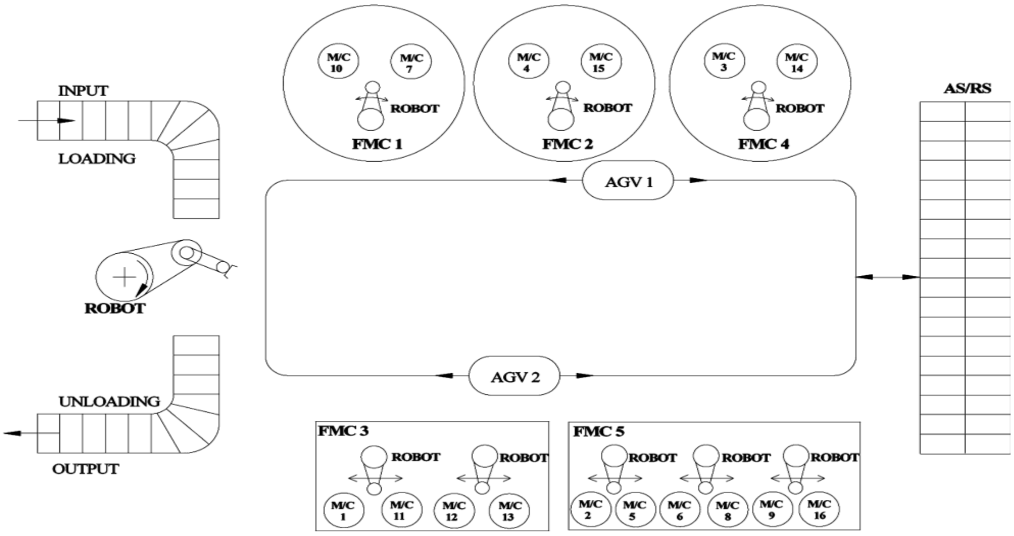


Figure 1. 2: Flexible Manufacturing System

But in most systems such flexibilities are not required. The tools needed for these systems was costly and the initial expenses were high. This caused in an expensive manufacturing setup and an expensive product. Thus, these systems were not taken up but few stages of manufacturing.

RMS targets at adjustability to customer needs, when it is required. Its objective is to increase reaction of a system. It is an off shoot of Just in time management system. The specialized adjustability anticipates low system along with product charges in contrast to FMS and quick amount and greater fabrication cost. Figure 1.3 shows relationship amongst these systems regarding their reaction time. FMS and DMS are stationary but RMS transcends through period [2]

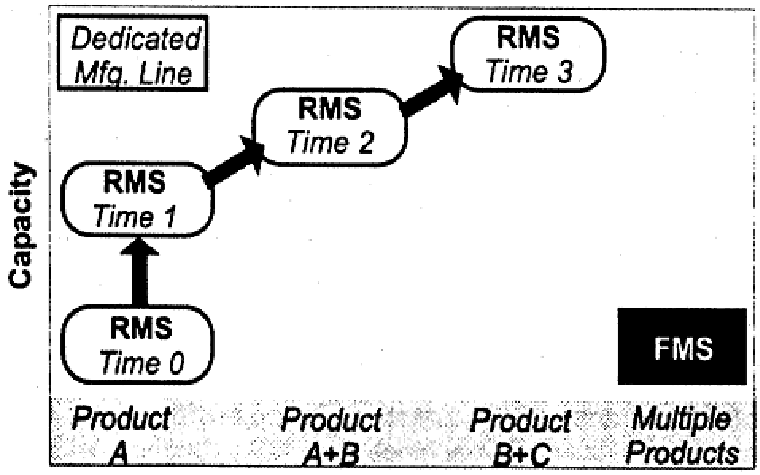


Figure 1. 3: RMS Vs. FMS Vs. DML

Though, combining and choosing of machine structure turns out to be hectic job for RMS. Table 1.1 shows overall relationship of three elementary forms of manufacturing systems.

Table 1. 1: Difference between Manufacturing Systems

Features	DMS	FMS	RMS
Aim	Specialized Product	Increased Variety	Increase Responsiveness
Product Variety	Specialized products	High	Customized
Quantity	High	Low	High
Machine Configuration	Dedicated	Flexible	Reconfigurable
Flexibility	No	High	Customized (when needed)
Scalability	No	Yes	Yes
Responsiveness (after market review)	Lowest	Medium	Fast
Market	Stable	Predictable	Uncertain
Process Technology	Fixed	Needs acceptability	Responsive
System Focus	Part	Machine	Part Family
System Structure	Fixed	Adjustable	Adjustable
Manufacturing Policy	Pushing	Pulling	Customizing
Cost	Low	High	Intermediate

Figure 1.4 illustrates the relationship based on variety,-volume and scale of a manufacturing setup. As explored earlier, DMS inclined to have high production but low variety.

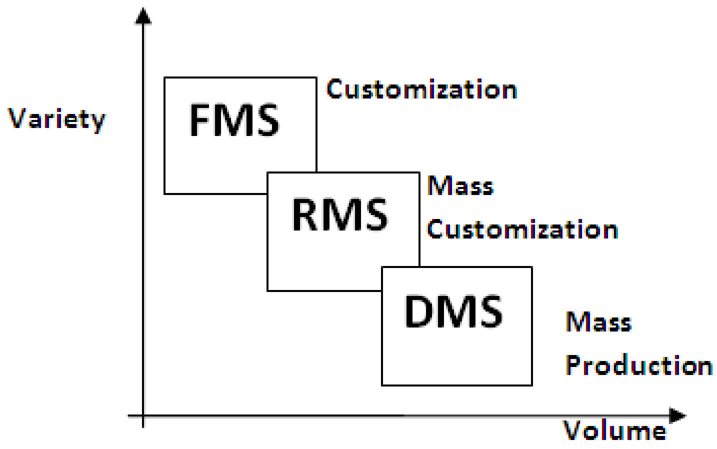


Figure 1. 4: Evaluation of DMS, FMS and RMS on Variety-Volume Gauge

1.5 Basic Definitions:

The product could have various meanings built on different ideas. In marketing, a product is anything that accomplish the need of the market [3].In project management, a product is an artifact resulting from an organizational process [4].In product design, a product is a multipart assembly of interrelating components [5].In this research, we give this concept a definition in the perspective of manufacturing.

1.5.1 Part:

A part is an inseparable element when assembling a product from manufacturing prospective. Part is the lowest structural block for a product, and every constituent of a product is either a part or a arrangement of a set of parts.

In the manufacturing paradigm of MC, part variety drives manufacturers to manage a set of parts at the same time instead of one part at each time. To gain benefits from commonality and modularity, parts are grouped into part families. Depending on the different context (marketing, design or manufacturing), the interpretation of part family could be different.

1.5.2 Part variety:

"*Part variety defines a design domain for similar parts, these similar parts are defined by a number of* ***common design variables*** *and* ***personalized design variables***." Common design variables define the mutual characteristics of these similar parts while the personalized design variables define their individualized characteristics. The value of the design variables could be a limited set or unlimited set depend upon the description of design domain.

1.5.3 Part family:

"Part family signifies a part domain which is further disintegrated into ***architecture*** *and* ***attribute sets***." A part variant can be resultant by selecting a set of changing constituents from the architecture of the part family and the values for the attributes of these constituents from the matching attribute sets.

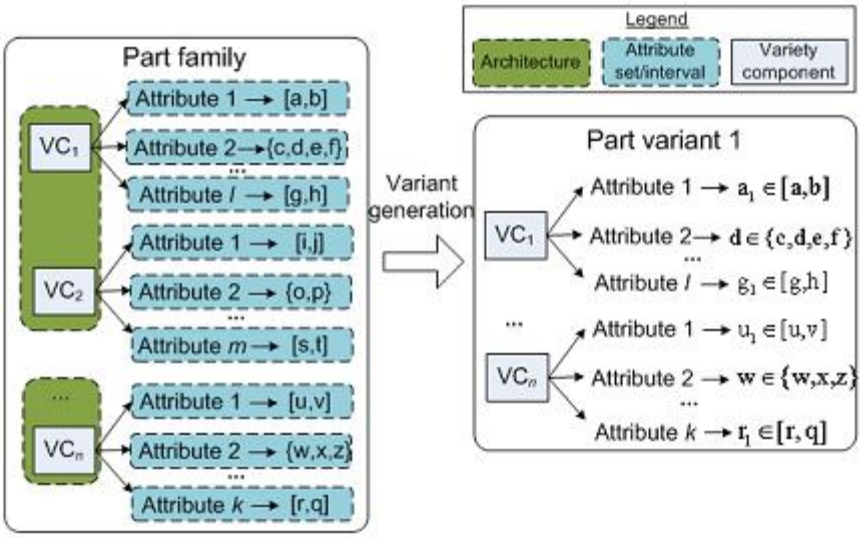


Figure 1. 5: The concept of part family

As shown in the above figure (1.5) architecture deliver the variety components that a part family can provide to its variants. Changing constituents are either the functional constituents or the physical constituents which are used to build a part variant. For example, part variant technical functions compromise a set of changing constituents. Changing constituents have set of attributes, whose domain bound the values to be picked for attributes of part change. For example, for hole feature, diameter and for pocket feature, depth. Domain for each set can be finite or infinite according to the data which will make the model more capable for flexibility.

From the viewpoint of ***Function behavior structure*** model, the structure of a part is specified by its behaviors essential in a product, and its behaviors rest on the technical functions it aids in the product [6]. So, to achieve the final function the parts are accordingly designed.

Part manufacturing processes governs how to alter the raw material into a final part. These manufacturing processes can generally be divided into eight types, as shown in figure (1.6) below. Only machining processes are considered, which means only parts that can be produced from machining processes are of focus.

1.6 Manufacturing process planning:

"Manufacturing process planning comprises of the sequence of planning events that define the process to convert raw material into the desired form before placing raw material into production".

These planning events include: explanation of design specifications, selection of manufacturing processes and tools, process parameters identification, generating operation sequences, and cost calculation. The output of manufacturing process planning is manufacturing process plan.

The specific events and methods involved in manufacturing process planning differ giving to the type of manufacturing process. As machining process are considered, this study only commits to address the matters of RPP related to machining process planning

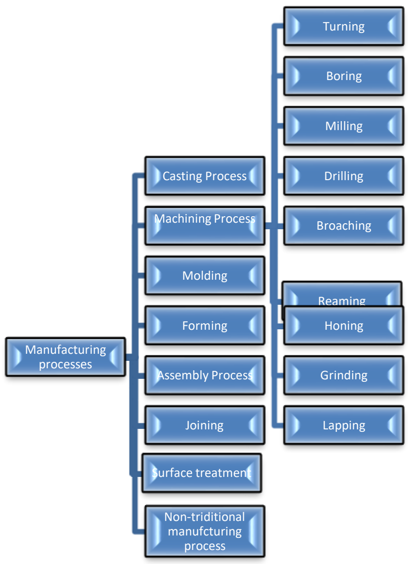


Figure 1. 6: Classification of various manufacturing processes

MPP (manufacturing process planning) has two granularities, given the level of detail, ***conceptual process planning (CPP)*** and ***detailed process planning (DPP)***. As shown in Figure (3).CPP emphases on the planning activities including: explanation of design specifications, selection of manufacturing processes, generation of operation sequences and cost calculation, while DPP delivers detail process information to personify the macro process plan comprising the facts about manufacturing tools, process parameters. The output of CPP is the input of DPP and the output of DPP is the final process plan which can be executed by a production system. One benefit of dividing process planning into two granularities is, CPP can be prepared without available manufacturing resource information, and then the CPP can be explained or evolved by DPP once the resource information from product system is available, which is advantageous for the implement of concurrent manufacturing. [7] [8]

