Developing of Integrated Process Planning System for Flexible Manufacturing Environment

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ABSTRACT

Recently, manufacturing systems are striving for an integrated manufacturing environment. The main aim of this research is to propose methodology and develop a system for generating flexible process plan according to Non-linear process planning approach (NLPP) which is based on a shop floor condition named flexible process plans for all parts before entering the shop floor. Four types of flexibility have been considered which can be related with the part manufacturing. Firstly, sequencing flexibility indicate to the possibility of the sequence interchanging in which required manufacturing operations are performed. Secondly, processing flexibility is refers to the possibility of producing the same manufacturing feature with alternative processes. Thirdly, machine tools flexibility is determined by the possibility of performing an operation on more than one machine and the last is cutting tools flexibility which refers to the possibility of producing the manufacturing feature with alternative cutting tool, the researcher creates mathematical model for each activity of process planning to provide mathematical solution for each one. The developed system basically consists of two modules; firstly, Product design module adopted to define design; secondly process planning module divided into five sub-modules: machining sequence, process selection, machine tools selection, cutting tools selection and machining time sub-modules.
Keyword: Process Planning, Flexibility, CAPP, NLPP, Manufacturing Features, CIM, CAM.

INTRODUCTION:

Process planning is a task included a wide range of functions and activities for producing a part through design and develops an appropriate manufacturing process. of Part design Interpretation, manufacturing processes selection, operations definition, operation sequences, machining data, geometrical dimensions and tolerances are some common activities associated with the process planning. From a manufacturing perspective, performing process planning independently or sequentially with manufacturing activities result in a range of inefficiencies. These include infeasible process plans, non-available resources and overloaded, high production costs and time, unbalanced resource loading, create bottleneck machines, lead to lower overall resource utilization, and poor on-time delivery performance. Therefore, this leads in limitation of the alternatives by the earlier decisions made at the process planning stage. The aim of this research is to propose a new method for generating a flexible process plan that have portability integration with the other activities of computer integrated manufacturing (CIM), the proposed method is a achieved based on creation and development a number of mathematical models that provide mathematical solutions for process planning activities, as well as developing a system can generate basic process plan and alternatives, the system designed to improve several objectives that have a vital impact on the manufacturing system by improving

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manufacturing lead time, reducing bottleneck machines, increasing utilization of machines, minimizing job tardiness, reducing the delay time as much as possible by providing alternatives ways to execute jobs and free humans intervention. This paper consists of number of sections includes literature review of update related research. Present a new proposed methodology about non-linear process planning. Explain the main modules and flowcharts of developing automated process planning system that implemented and tested by case study with results and conclusions.

Literature Review:

Computer Aided Process Planning CAPP is rightly seen as an integration fabric for CIM with its relations to Design and Manufacturing, integration of process planning with CAD or CAM provided by multilateral research:

Shaw and Eugene (2000) [1] presented a new model includes multi-activity model for the conceptual design and object model for classes of design process. Firstly, the multi-activity model includes defined the context of the objects. Secondly, the object model explains the data and functions used in design process and process planning integration. has been

Collecting and modelling of the design information that is necessary for conceptual process planning using unified modelling language. The goal of the developed model is to initiate standard interface specifications that are necessary for design and process planning integration.

Berend and Alessandro (2006) [2] presented a new approach for process planning and production control integration, that combined between the management gliding planning with nonlinear process planning, allowing at the same time a partial decentralization. a novel approach conceived in the frame of the “Gentelligent Components in their Lifecycle” has been introduced. The main advantages of this method are the high flexibility in reacting to disturbances combined with the possibility to control the global result in the consideration of strategic goals.

Elsa (2006) [3] developed a optimisation model for cutting parameters includes a shop floor constraint and simultaneously the technology-related constraints determined by the available time at each workstation. The integration between process planning and production planning in this approach, part machining time is a new variable for shop floor scheduling. Since the limiting factor of workstation available time at every scheduling date depends on the shop floor status. Machining time optimization can range from the time for minimum cost to the time for maximum production rate. Part machining time considered a new variable for shop floor scheduling. The proposed optimisation model includes; non-linear, uni-criterion and multi-variable. The search is carried out using sequential quadratic programming for the optimal solution.