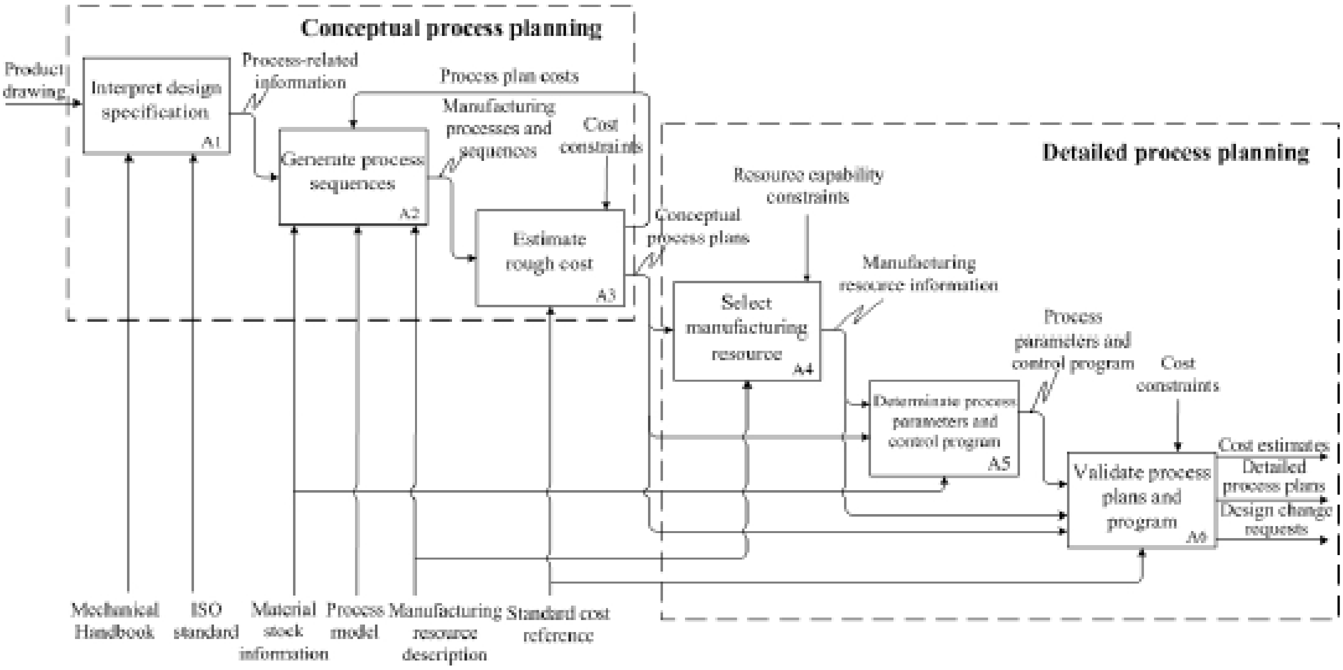


Figure 1. 7: Manufacturing process planning Diagram

1.7 Reconfigurable Process Planning RPP:

RPP is a favorable process planning technique for part variety. This study scrutinizes the RPP methods on machining process planning for part family with prominence on their proficiencies to co-evolve with product design system and production system.

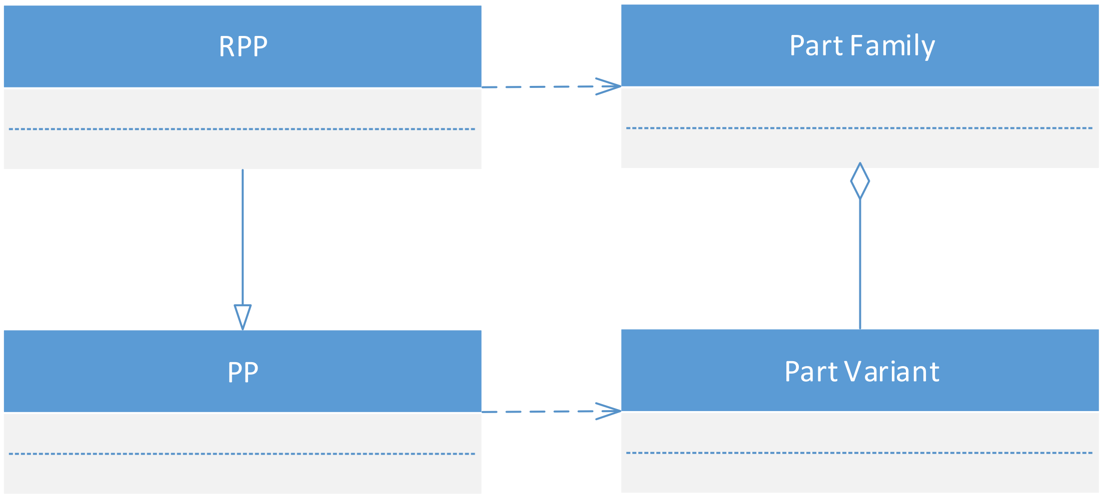


Figure 1. 8: UML Class Diagram of Key Concepts Relationship in thesis.

The relationships between the main concepts of this work is shown by UML class diagram presented in figure (1.8). Part variant has an aggregation relation with part family, because a part family is composed of a set of part variants. RPP has dependency relations with part family, because RPP needs the information from part family for the generation of reconfigurable process plans. The same relation is also found between process planning and part variant. RPP has generalization relationship with process planning, because it is new process planning method for part variety.

1.8 **Problem Description**

Main aim of this study is to develop Representation model and generation methods for RPP which can be implemented for co-generation of process plans and kinematic configurations for part family. This work starts with the basic definitions from manufacturing according to the related scope of research. In the next section, literature review of the part family modeling with process plan development and configuration technologies is provided. The chapter ends with an overview of the reviewed literature with prominence on necessity of this research.

1.9 Construction of the Thesis

This research work is based on mass customization and co-evolution concepts for RMS and generates a framework for reconfigurable process planning of the whole part family instead of single part variant. The part variety decomposition model (PVDM), developed by Qing's, is used with reconfigurable machining operation plans (RMOPs) developed in matlab by using the feature clustering from models and cutting tool charts data and precedence relationships (PRs) developed for part family.

To extract the configurations of part and RPP, for part variant of the same part family dynamic constraint satisfaction problem (DCSP) in constraint logic programming (CLP) language Eclipse is used. The data obtained from DCSP is then used to develop process plan and kinematic configurations for the required part variant of the part family.

1.10 Summary

In this chapter, we have concisely linked different manufacturing systems and the need of advanced reconfigurable systems. Some basic definitions like part, part variety, an part family which are used in the thesis work. Manufacturing process planning types in literature are discussed and at the end framework of the thesis is represented by UML diagram

CHAPTER 02: Literature Review

RMS consists of different elements contributing its sustainability including material handling and machinery having the tendency to reconfigure the system logically or physically depending upon its constraints i.e. either by changing machine structures, machine outline, and material control plans or by appropriate channeling, forecast, and design. The hypothesis of a modern production paradigm was proposed by highlighting the challenges and opportunities for manufacturing industries. Numerous academics are also concentrating on the idea of co-evolution more than a decade [9] proposed a model to formalize co-evolution problems in different industries and concluded that the changes in product, processes and production system are interlinked. Co-evolution of product families and assembly systems are introduced as a product development methodology for the joint design and reconfiguration of assembly systems within and across product generations. Relationship between product design, process planning, and production scheduling is shown in figure

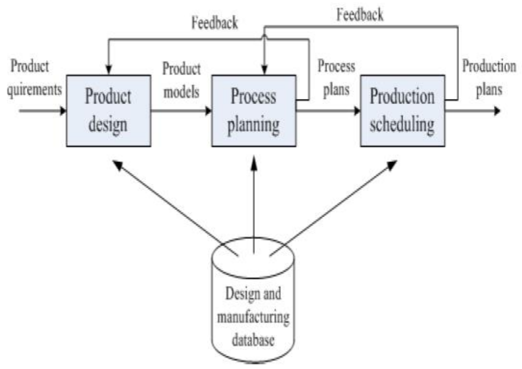


Figure 2. 1: Co-evolution Model [Feng, 2003]

Configuration technology has been recognized as a facilitating technology for mass customization [10] So to achieve mass customization along with co-evolution, for effective reconfigurable manufacturing system [11] developed representation models and generation methods, by using configuration technology, to handle part/product variety at different levels of RMS.

2.1 RMS research areas:

The evolving range of RMS is because of the alertness of system at different granularity levels in two dimensions as shown in the figure [2.4]. In this view a proportion of study is in evolvement of the arena of reconfigurable process planning (RPP). Process planning classifies how a artefact is to be factory-made according to the planned stipulations of specific part/product satisfying different constraints and available resources. RPP allows the changeability of process plans for evolving products and manufacturing systems by considering the design specifications for the whole part/product family instead of single part/product as an input to RPP. RPP implements configuration technology in the activity of process planning to cope with product variety, the process variants for new product variants are linked by configuring the existing process components with the consideration of the available manufacturing resources. In RPP two elementary measures are used. One, part's management and re-fixturing time is abated to acquire the optimum process plan having the least rate of reconfigurability index. Next, changeability metric is presented to calculate reconfigured process plans. Changeability metric determines rate of fluctuations in process plan. Which can be cast-off for choosing one PP between APP and the design having the smallest variations is designated. This practice is suitable for macro level PP in which the finest strategy is explored while sustaining the precedence constraints. Macro level PP has wholly material concerning product's manufacturing stages and its reasonable arrangements that eventually delivers superior product variation and shrink price. However, these RPPs are only implemented on the specific granularity levels and covers limited part variety only also don't have any representation models for RPP

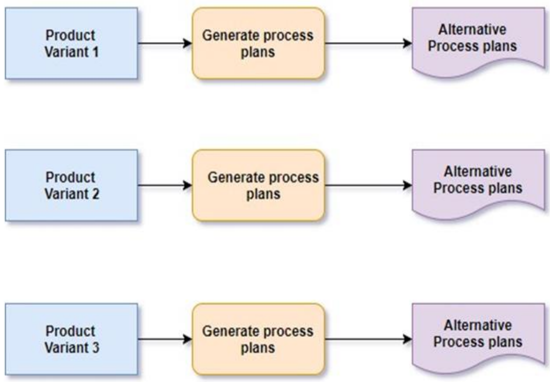


Figure 2. 2: Conventional Process Planning

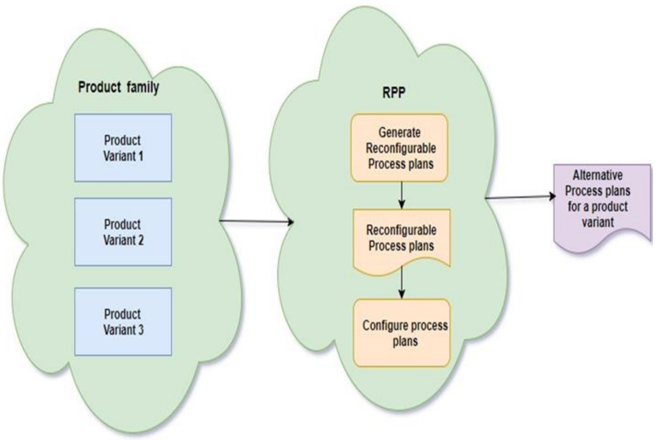


Figure 2. 3: Reconfigurable Process Planning

[11] Proposed the representation models and generation methods to support RPP for part/product variety and cover all the granularity levels of RMS, the representation of design specifications for part/product family is carried out and knowledge base is developed. The models are developed for different granularity levels for representation of part/product family. The methods and algorithms for RPPs generation for part/product family are developed. These methods and algorithms use the pre-defined information and knowledge to produce reconfigurable process plans for a par/product family, then by using configuration techniques process plans for any part/product alternative of the part/product family are instantly extracted from the developed model according to the manufacturing scenario.

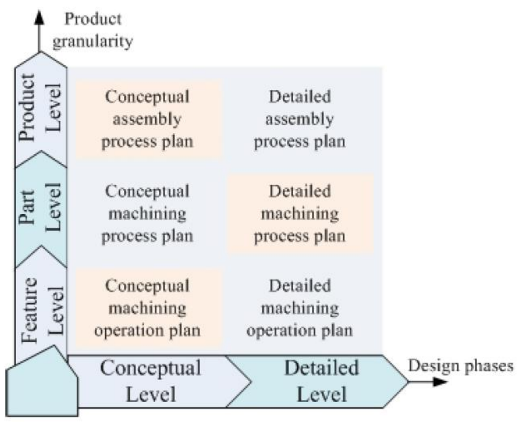


Figure 2. 4: Granularities of Reconfigurable Process Plan

Based on modular, platform-based and configuration-based techniques Knowledge base is developed for part specifications of product family for RPP. For each granularity level at part and product level, from knowledge base, models are developed for the generation of Reconfigurable assembly and machining plans for part/product family.

2.2 Existing Approaches:

Reconfigurable Machine Tool (RMTs) kinematic prototypes are chosen on the basis of working necessities and can be stretched up to practical necessities. structural abilities are related with the equipment choice, an method for generating minimum machine capabilities against each operation cluster was proposed by [12]. An efficient algorithm for allocating storage ability in serial manufacturing lines has been established to catch out the dispersal of storage ability among structures that curtails the whole buffer region allocated to the line satisfying an anticipated production amount. Different approaches related to layout problems of RMS are also available in literature. Recently, a methodology was presented in which arrangement progress efforts, constraints like compatibility and productivity requirements, and performance metrics design purposes were demonstrated arithmetically. The prototype permits winning choices among range of machining necessities, compulsory for structures and configuration/reconfiguration of arrangement liable on the product families to be shaped and the mutual abilities of selected structures.

The utilization of a manufacturing upper ontology, aimed to draft a common semantic net in manufacturing domain, with the Design methodology for RMT was presented by. [1]. The usefulness of ontologies for data formalization and sharing, especially in an open manufacturing environment was discussed. RMT, FBS (function behavior structure) approach and its common features were introduced. Ontologies must play a central role in intelligent manufacturing: they enable fluent and consistent flows of data. RMSs are built around product families to fulfill these characteristics, to achieve stated goals and to ensure mass customized production at low cost. Here, products are grouped according to their geometric similarities into families, where each family requires a separate system configuration. Thus, the system is reconfigured for each family of products to produce it, i.e. configure the system to produce the first family, and once this production is complete, we reconfigure the system to produce the second family, and so forth [13]. Developed a model to produce alternative process plans and its structural configurations concurrently seeing the priority, topological and rational constraints. In the extension of this work, a methodology based on co-evolution was proposed by [14],for assignment of machines through optimum capabilities in case of production changeovers. A scientific framework formulated by [15] to be applicable to an engineering design tool that can improve the relation between product design and reconfiguration process of RMS. [16] introduce a methodology based on control loop for nominal arrangement and development for structure reconfiguration; the intrinsic appearances of RMS are examined to device anticipated deviations at organization or structure stage [17] proposed an approach to fit in process planning and development concurrently rather than two distinct purposes. Allowing for multi configuration environment of RMTs, a choice index governs the aspirant structure which is accomplished adequate to achieve assured processes. Another mathematical approach was proposed by [18] that maximized the system throughput after reconfiguration. This approach suggests a set of values for arrangement plan for scalability and was validated for an industrial case. Most of the research is also done on reconfigurable layout considering performance measures to achieve high responsiveness, selection of reconfigurable machines, and formation of part family. Analysis for performance evaluation of two machine systems with finite buffer capacity and generalized thresholds was carried out by [9], [16] offered a procedure in displaying of huge problems which included subfamily sequencing and variant in each subfamily to reduce the extreme achievement time using mathematical software design. Since RMS suggests made-to-order flexibility and a change of substitutes. These machines embody a main constituent of RMS and are founded on an adaptable, modular and reconfigurable structure. The structure modularity is of great importance. RMS has been developed within modular frameworks to meet the dynamic manufacturing demand. A framework of a design tool that is capable of objectively registering development of new process modules for RMS was developed by [15] In five consecutive stages, the development progression is indexed. The method has been tested on a true case; monitoring the development of a 3D measuring probe for geometrical measuring. Visualization of development-progression, the appropriate feedback cycle and the improved communication with technological and operational management provided better system architecture of product and production means at a more competitive cost. Modularity assessment based multi-objective approach was developed by [19] that uses an adapted version of the "Archived Multi-Objective Simulated Annealing" (AMOSA) method to solve the optimization problem by selecting from a set of candidate machines the most suitable ones. Three objects were considered: the maximization of the system modularity, the minimization of the system completion time and the minimization of the system cost [19] addressed the problem of machine selection in a reconfigurable environment and developed a model for the selection of best performance process plan using NSGA. The responsiveness is increased based on flexibility of the designed system and generated process plan which also caters the situation of unavailability of machine. The concept of learning factories was proposed by [20] wherein the methodology for product family development was introduced to an existing learning factory characterized by changeability factors. When a new product was to be manufactured, the intelligent manufacturing system initially assembled family desk with variants. [21] also proposed an approach for determining the similarities between the product families by analyzing the aim of increasing the efficiency and speed of production. Master operation sequence was retrieved for new variants

This results in improving the planning efficiency and variety of product design. A model was proposed for the synthesis of manufacturing systems by [22] to reduce the cost of product variants by optimization of co-platforming model. This integrated approach is highly customized assembly and increases the system life due to the strong mapping product and system platform. An approach for utilizing the industrial waste and postconsumer product is recently proposed by [10] This paradigm can potentially support the sustainability challenges in strategic manufacturing sectors. A methodology by [15] compares the alternatives for the ways to implement reconfiguration. The approach adopted index method based on axiomatic design methodology. Alternative configuration schemes are obtained combining different process modules.

Conclusively, sustainability of any manufacturing industry is the requirement of this era that ultimately improves country's economy. Various methodologies and models have been presented in literature related to the state of art in manufacturing and a road map for future research and developments. Reconfigurable manufacturing systems constitute a new manufacturing paradigm and are considered as the future of manufacturing because of their changeable and flexible nature.

Chapter 03: Existing Methodologies

Two manufacturing paradigms, mass-customization and co-evaluation are of central focus in the development of reconfigurable manufacturing system. Some researches focuses on co-evaluation only while in some works both paradigms are taken into consideration. According to the nature of manufacturing system required. As RMS is developed for customized product generation in greater quantity for which system modularity, integrality, scalability and responsiveness are needed at different granularity levels. At process planning level part and product variety are used to the advantage of commonality for generation of reconfigurable process plans. Now in literature this product/part variety is used, according to the given manufacturing scenario, for development of reconfigurable process plans for either evolving part/product family or mature part/product family. The following figure shows the above discussed cases of reconfigurable process planning.

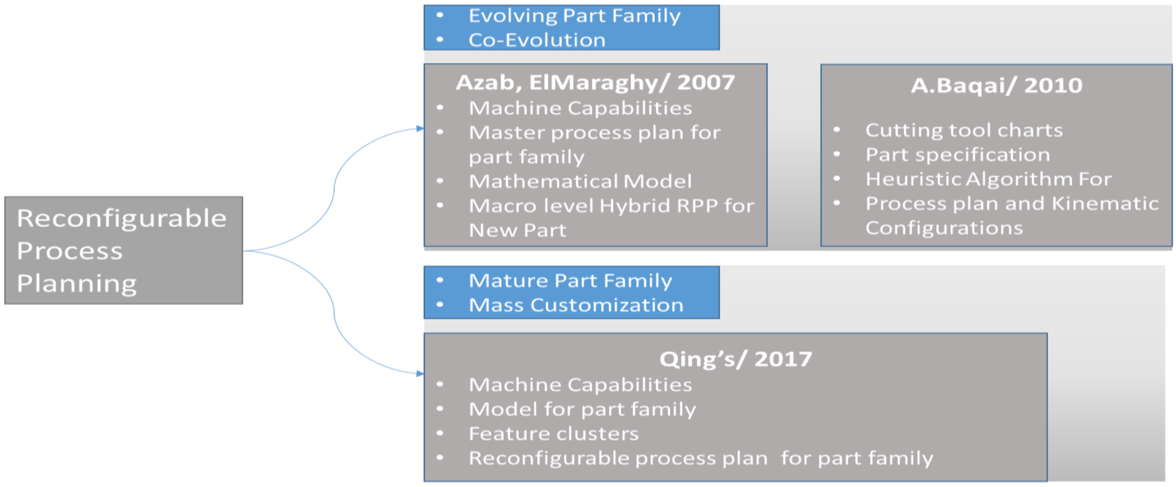


Figure 3. 1 Reconfigurable process planning in literature

Mathematical Model is proposed by [23] for reconfigurable process planning, which can add/remove the features from the existing developed process plans in part family, thus makes the part family evolving. The input are machining capabilities of manufacturing system and design specifications for the part. In this work semi generative macro level process plans are developed for new part which is close by feature's commonality to the master part family.

3.1 Generation of Process Plans and Architectural Configurations of Manufacturing Systems:

[13] Process plan and kinematic configuration are generated concurrently for the designed framework of reconfigurable manufacturing system. Designing system for RMS mainly focuses on similarities of part family, which are used to the advantage by increasing the flexibly of the system. The modelling of the system is done on the basis of FBS (function behavior and structure) approach.

The inputs to the proposed approach are

- Functional specifications
- Topological interactions
- Process knowledge base

Structure configurations generation relies on functional specifications and process plan. The following figure shows the process proceedings.

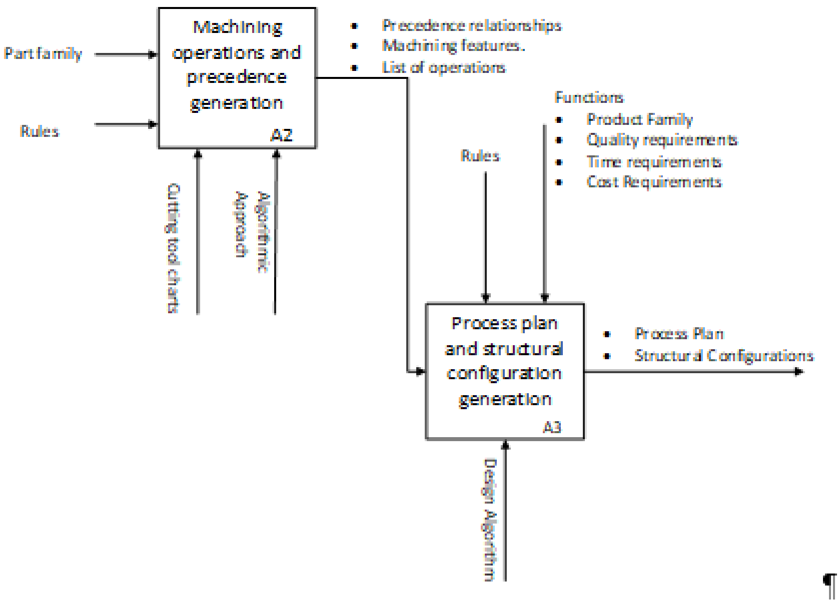


Figure 3. 2 Framework for generation of process plan and kinematic configuration

The approach consist of two activities as shown in the figure ().

- Machining operation and precedence relationship generation.
- Process plan and structural configuration generation.

3.1.1 Machining operations and precedence relationship generation:

Generation of machining operations and precedence constraint is achieved through this activity.

Inputs:

Following are the inputs required for generation of operation plan and precedence relationship.

- Part description, which has geometric specifications of features in tabular form.
- Topological interactions, Relationships between different features denoted by specific numbers in a table.
- Knowledge base, in the form of cutting tool charts.