Khalid (2007) [4] developed an algorithm to build an (Integration of Product Design and Process Planning) system called IPDPP to link design phase with conceptual process planning phase using machining feature to help the designer to explore alternatives at early design stage which validates the calculation of manufacturing time using feature technology. The architecture of his developed system classifies the main task of conceptual process planning into four steps: description of part features, manufacturing process selection, machining parameters selection and manufacturing time calculation.

Lonel (2008) [5] Discussed a CAD/CAPP integration by developed a computational technique mode. Limited number of important design and manufacturing features can be used to achieve an integrated product model that provides not only a direct interpretation of CAD data to the CAPP system, but supplies sufficient information for the generation of the correct process plan’s operations sequence. The approach simplifies engineering drawing information complexity, and offers better computability, reusability and improved communication between CAD and CAPP and it is used to develop software applications that apply object-oriented programming as a new way of thinking about solving CAD/CAPP problems and as a promising alternative to other techniques.

Aleksandar et al. (2011) [6] suggested a new model uses ability of installed software for sharing information derived from processes with which they are connected. Information obtained used for generating the optimal process plan for CAPP module. Modular CAPP solutions are created and customized to fit the needs of different manufacturing enterprises, taking into consideration the implementation costs and time by using the presented conceptual framework.

Mithal and Amjad (2008) [7] developed an algorithm for extracting and of hybrid manufacturing features of symmetrical parts to fill the gap between CAD and CAM and this will require solution to several fundamental problems in planning and geometric reasoning. The first problem is the interface between CAD and CAM, that automatic feature recognition is an indispensable technique. The developed algorithm is based on the syntactic pattern primitive concept supported by production rule technique.

Juan and Xianguo (2012) [8] proposed a multi agent process planning system based on STEP-NC in manufacturing. Manufacturing feature oriented process planning and the distributed artificial intelligence methods are addressed. Collaborative multi agent process planning was employed to accomplish process planning of part. The multi agent process planning system consists of three types of autonomous agents, which are global manager agents, planning agents and manufacturing resource agents. Process planning can be automatically completed by multiple agents' cooperation. Each agent is capable of communicating with each other through improved Knowledge Query and Manipulation Language (KQML). And by using a feature recognition technology based on macro code manufacturing features as information carriers from design to process planning and CNC machining.

Mats Bagge (2014) [9] Proposed a new method that cover many activities for process planning, which includes the ability to predict the outcome of a proposed manufacturing process. This is realised by gathering supporting methods suitable to manage both qualitative and quantitative characterisation as well as analyses of a manufacturing process.

Satish Kumar et al (2015) [10] Presented novel product model basded on an object-oriented approach used in supporting the task of CAPP. The product model based on AP 203 and AP 224 presented. The description of EXPRESS entities which are used to represents the STEP part21 file. Mapping of design attributes to feature attributes i.e. AP 224 has been presented. Implementation of product model based on object class hierarchy also presented with an example to demonstrate the application of model.

Proposed Methodology of Flexible Process Planning:

In this research a new methodology has been developed for automated generation of process planning. The proposed method is designed to be implemented according to Non-linear process planning approach (NLPP) which is based on a static shop floor condition (called multiple or flexible process plans) for each part before entering the shop floor. Considering four types of flexibility can be associated with the manufacturing of a part as shown in Figure (1).