Processing:

Part description for different types of defined features, from STEP application handbook standards, is carried out and is composed as parameters of features in excel tables, for specific part CAI. Topological interactions between the features are defined and presented in table, each interaction type is given a specific number to be recognized by the program. Knowledge based is developed for each feature in the form of cutting tool charts. On the bases of part model, feature types are selected from the design of the part. Then cutting tool charts are accessed by type of feature. Now from geometric data of the part description like radius, tolerance and materials, corresponding sequences of the operations are selected from the cutting tool charts for each feature. By VBA developed application all possible sequence combinations are generated and are known as pre-process plans which are compiled in a table. Precedence constraints are defined for two scenarios, firstly for different features topological relationship is used and secondly for same operations but different features sequence given In the cutting tool chart is considered. An algorithm is developed for generation of precedence relationship matrix.

Output:

Output of this activity is following.

- All Machining sequence combinations, in the form of pre-process plan

- Precedence relationship Matrix.

3.1.2 Process plans and structural configurations:

Topological interactions, pre-process plans and precedence matrix are then used by heuristic algorithm to generate alternative process plans and there machine configurations concurrently.

3.2 Generation of RMPP of a mature part family by using design specifications and machine capabilities

[11] The idea of reconfigurable process plan is extended to reconfigurable machining process plan by which process planning can be done for part family instead of single part. Following are the steps of the methodology

1. Solution RMPP.
2. FBPV model for generation of part family.
3. RMPP generation.

3.2.1 Solution RMPP.

For the development of framework for part family, FBPV ***model*** is proposed. It covers all the design information of each part in the part family. It is based on the concepts of Modularity, Platform-based and Configuration-based.

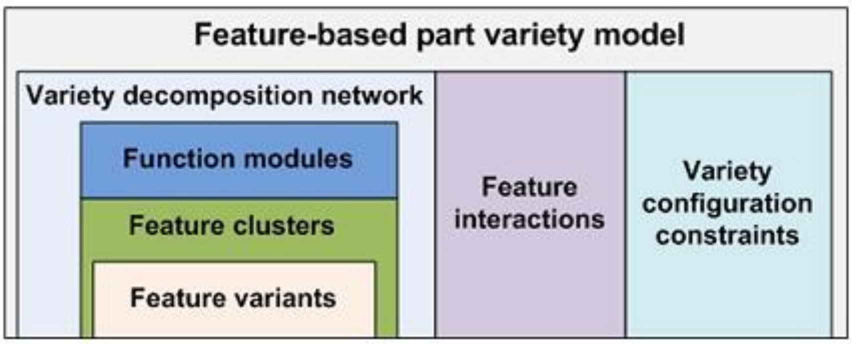


Figure 3. 3 Framework of FBPVM.

Concepts used in the model are defined by [Qing's 2017]

Part Family, ‘’ A part domain which is supplementary disintegrated into architecture and attributes sets’’.

Feature cluster, ‘’ A domain of feature variants, these feature variants have the same feature type; meanwhile, they serves the same design functions in a part variants’’.

Following are the three portion of information of part family information in the proposed model.

1. PVDN.
2. Feature interaction.
3. Variety configuration constraints.

3.2.2 PVDN:

It is a linked part family building block with three stages, represented by directed graphs, each stage is discussed below

a. <u>Function Module Level.</u>

It comprehends design purposes of the part family, every purpose consist of design functions for one or more features.

b. <u>Feature Cluster Level.</u>

Physical structures of part family are disintegrated into group of feature clusters. Each feature cluster is at minimum linked to a feature variant stage. With function level the corresponding feature cluster is configured.

c. <u>Feature variant level.</u>

Feature variants of feature cluster are organized at this stage. Physical constituents of part variants are arranged at this level.

Above three levels are linked by mapping, the configuration between these levels is done by logical operators such as AND, XOR and OPTION.

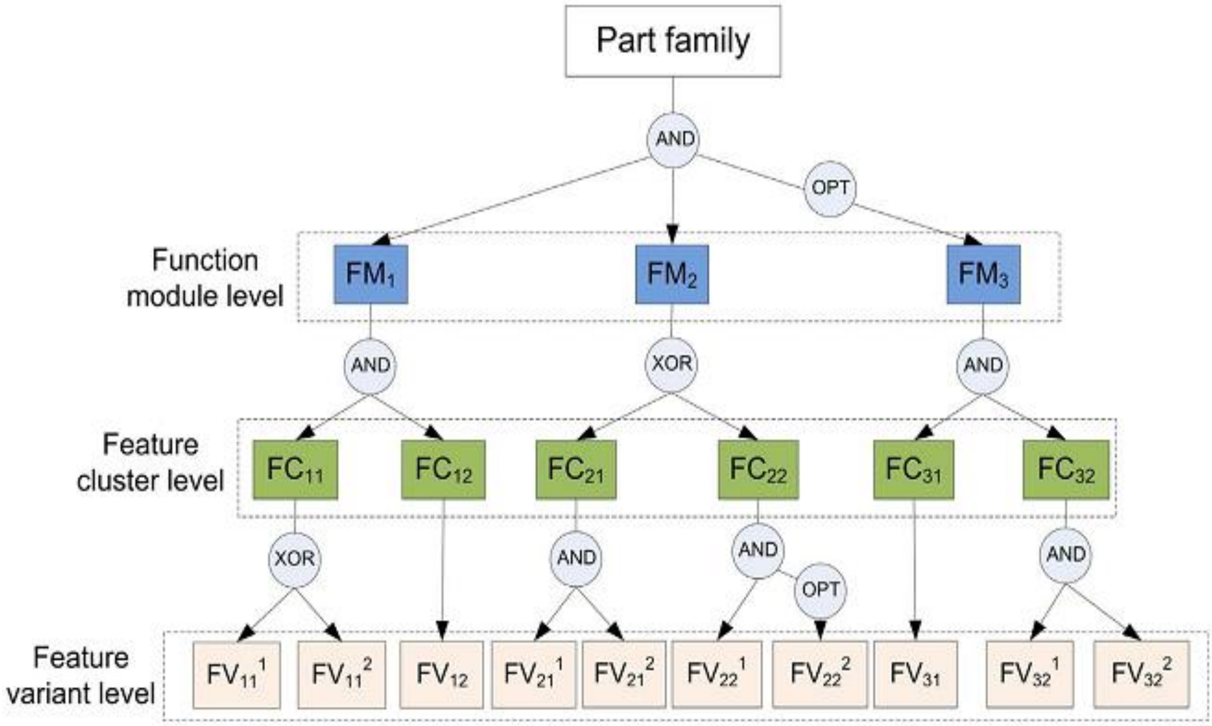


Figure 3. 4 Part Family Model Directed Graph.

3.2.2.1 Feature Interactions:

In the defined model feature interactions are of two types.

i. Tolerance / datum dependencies.
ii. Topological interactions.

3.2.2.2 Variety Configuration constraints:

These constraints are represented in the model by logical operators AND, XOR and OPTION which shows the relationship between the lower level and same upper level and to show the relationship between the different upper levels ‘’ prepositional logic based scheme’’ is proposed

3.2.3 Reconfigurable machining process planning model:

RMPP is the set of integrated constituents that can be organized or reorganized into the MPPs of any part of the part family''.

Featured based machining process plan in literature can generally be carried out in two steps.

i. Machining operations selection and feature sequencing of those operations.
ii. Generation of process plans from the sequences of those features in the feasible vicinity provided by the constraints on those operations and between the features.

By these steps process plan is generated for the part of specific part family. In this work a new concept is introduced of RMPP which generates RPP for the whole part family.

In RMPP a novel idea of ***RMOPs*** is presented, ''which comprise of a set of alike MOPs that fulfil all the machining necessities of feature cluster''.

In RMOP machining operation plan ''MOP'' is set of machining operation sequence which comprise machining operations and precedence sequences. Machining capability depends upon the latest process in the operation arrangement. RMOPs are signified by directed graphs G (V, E).

V → Nodes which represents machining operations.

E → Edges which represent operation precedence.

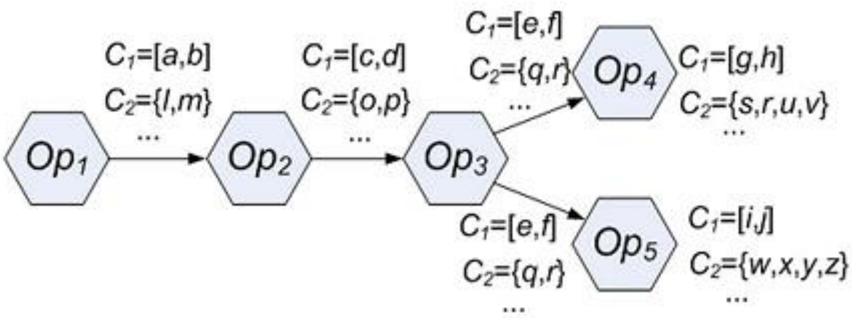


Figure 3. 5 RMOP as directed graph

3.2.4 Reconfigurable machining process plan

RMPP are developed for part family by using RMOP and precedence relationships. Following are the inputs to the process of RMPP generation.

3.2.4.1 INPUTS:

For generation of reconfigurable machining process plan the inputs are.

I. Feature clusters in part family.
II. Reconfigurable machining operation plan for each feature cluster.
III. Five precedence constraints.
    a. Softbefore
    b. Hardbefore
    c. Softimmebefore
    d. Hardimmebefore
    e. Equal

IV. Design specifications from part design data
    a. Geometric
    b. Tolerance
    c. Surface finish
V. Machining capabilities from machines data base
    a. Geometric
    b. Tolerance
    c. Surface finish

3.2.4.2 Generation Method:

RMPP is generated in two parts.

I. RMOP generation for each feature cluster is carried out by developed algorithms and mathematical models in two steps as.

a) Step 01

In generation of RMOPs, first feasible operations are selected by comparing the geometric specifications and capabilities, the technique used for operation selection is neural networks. For this a knowledge base is developed in first order logic language, for representation of design specifications and machine capabilities. A resolution based breath-first algorithm is used for selection of feasible operations.

b) Step 02

Secondly for finding possible sequences between these selected feasible operations a mathematical model is proposed and depth-first algorithm is proposed for generating these sequences. The principle of generating the sequences between the operations is comparison of design specifications tolerance and surface finish with machine capabilities tolerance and surface finish.

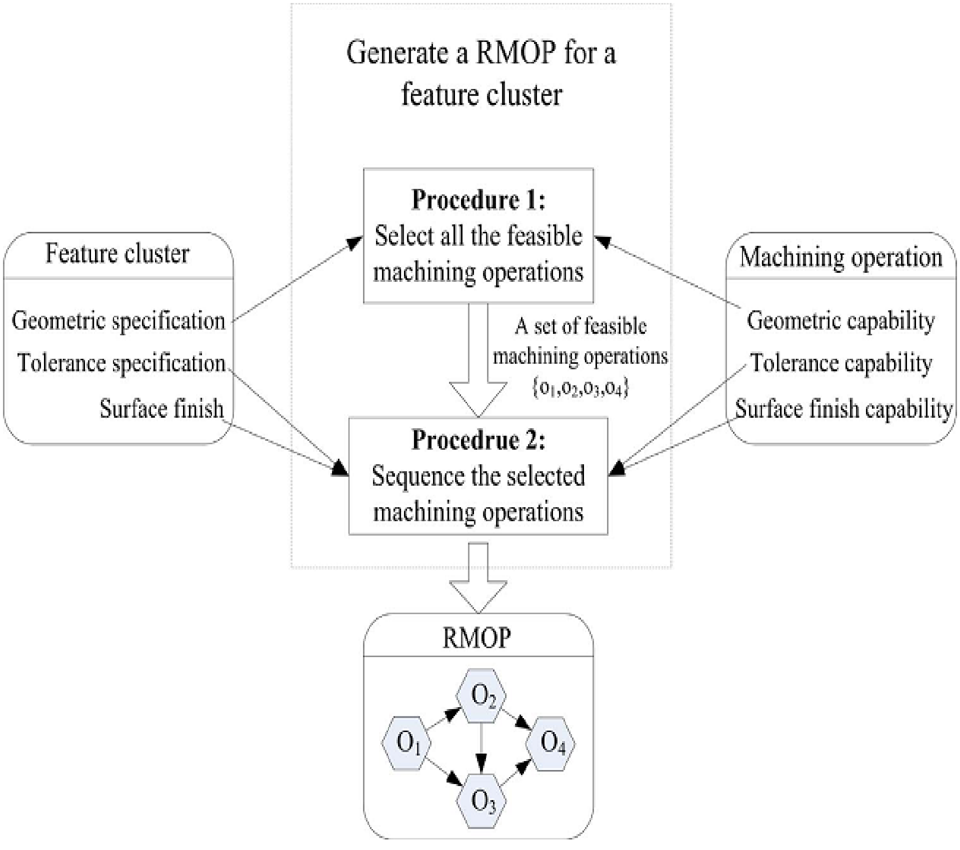


Figure 3. 6 RMOP generation flowchart.