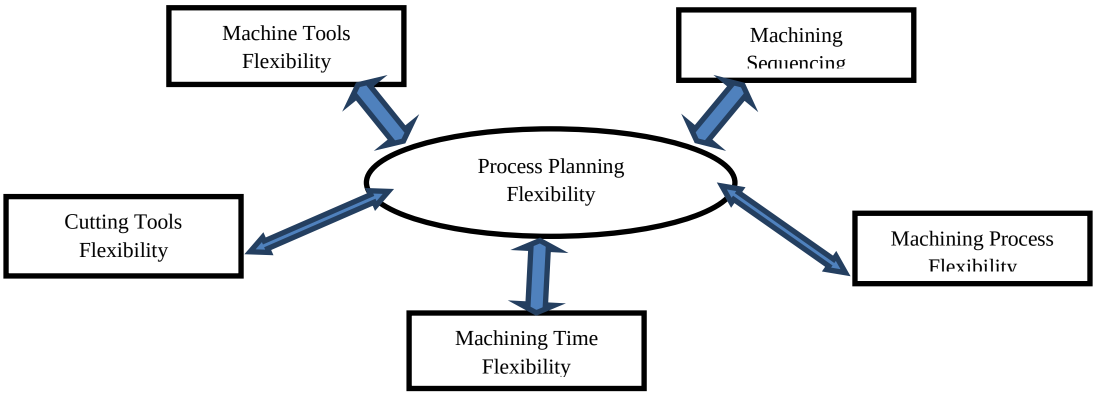


Figure (1): Process Planning Flexibility

The first, sequencing flexibility refers to the possibility of interchanging the sequence in which required manufacturing operations are performed. The second, processing flexibility is determined by the possibility of producing the same manufacturing feature with alternative processes. The third, machine tools flexibility relates to the possibility of performing an operation on more than one machine and the last is cutting tools flexibility which refers to the possibility of producing the manufacturing feature with alternative cutting tool. The researcher develops a new mathematical model for process planning activities to provide mathematical solution for each one. According to the process planning perspective, part design is an important main input therefore that needs to be defined significantly. Manufacturing features of part design are an enhancement of feature class, feature subclass, feature location, dimensions, surface finish, and tolerance size. The complexity of design and manufacturing usually determines the number and type of form features required to represent a part or an object for manufacturing. Features can be classified as primary feature and secondary (or class and sub-class) Manufacturing feature tree, is shown in Figure (2).

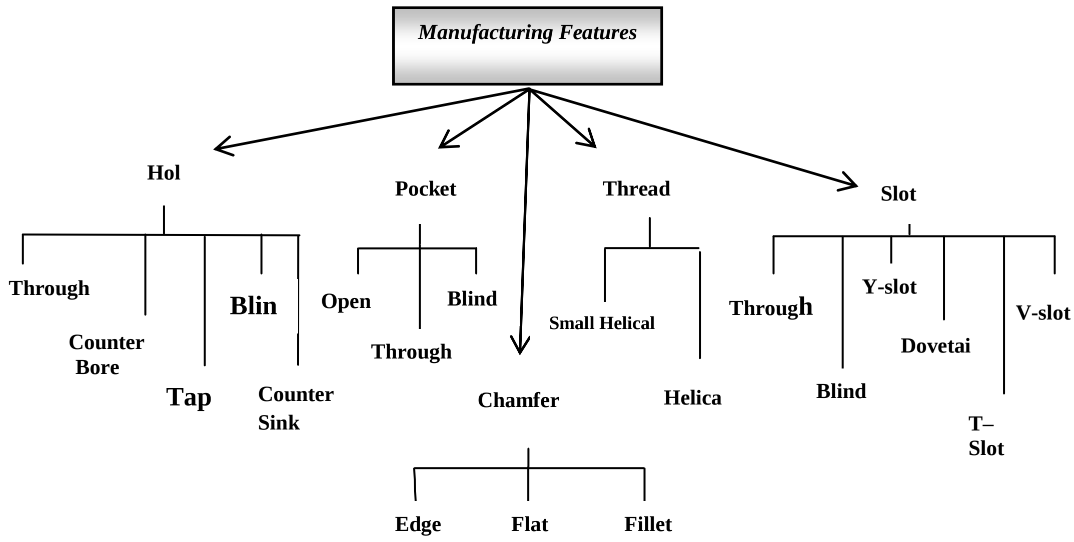


Figure (2): Manufacturing Features Tree.