II. Precedence relationship for interactive variety components is developed in knowledge base and expert system is used to automatically gather these feature relationships.

3.2.4.3 Outputs:

The generated RMOPs of feature clusters and developed precedence relationships between the operations and feature cluster are used for reconfigurable machining process plan development.

3.3 Summary

Existing Methodologies mostly focus on reconfigurable process planning for a new part in evolving part Family Clustering of operations is performed to get machine configurations for particular set-up. Generation of alternative process plans and its Kinematic configurations simultaneously for a new part variant is also carried out in the literature. Work is required to generate **Model** of part family for the **framework** of generation of process plan and kinematic configurations simultaneously.

Chapter 04: Proposed Methodology

The Frame work of the proposed methodology is shown the Fig [4.1].

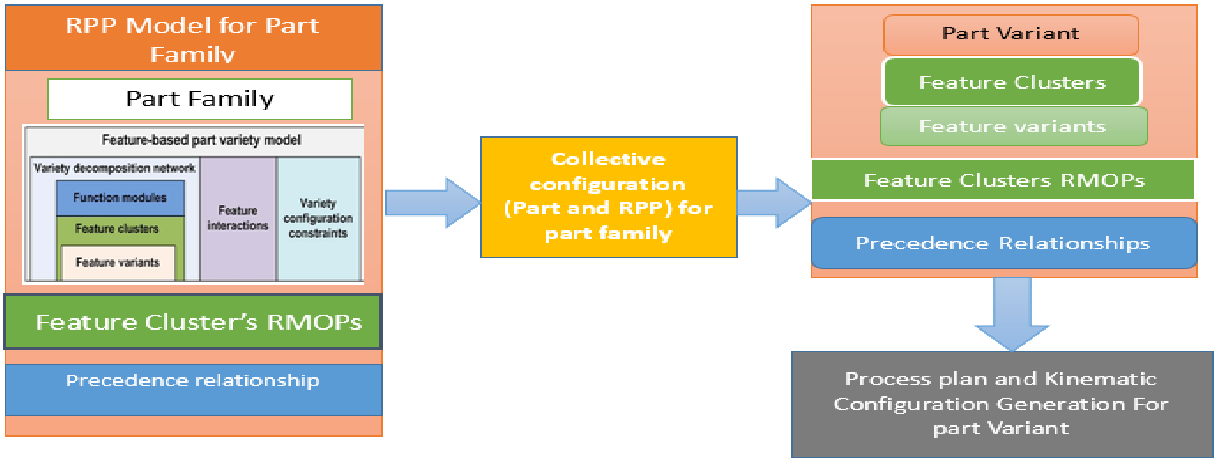


Figure 4. 1 Frame work of the proposed methodology

This framework processed with generation model for part family and model for reconfigurable machining operation plans (RMOPs) of feature clusters and developing a precedence relationships between the features and feature clusters. These Models and precedence relationships gives reconfiguable process plans for the whole part family. For generation of process plan and kinamatic configuration data is extracted from models and precedence relationships by applying configuration technique of dynamic constraint satisfaction problem (DCSP).

4.1 RPP model for part family

Generation of reconfigurable process plan (RPP) for part family, following models and precedence relationships are required.

I. Feature based Model for part variety
II. Feature Cluster's RMOPs
III. Precedence relationships

4.1.1 Feature based Model for part variety in part family:

The case study choosen for this problem, the oil pump body part family there are two part variants, part variant 1 and part variant 2, as shown in the fig [4.2]. For these two part variants of the part family feature-based part variety decomposition network (PVDN) is developed by directed graphs. These graphs shows the relationship between the different levels of (PVDN).

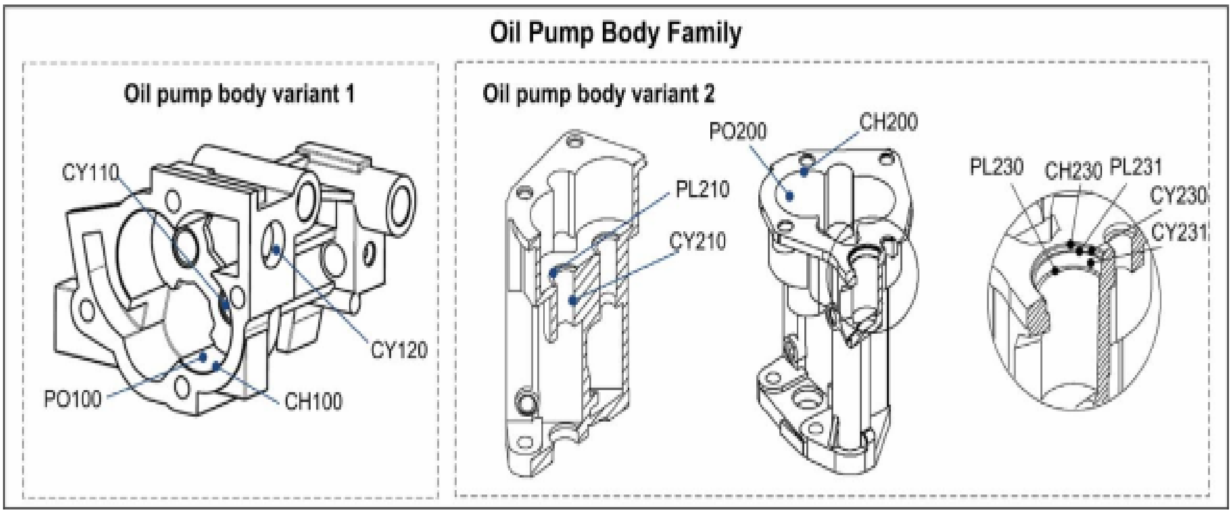


Figure 4. 2 Part Family of oil pump body

Genration of reconfigurable process plan,for whole part family instead of single part variant,feature based model for part variety of the part family is developed. This model is represented by directed graphs with mapping relationships between each level as shown in the Fig [4.3]. This model has three decompostion levels as fallows

1. Function modules level, which gives the functions for which the feature clusters are machined. For example for F4 is function variant for postioning the pressure valve of part variant 2 of (oil pump body part family).
2. Feature cluster level, this level contains the feature clusters for specific function variant. For example for F4, positioning the pressure valve, hole cluster (HC4), plane cluster (PLC4) and Chamfer cluster (CC4) needs to be machined.

3. Feature variant level, this level contains the details of feature variants for specific feature clusters. For example plane cluster (PLC4) contains feature variants PL230 and PL231.

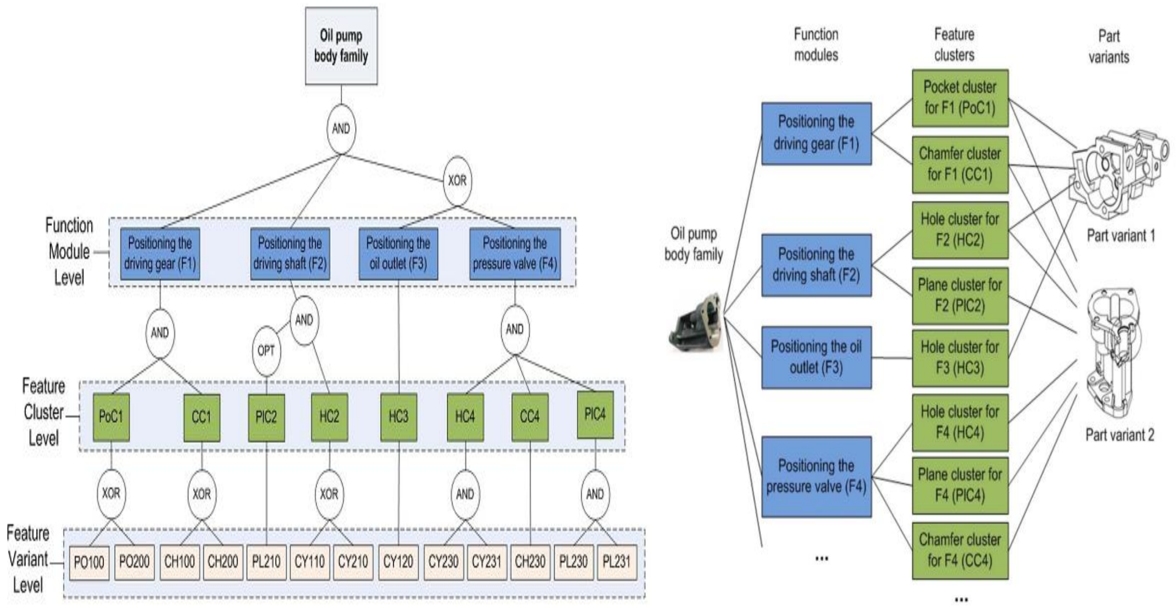


Figure 4. 3 PVD network of the oil pump body part family's Model

This model also contains three different mapping relationships i-e AND, XOR and OPT. Which shows relationships between different decompsition levels of the model. For example AND relationship between F1 and PC1, CC1 shows that for postioning the driving gear (F1), PC1 and CC1 both feature clusters are selected.

4.1.2 Feature Cluster's RMOPs:

As shown in the above model feature clusters are developed at feature cluster level of part variety decomposition model. For generation of RPP, reconfigurable machining operation plans (RMOPs) are developed for feature clusters, keeping in view that no machining capabilities are known, and design specifications are given for the features of particular feature cluster. The model developed by [11] for part family is used, with modification at generation of reconfigurable machining operation plans (RMOPs) for feature clusters. This model contains details of all parameters obtained from design specifications for part variants of the part family, means details of all the parts variants of part family are present at feature clusters and also feature variants levels.RMOPs are represented by directed graphs.

Operation features are clustered into feature clusters in order to use the shared aims of dissimilar part variants of the part family. Features are clusters on the basis of functions to be performed by part variant features. For example if hole is required to be drilled for oil inlet, which requires specific operations according to the hole requirments, then clustering of these operations is carried out for function of oil outlet.Feature of all part variants are clustered at feature cluster level of decomposition model.

4.1.2.1 Generation of Feature cluster:

Feature cluster are generated in two steps.

1. Operations Sequence for Feature Cluster
2. RMOPs Generation for Feature Cluster

Operations Sequence for Feature Cluster:

The following flow diagram show the methodology for selection of operation sequence from cutting tool charts by using the part specification data.

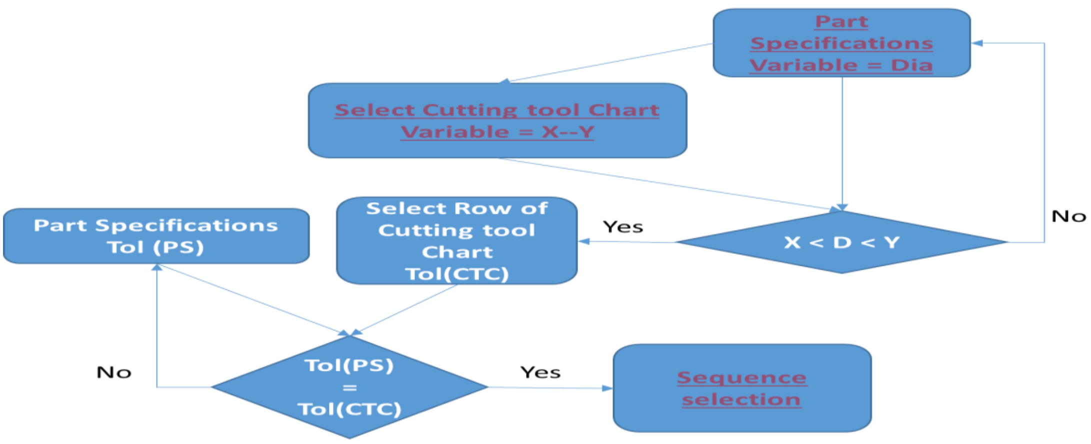


Figure 4. 4: Flow diagram for sequence selection

As shown in the flow diagram (fig 4.4) the input to the process are part specifications Fig[4.5] for case study of part CDV and cutting tool charts Fig [4.6].

CAI

Type	Name	Diametre	Depth	Length	Width	Hieght	Orientation						Accecibility						Position			Angle
							X	(-)X	Y	(-)Y	Z	(-)Z	X	(-)X	Y	(-)Y	Z	(-)Z	X	Y	Z	
Plan	PL 100			83,934	82,01						1		1	1	1	1		1	10	10	0	
Hole	CY103	6	14								1							1	10	38	0	
Hole	CY104	6	14								1							1	94	38	0	
Hole	CY105	40	10,56									1					1		42	52	0	
Threaded Hole	CY107	M6-1	14,5									1					1		24	23	0	
Threaded Hole	CY108	M6-1	14,5									1					1		19	23	0	

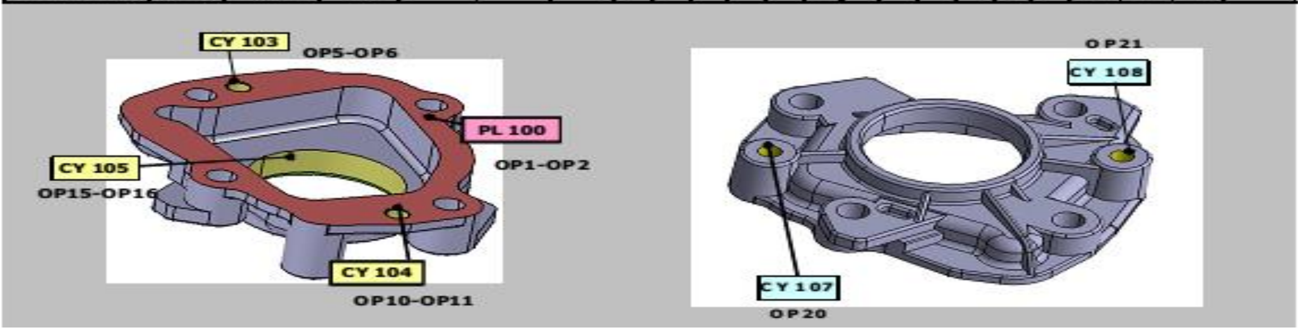


Figure 4. 5: Part specifications of CDV

Algorithm first take the diameter from the part specification, for through hole CY 105 the diameter is 40mm, and select the corresponding rows from cutting tool chart of through hole. As we can see in Fig[4.6] 40mm lies in the range of 12mm and 125 mm. Then after the selection of corresponding rows tolerence and materials are compared from design specifications with rows of cutting tool charts and on satisfiction

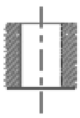
Feature	Diameter D		Tol	Depth L	L Max	Material	Operation	Operation	Operation	Operation
 Trou débouchant / Through hole	12	125	IT9	320		All	Drilling (Factory Std)	Rough Boring (CoroMill 390 - R390012A1611L)	Finish Boring (CoroMill 391.38 - 1 - T09 A)	

Figure 4. 6: Cutting tool chart

of these conditions corresponding operation sequences are selected. In case of through hole CY105 following two sequences are selected from the cutting tool charts. Fig [4.7]

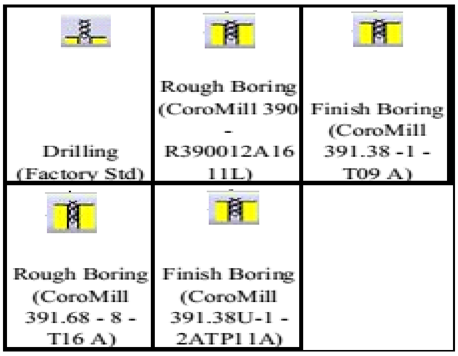


Figure 4. 7: Possible operation sequence selected from cutting tool chart for CY105

RMOPs Generation for Feature Cluster:

After the possible sequences are selected, RMOPs for feature clusters are generated. Fig[4.8] shows the flow diagram for RMOP generation.

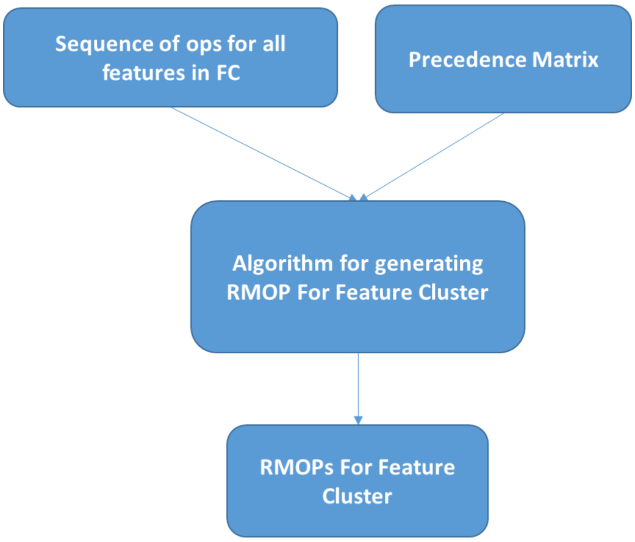


Figure 4. 8: Flow diagram for RMOP generation

Precedence matrix and sequence of operations are generated in matlab, which acts as input to the algorithm and the developed algorithm generates the RMOPs which are represented by directed graph.

4.2 Collective configuration (Part and RPP) for part family

Configuration technology has been recognized as a facilitating technology for mass customization [10] Configuration technology can be applied on part variant generation which is called part configuration. However, the full latent rewards of part configuration can barely be gained if there is no alert process planning to initiate the manufacturing system to manufacture the configured part variant.

The solicitation of the suggested RPP is adding RPP configuration with part configuration such that the process plan elements linked to a part variant can instantly be obtained from the RPP when the part variant is configured. As RPP contains all process plan constituents for the variants in a part family, when one variant is obtained, only the process plan constituents for this variant should be nominated in order to create the manufacturing process plans for this variant: while for RMPP, the process plan constituents for a part variant include the RMOPs for its feature clusters and the precedency relationships among the interactive feature variants on that part variant.

The input of combined RPP and part configuration is the formation requirements for a part variant and in output it gives consecutively the configuration of a part variant and a set of process plan components for this part variant. The formation of a part variant comprises of the functional and physical variety components in the part variety model which satisfies a set of given functional and certain attribute requirements. In relationships to RMPP, the set of process plan components are a set of RMOPs and precedence relations generated for a part variant.

4.2.1 Configuration technologies:

In the initial phase of configuration technologies developments, rule-based configurators existed to answer configuration problem. [24] Developed (R1/XCON) which support order generation for computer system. Back then, production rules were used for configuration knowledge base generation. Though rule-based configuration systems had positive application in that era, but also have shortcomings pointed out by [25]

i-e firstly Knowledge base requires tedious effort to maintain and develop while secondly the result of the configuration intensely rest on the ordering in which different rules are understood.

Because of these drawbacks [25] also proposed Model-based approach. Research focus was shifted for configuration technologies from rule-based to model-based technologies. The main gain of model-based technology is that domain knowledge and problem solution knowledge are separately operated.

Constraint satisfaction problem (CSP) is a broadly used model-based knowledge representation formalism because problem representation is very simple and within the same framework both modelling and solving of problem is carried out. Values to variables are given from the domain which fulfils all the constraints in a standard problem representation design. This sort of designing makes CSP domain independent. However, conventional CSP for configuration problem has a flaw: it has no procedure to tackle the dynamic variety for the set of variants and constraints through the process of configuration. To remove this flaw of the conventional CSP, dynamic constraint satisfaction problem (DCSP) was introduced. The key idea is to only transmit a subset of variables that are related to the solution and duly be given values during the progression of problem solution.

4.2.2 Dynamic constraint satisfaction problem:

Every variable in DCSP can either be of state: active or inactive, and only active state variables are processed in value assignment. Activity constraints are used to identify the conditions for which variables become active. The solution begins with triggering a set of variables and the value assignment to those variables. Additional variables are triggered into the solution process the moment activity constraints are fulfilled for these variables. Similarly, a constraint is "active" if all the variables in this constraint are active; else, it is "inactive". Only active constraints are tested in the problem-solving process. Because of this vibrant proceeding, the examining for the unrelated variables can be escaped. IPC and RPP configuration is a vibrant problem in nature. For example, for RMOP configuration, if a feature variant is not selected for a variant configuration, then the Precedence relationships linking to this feature variant can also be avoided. By considering its dynamic nature, DCSP is adopted to formalize the problem for IPR and RPP configuration.

4.2.2.1 DCSP Variables

In part variety decomposition model there are three levels of breakdown, Function module, feature cluster module and feature variant module. In dynamic constraint satisfaction problem, which is used for solving this configuration, each component of PVDM is taken as a variable. Reconfigurable machining operation plans as well as the precedence relationships for RMPP are also the variables considered in the DCSP.

Function module feature cluster level, feature variant level, precedence relationships and reconfigurable machining operation plans for feature clusters are shown **in the table** which are taken as variables for DCSP problem.

Table 4. 1 Variables for configuration code of DCSP.

Variables		Variety Components
v_f	V_{f1}	Positioning the driving gear (F1)
	V_{f2}	Positioning the driving shaft (F2)
	V_{f3}	Positioning the oil outlet (F3)
	V_{f4}	Positioning the pressure valve (F4)
v_{fc}	V_{pc1}	F1 of Pocket cluster (PC1)
	V_{cc1}	F1 of Chamfer cluster (CC1)
	V_{hc2}	Hole cluster for F2 (HC2)
	V_{pc2}	Pocket cluster for F2 (PC2)
	V_{hc3}	Hole cluster for F3 (HC3)
	V_{pc4}	Pocket cluster for F4 (PC4)
	V_{cc4}	Chamfer cluster for F4 (CC4)
v_{fv}	v_{pc1-1}	Pocket variant in PC1 (PO100)
	v_{pc1-2}	Pocket variant in PC2 (PO200)
	v_{cc1-1}	Chamfer variant in CC1 (CH100)
	v_{cc1-2}	Chamfer variant in CC1 (CH200)
	v_{hc2-1}	Hole variant in HC2 (CY110)
	v_{hc2-2}	Hole variant in HC2 (CY210)
	v_{pc2-1}	Pocket variant in PC2 (PO210)
	v_{hc3-1}	Hole variant in HC3 (CY120)
	v_{pc4-1}	Pocket variant in PC4 (PO230)
	v_{pc4-2}	Pocket variant in PC4 (PO231)
	v_{cc4-1}	Chamfer variant in CC4 (CH230)
v_{rm}	v_{rm1}	RMOP for PC1
	v_{rm2}	RMOP for CC1
	v_{rm3}	RMOP for PC2
	v_{rm4}	RMOP for HC2
	v_{rm5}	RMOP for HC3
	v_{rm6}	RMOP for PC4
	v_{rm7}	RMOP for CC4
v_{pr}	v_{pr1}	HC2 $solidBefore$ PC1
	v_{pr2}	PC1 $hardBefore$ CC1
	v_{pr3}	HC2 $hardBefore$ HC3
	v_{pr4}	HC2 $hardBefore$ PC4
	v_{pr5}	PC4 $hardBefore$ CC4
	v_{pr6}	PO231 $softImmeBefore$ PO230

4.2.2.2 Constraints of DCSP:

In proposed DCSP model two types of constraints are used

1. Compatibility Constraints
2. Activity Constraints

Compatibility Constraints

Compatibility constraints comes from two sources of part variety decomposition model

I. Configuration constraints
II. Mapping relationships

Configuration constraints are formulated of PVDN from lower and upper level relationship and from Constraints between feature variants of different feature clusters as shown in the **table 2**. There are (Cc_i) compatibility constraints express in prolog from the knowledge of **table 2**. Cc_1 to Cc_{12} are constraints between the upper and lower levels and from Cc_{13} to Cc_{18} are constraints between feature variants of different feature clusters.