The proposed generating methodology is designed to be implemented according to Non-linear process planning approach (NLPP) which is based on a static shop floor condition (called multiple or flexible process plans) for each part before entering the shop floor. The process planning module is divided into five sub-modules, these sub modules work concurrently among them and relatively with product design module according to several mathematical models as follow.

Machining Feature Sequencing Flexibility

Process planning module generates machining features sequencing and specifying machining process, machine tool and cutting tool with alternative for part design to generate basic process plan and alternatives. Mathematiclly, the factorial of a non-negative integer n denoted by (n!) mentioned in equation (1), is the product of all positive integers less than or equal to n, this factorial is employd to generate machining sequence, Sequence of machining features generation is based on a number of features in the part design and precedence sequence constraints (process and geometric).

$$S = n! \qquad \text{.......(1)}$$

Where:
S = number of sequence possiblities
n = number of features includes in part design.

Machining Processes Selection Flexibility

After describing the part, the second step is to select the suitable processes to machine that part. The procedure of process selection depends on the feature type (slot, pocket, hole …etc.). If a feature is a simple form feature (slot, pocket, hole …etc.) the suitable process will be assigned to produce that feature, but if it is a compound feature (e.g. Threading Hole) in this case the feature will be divided into two sub- features, hole and thread and suitable processes for them independently will select. Feature – Process (FP) model is used for this case It is defined mathematically as mentioned in equation (2). Two constraints are practiced parallel to FP model The first is **group selected constraint** to restrict group selected by one process and one feature only and **process constraint** used to exclude the groups are including process that does not meet shape, tolerance and surface finish required for producing a feature selected with that process.

$$(FP) = \frac{\left[\frac{p!}{r!(p-r)!}\right]!}{g!\left[\left(\frac{p!}{r!(p-r)!}\right)-g\right]!} \quad \text{…....(2)}$$

Where:
p = number of processes and features.
r = process combination group (Process + Feature).
g = process selection group ($Process^1$-$Feature^1$) - ($Process^2$-$Feature^2$) …..… (Process ^{N} – Feature $^{n)}$.

Machine Tool Selection Flexibility

Availability of more than one machine to perform the same (feature – process) with the same accuracy is considered important point in process planning flexibility because it is providing alternative choice to select machine tools. Prioritization of machine tool selection is based on the best in terms of Earliest Possible Start (EPS), Earliest Possible Finish (EPF), and Shortest Processing Time (SPT). Featur – Process – Machine (FPM) model defined mathematically in equation (3) is used for specifying machines that meets the required parameters of (Features - Process) statuses previous selected. **Group selected** and **machine tool constraints** are employed to eliminate possibilities which does not include one (Feature-Process) and one machine in the group, as well as the possibilities include machines that cannot perform the (Features -Process) selected.

$$(FPM) = \sum_{k=1}^{n} \frac{\left[\frac{(FP^{(k)}+m)!}{b!\left((FP^{(k)}+m)-b\right)!}\right]!}{x!\left[\left(\frac{(FP^{(k)}+m)!}{b!\left((FP^{(k)}+m)-b\right)!}\right)-x\right]!} \quad \text{........ (3)}$$

Where:
(FPM) = Feature – Process – Machine.
m = Number of suitable machines.
$FP^{(k)} = FP^{(1)}$(features - processes) , $FP^{(2)}$,$FP^{(3)}$……… $FP^{(N)}$ Selected.
b = Group selected of [(Feature - Processes)- Machine Tool].
x = Machine Selection Group ($Process^1$-$Feature^1$-$Machine^1$) - ($Process^2$-$Feature^2$-$Machine^2$)…..(Process ^{N} – Feature ^{N}-Machine ^{N}).

Cutting Tool Selection Flexibility

A feature to be produced accurately may need a different type of manufacturing processes. For each process and machine required a special cutting tool is to be compatible with their parameters. Feature – Process Machine – Tool (FPMT) model is used to provide mathematical solution for selecting tools which is defined mathematically as mentioned in equation (4).