Cc1: |= (vf1 ∧ vf2 ∧ vf3 ∧ ¬vf4) ∨ (vf1 ∧ vf2 ∧ ¬vf3 ∧ vf4);

Cc2: vf1 ↔ $v$pc1 ∧ $v$cc1;

Cc3: vf2 ↔ ($v$pc2 ∧ $v$hc2) ∨ (¬$v$pc2 ∧ $v$hc2);

Cc4: vf3 ↔ $v$hc3;

Cc5: vf4 ↔ $v$pc4 ∧ $v$cc4;

Cc6: $v$pc1 ↔ ($v$pc1-1 ∧ ¬$v$pc1-2) ∨ (¬$v$pc1-1 ∧ $v$pc1-2);

Cc7: $v$cc1 ↔ ($v$cc1-1 ∧ ¬$v$cc1-2) ∨ (¬$v$cc1-1 ∧ $v$cc1-2);

Cc8: $v$pc2 ↔ $v$pc2-1;

Cc9: $v$hc2 ↔ ($v$hc1-1 ∧ ¬$v$hc1-2) ∨ (¬$v$hc1-1 ∧ $v$hc1-2);

Cc10: $v$hc3 ↔ $v$hc3-1;

Cc11: $v$pc4 ↔ ($v$pc4-1 ∧ ¬$v$pc4-2);

$Cc12: vcc4 \leftrightarrow vcc4\text{-}1;$

$Cc13: vpc1\text{-}1 \leftrightarrow vcc1\text{-}1;$

$Cc14: vpc1\text{-}2 \leftrightarrow vpc2\text{-}1;$

$Cc15: vpc1\text{-}1 \leftrightarrow vhc3\text{-}1;$

$Cc16: vpc1\text{-}1 \leftrightarrow vhc2\text{-}1;$

$Cc17: vpc1\text{-}2 \leftrightarrow vf4;$

$Cc18: vpc1\text{-}2 \leftrightarrow vpc2.$

Mapping relationships are between the Feature clusters of feature cluster level and RMOPs and precedence relationships between different feature clusters as shown in **table: 1** their representation in programming is represented as fallows

Cc19: $vpc1 \leftrightarrow vrm1;$

Cc20: $vcc1 \leftrightarrow vrm2;$

Cc21: $vpc2 \leftrightarrow vrm3;$

$Cc22: vhc2 \leftrightarrow vrm4;$

$Cc23: vhc3 \leftrightarrow vrm5;$

$Cc24: vpc4 \leftrightarrow vrm6;$

$Cc25: vcc4 \leftrightarrow vrm7;$

$Cc26: vhc2 \wedge vpc1 \leftrightarrow vpr1;$

$Cc27: vpc1 \wedge vcc1 \leftrightarrow vpr2;$

$Cc28: vhc2 \wedge vhc3 \leftrightarrow vpr3;$

$Cc29: vhc2 \wedge vpc4 \leftrightarrow vpr4;$

$Cc30: vpc4 \wedge vcc4 \leftrightarrow vpr5;$ $Cc31: vpc4 \leftrightarrow vpr6.$

From Cc_{19} to Cc_{25} are feature clusters and RMOPs mapping relationships and from Cc26 to Cc31 are feature clusters and precedence relationships mapping.

Table 4. 2 Variety configuration constraints. From PVDN

(f1 ∧ f2 ∧ f3 ∧ ¬f4) ∨ (f1 ∧ f2 ∧ ¬f3 ∧ f4) ↔ true f1↔ poc1 ∧ cc1; f2 ↔ (plc2 ∧ hc2) ∨ (¬plc2 ∧ hc2); f3↔ h3; f4↔hc4 ∧ cc4 ∧ pl4; plc4 ↔ pl230 ∧ pl231; poc1↔ (po100 ∧ ¬po200) ∨ (¬po100 ∧ po200); plc2↔ pl210; cc1↔ (ch100 ∧ ¬ch200) ∨ (¬ch100 ∧ ch200); hc3 ↔ cy120; hc2↔ (c110∧ ¬cy210) ∨ (cy110 ∧ ¬cy210); cc4↔c h230.	Constraints between two component levels of PVDN
plc2↔ hc4 ∧ cc4 ∧ pl4; po100 ↔ch100; po100 ↔ cy110; po100↔cy120; po200 ↔ pl210;	Constraints between feature variants of different feature

Activity Constraints:

These are the hierarchical relationships between the different levels of part variety decomposition network and are shown in the **table 3**

Table 4. 3 Activity constraints in the DCSP for integrated part and RMPP configuration

Activity constraints of table 3 are formulated as Ca_i, for DCSP, given as,

f1 = 1 →Active: poc1 ∧Active: cc1; f2 = 1 →Active: plc2 ∧Active: hc2; f3 = 1 →Active: hc3; f4 = 1 →Active: hc4 ∧Active: cc4 ∧Active: plc4;	Hierarchical relationship between FM and FCs
poc1 = 1 →Active: po100 ∧Active: po200; cc1 = 1 →Active: ch100 ∧Active: ch200; plc2 = 1 →Active: pl210; hc3 = 1 →Active: cy120; hc2 = 1 →Active:cy110 ∧Active: cy210; hc4 = 1 →Active:cy230 ∧Active: cy231; cc4 = 1 →Active: ch230; plc4 = 1 →Active: pl230 ∧Active: pl231	Hierarchical relationship between FC and FVs

$Ca1$: vf1 = 1 ↔ Active: $v$pc1 ∧ Active: $v$cc1;

$Ca2$: vf2 = 1 ↔ Active: $v$pc2 ∧ Active: $v$cc2;

$Ca3$: vf3 = 1 ↔ Active: $v$hc3;

$Ca4$: vf4 = 1 ↔ Active: $v$pc4 ∧ Active: $v$cc4;

$Ca5$: $v$pc1 = 1 ↔ Active: $v$pc1-1 ∧ Active: $v$pc1-2;

$Ca6$: $v$cc1 = 1 ↔ Active: $v$cc1-1 ∧ Active: $v$cc1-2;

$Ca7$: $v$pc2 = 1 ↔ Active: $v$pc2-1;

$Ca8$: $v$hc2 = 1 ↔ Active: $v$cc2-1 ∧ Active: $v$cc2-2;

$Ca9$: $v$hc3 = 1 ↔ Active: $v$hc3-1;

$Ca10$: $v$pc4 = 1 ↔ Active: $v$pc4-1 ∧ Active: $v$pc4-2;

$Ca11$: $v$cc4 = 1 ↔ Active: $v$cc4-1.

4.2.3 Processing:

Eclipse is (CLP) constraint logic programming, software used for solving this DCSP for part and RPP configuration. It is a software for development and placement of CLP applications in configuration, planning and scheduling. It comprises of many constraints solving libraries, the program relates different constraint propagation techniques to discover the values for all the variables which are consistent with all the constraints in a CSP problem. For solving our DCSP problem we use (**ic** library) of eclipse which is a finite domain solver. Prolog-based CLP programming language is used for defining DCSP's variables, constraints and some useful predicates of our problem.

The program is processed as fallows

1. Head.
2. Body.
3. Tail.

4.2.3.1 Head:

Contains predicates defined for beginning the problem solution. It performs two functions

a) It permits the inputs of problem to the CSP solver.
b) Carries the solutions from the solver

Activate /4: A predicate (code) as shown below, is used to feedback the list of active variables to the solution searching process. This predicate creates a list which is used during solution to decide whether the variable is active or inactive. Activity constraints are applied by this predicate.

activate (_: Head, L2, Active,New_active):-

((nonvar (Head), Head =1) -> add (L2, Active, New active); New active = Active).

This code means that if H is not a variable and H = 1 then put L2 (variable) into the list "Active" to form new list "New Active" else "New Active" equals "Active".

Memberd/2: a predicate to test whether the variable is active or not, in (CHL) Constraint handling rule.

```
Memberd (_, []):-fail.
Memberd (X: _, [H:_|_]):-
                X = H,!.
memberd (M:_,[_:_|Ts]):-
memberd (M: _, Ts),!.
```

Find solution/1: This predicate searches the consistent value of the "Active" variables. It repeatedly raises an in-built predicate **indomain/1,** of "ic library", to activate an "Active" variable in its domain.

```
find solution ([]):- true.
find solution ([_:D|Active1]):-
Indomain (D),
find solution (Active1).
```

4.2.3.2 Body:

Body of the program is composed of three main parts.

I. Specifies the variables and their domain.
II. Specify the constraints.
III. Specifies the methods used for searching solution.

The following structures are defined to denote the objects of problem in the program.

```
: - local struct (fms (f1, f2, f3, f4)).
: - local struct (fcs (pc1, cc1, hc2, pc2, hc3, pc4, cc4)).
: - local struct (part family (fms, fcs, fvs, rms, prs)).
: - local struct (rms (rm1, rm2, rm3, rm4, rm5, rm6, rm7)).
```

: - local struct (fvs (pc1_1, pc1_2, cc1_1, cc1_2, hc2_1, hc2_2, pc2_1, hc3_1, pc4_1, pc4_2, cc4_1)).

: - local struct (prs (pr1, pr2, pr3, pr4, pr5, pr6)).

: - constraints (cc1/3, cc2/4, cc3/4, cc4/4, cc11/3, cc12/4).

Fms→ denotes function module,

Fcs →denotes feature cluster level,

Rms → are used for RMOPs of RMPP,

Fvs →denotes feature variant level,

Prs →represents precedence relationships

There local structure is defined in the above code.

In eclipse the variables are represented by upper-case or underscore, so in our program all the variables given in the structures are converted to upper-case as shown below.

(Part family (fms (f1:F1, f2:F2, f3:F3, f4:F4),

fcs (pc1:PC1, cc1:CC1, hc2:HC2, pc2:PC2, hc3:HC3, pc4:PC4, cc4:CC4),

fvs (pc1_1:PC1_1, pc1_2:PC1_2, cc1_1:CC1_1, cc1_2:CC1_2, hc2_1:HC2_1,

hc2_2:HC2_2, pc2_1:PC2_1, hc3_1:HC3_1, pc4_1:PC4_1, pc4_2:PC4_2,

cc4_1:CC4_1),

rms (rm1:RM1, rm2:RM2, rm3:RM3, rm4:RM4, rm5:RM5, rm6:RM6, rm7:RM7),

prs (pr1:PR1, pr2:PR2, pr3:PR3, pr4:PR4, pr5:PR5, pr6:PR6))).

As all the variables of our problem are in Boolean domain so are represented in the Boolean domain as below.

[F1, F2, F3, F4]:: [0, 1],

[PC1,CC1,HC2,PC2,HC3,PC4,CC4]::[0,1],[PC1_1,PC1_2,CC1_1,CC1_2,HC2_1,HC2_2 ,PC2_1,HC3_1,PC4_1,PC4_2,CC4_1]::[0,1],

[RM1,RM2,RM3,RM4,RM5,RM6,RM7]::[0,1],

[PR1, PR2, PR3, PR4, PR5, PR6]:: [0,1],

In the DCSP, a compatibility constraint is triggered once all the variables in Cc_i are "Active".

Constraint Handling Rule (CHR), a declarative high-level CLP language, is used for activation of compatibility constraints', can drop compatibility constraint if one of its variables is "Inactive". CHR consist of two kind of rules i-e simplification and propagation. Simplification substitutes constraints by simpler constraints also protecting logical correspondence. Propagation adds new constrains which are logically redundant and cause further simplification.

CHR has the following structure.

[Head <=> Guard | Body].

Head is Cc_i representation which has same constraint structure

Guard represent the activation condition of Cc_i.

Body is the logical class represented for Cc_i in the head.

The code of CHR for compatibility constraint define in the above section, is shown below.

CHR for Direct Relationship:

cc1(A:L, B:M, Active)<=>memberd(A:L, Active),memberd(B:M, Active)|L $= M.

CHR for Feature cluster and RMOPs relationships:

cc11 (A:L, B:M, Active)<=>memberd (A:L, Active)|L $= M.

cc11 (A:L, B:M, Active) <=>not memberd (A:L, Active)|M = 0.

CHR for Feature clusters and PRs relationship:

cc12(A:L, B:M, C:N, Active)<=>memberd(A:L, Active),memberd(B:M, Active)|N $= (L and M).

cc12 (A:L, B:M, C:N, Active)<=>not memberd(A:L, Active)|N = 0.

cc12(A:L, B:M, C:N,Active)<=>not memberd(B:M, Active)|N = 0.

CHR for AND mapping relationship between two levels of PVDN:

cc2 (A:L, B:M, C:N, Active)<=>memberd(A:L, Active), memberd(B:M, Active), memberd(C:N, Active)|L $= (M and N).

CHR for AND and OPT relationship between two levels of PVDN:

cc3 (A:L, B:M, C:N, Active)<=>memberd(A:L, Active), memberd(B:M, Active),

memberd (C:N, Active)|L $= ((M and N) or(neg M and N)).

CHR for OR Relationship between two levels of PVDN:

cc4 (A:L, B:M, C:N, Active)<=>memberd(A:L, Active), memberd(B:M, Active),

memberd (C:N, Active)|L $= ((M and neg N) or(neg M and N)).

When a compatibility constraint is displayed as an instance of Head, the guard tests to decide whether the rule is true. Once the rule is true, the Head is substituted by the Body and then the Guard is initiated and turns as a compatibility constraint in the process. After defining CHR, any compatibility constraint in our problem is stated as an instance of the Head of the corresponding rule. For example $Cc2{:}(vf1 \leftrightarrow vpc1 \wedge vcc1;)$ is stated as cc2(f1:F1,pc1:PC1,cc1:CC1,New_active4).

4.2.3.3 Tail:

Tail contain problem specific predicates which are used in the program Body.

add ([], List2, New list):- New list=List2.

add ([E1|Es], List2, New list):-

add (Es, [E1|List2], New list).

This predicate is used for list generation and propagation.

print configuration (part family (Fms, Fcs, Fvs, Rms, Prs)):-

writeln ("Find the following configuration result :"), write (" Function Modules :"),

(foreacharg (Fm, Fms) do write configuration (Fm)), nl,

write (" Feature Clusters :"),

(foreacharg (Fc, Fcs) do write configuration (Fc)),nl,

write (" Feature Variants :"),

(foreacharg (Fv, Fvs) do write configuration (Fv)),nl,

write (" RMOPs :"),

(foreacharg (Rm, Rms) do write configuration (Rm)),nl,

Write (" Precedence relations :"),

(foreacharg (Pr, Prs) do write configuration (Pr)),nl.

write configuration (A: B):-B==1-> write (A), write (" "); true.

4.2.4 Results:

The above defined code is composed in prolog source file with all the definitions of variables, constraints and problem related predicates. Then this file is compiled in the eclipse system. Following Query is then executed to run the problem-solving process,

solve_dcsp (part family (fms (f1:F1, f2:F2, f3:F3, f4:F4),

fcs (pc1:PC1, cc1:CC1, hc2:HC2, pc2:PC2, hc3:HC3, pc4:PC4, cc4:CC4),

fvs (pc1_1: PC1_1, pc1_2:PC1_2, cc1_1:CC1_1, cc1_2:CC1_2, hc2_1:HC2_1,

hc2_2:HC2_2, pc2_1:PC2_1, hc3_1:HC3_1, pc4_1:PC4_1, pc4_2:PC4_2,

cc4_1:CC4_1),

rms (rm1:RM1, rm2:RM2, rm3:RM3, rm4:RM4, rm5:RM5, rm6:RM6, rm7:RM7),

prs (pr1:PR1, pr2:PR2, pr3:PR3, pr4:PR4, pr5:PR5, pr6:PR6)))

The program creates a configuration outcome which is shown in the output and error message section as shown in the figure (4.10). When we run the query on program it gives us first configuration result and says "maybe more" means there may exist some other possible configurations, for that by pressing "more" in the main window we get the second configuration and the program ends there shown by black writing in fig (4.11). In first configurations there are 3 delayed functions which are the inactive variables while in second configuration there are 5 delayed functions. The configuration results shown are consistent with the oil pump body family. Two configurations are given as

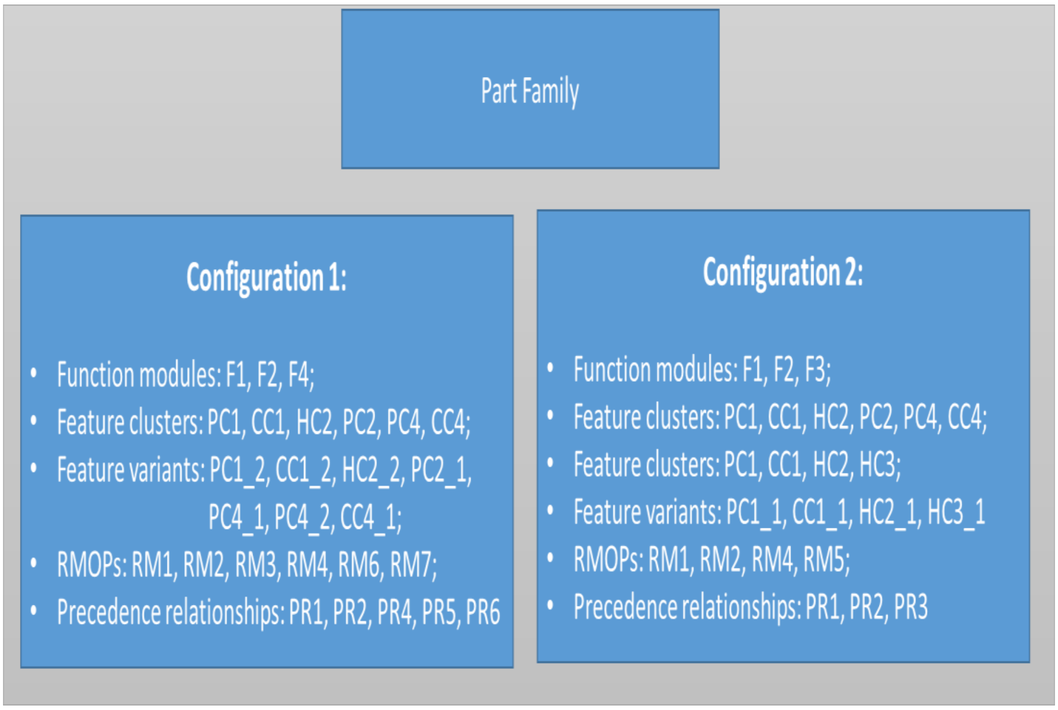


Figure 4. 9 Results of part family configuration

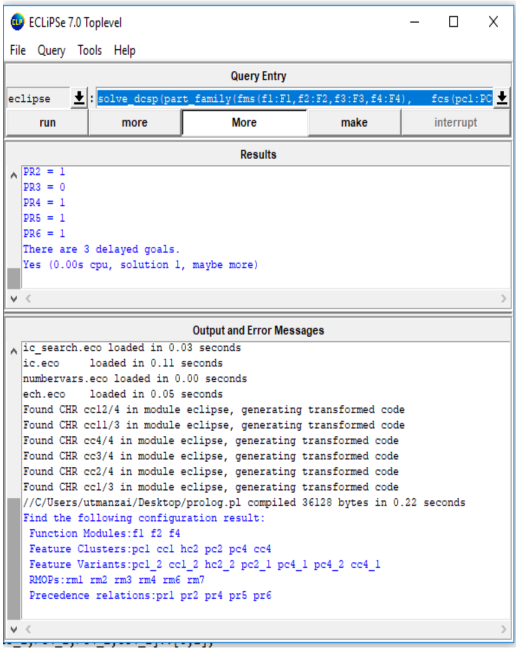


Figure 4. 10 TkEclipse execution

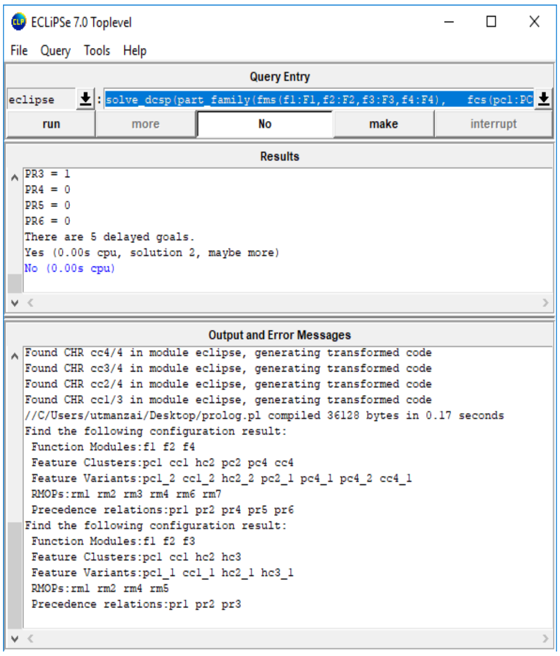


Figure 4. 11 TkEclipse execution

4.3 Conclusion:

The reconfigurable process planning is mostly carried out for evolving part family under the paradigm of co-evolution, there exist very little research in literature for Representation models of part family which can be used for development of reconfigurable process plan. So in this chapter part family representation model is developed and representation of model is in directed graphs.A framework, based on FBPVM, of mature Part family is proposed by using function-based feature clustering, which generates process plan and kinematic configurations simultaneously for the part family variants Then MPP for part family are formed by using reconfigurable machining operation plans and precedence relationships.at last collective configuration (part and reconfigurable process plan) for explicit part variant is carried out by using the TKEclipse and Prolog soft wares, which extract the data from model generated for part family.

Chapter 05 Analysis and Future Recommendations

6.1 Analysis and Future Recommendations

This thesis falls in the domain of Reconfigurable process planning for Reconfigurable manufacturing systems. It aims in generating representation models part/product family and develop alternative process plans for a part/product family. For single part variant of part family process plans and kinematic configurations are generated The subject addressed in this thesis comprise not only model representation but also generation of process plan and kinematic configurations around a part family, thus it can accommodate future requirements and can be made responsive.. The methodology proposed to address the above-mentioned subject can be collapsed as follows:

- A Model is developed for part family, instead of single part variant.
- For feature clusters, reconfigurable machining operation plans (RMOPs) are developed which are used for Reconfigurable machining process plan (RMPPs) for part family with precedence relationships.
- Extraction of required configurations for generation of part variant's process plan and kinematic configuration simultaneously, is done by DCSP.

Certain future work recommendations which can be an extension to the present work are as follows:

1) The developed model is for mature part family which can be modified for evolving part family.
2) The proposed model can be applied on a more complex industrial case and different frameworks of process planning.
3) Industrial implementation of this model for specific framework of process plan and kinematic configuration generation.

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