Group selected constraint is use to eliminate possibilities that did not contain one tool and one (Feature - Process- Machine) in the same group. **Cutting tool constraint** eliminates the possibilities which include groups contains tools that did not meet the required parameter of (Feature - Process- Machine) selected.

$$(FPMT)\ Model = \sum_{k=1}^{n} \frac{\left[\frac{(FPm^{(k)}+t)!}{z!\left((FPm^{(k)}+t)-z\right)!}\right]!}{y!\left[\left(\frac{(FPm^{(k)}+t)!}{z!\left((FPm^{(k)}+t)-z\right)!}\right)-y\right]!} \quad \ldots\ldots (4)$$

Where:
(FPMT) = Feature - Process - Machine - Tool
t = Number of Suitable Cutting Tools and Alternatives assigned.
$FPM^{(k)} = FPM^{(1)}$(Features- Processes- Machine) , $FPM^{(2)}, FPM^{(3)} \ldots\ldots\ldots\ldots\ldots FPM^{(N)}$
z = Group Selected of [Feature- Processes-Machine Tool) - Cutting Tool]
y = Tool Selection Group ($Feature^1$-$Process^1$-$Machine^1$ -$Tool^1$) - ($Feature^2$- $Process^2$-$Machine^2$- $Tool^2$) ……………….($Feature^N$ – $Process^N$-$Machine^N$- $Tool^1$).

Machining Time Calculation Flexibility

The last activity of process planning is calculation of machining time, machining time is achieved mathematically in equation (5). Generally setup time and handling time are consider based on machine tool types, cutting tool types and fixtures as well as plant layout and equipment used to transmit parts.

$$MT = PCT + (HT*n^1) + (CT*n^2) + PST \quad \ldots(5)$$

Where:
MT = machining time.
PCT = process time which is calculated according to special equation for each process.
HT = part handling time.
n^1 = number of times the part is transmit between machines.
CT= cutting tool setup time.
n^2 = number of times the cutting tool is changed to machine the part.
PST = part set up time.

Process planning flexibility generation is based on sequence, process, machine tool and cutting tool flexibilty as mentioned, threrefore all posibilities are generatd which are summarized true FPMT, so these result of each one will be swapped with sequences generated firstly and then combination of two elements (FPMT-Sequence) is generated according to Feature – Process – Machine – Tool – sequence (FPMTS) model defined mathematically as mentioned in equation (6). Implementing of **process plan group selected** constrain [group selected should consist of (Feature, Process, Machine, Tool, Sequence)] to restrict the area of running and exclude unacceptable process plans.

$$(FPMTS) = \frac{A!}{V!(A-V)!} \quad \ldots\ldots (6)$$

Where:
FPMTS = Feature – Process – Machine – Tool – Sequense.
A = number of alternatives sequences, processes, machine tools and cutting tools.
V= group selected of [(FPMT - Sequence)].

CAPP System Developing:

In this research has been developed CAPP system based on two major functional modules product design module and process planning module. The system requires interaction between the user and functional modules. The arrangement of functional modules allows the user to implement the functional modules without having any effects on the overall system structure. The product design module is considered the first stage of the system, Figure (3) shows the working mechanism of this module. The second stage of system is process planning module, which is divided into five sub-modules as follows:

Machining Feature Sequencing Sub Module

Sequence of machining features generation is based on number of features of part design and precedence sequence constraints (process and geometry). Figure (4) shows the flow chart of machining feature sequencing module.

Machining Processes Selection Sub Module

After sequencing machining of parts feature, the next step is to select the suitable process to machine each one, if a feature is described as a form feature in the database, the system directly selects the suitable process for the feature, but if it is a compound feature in this case the process will partially satisfied the requirements and it is select as candidate process for the feature and unsatisfied requirement will be defined as a new feature which has passed again to the data base, and the suitable process is select to produce it. Figure (5) shows the step series of process selection module.

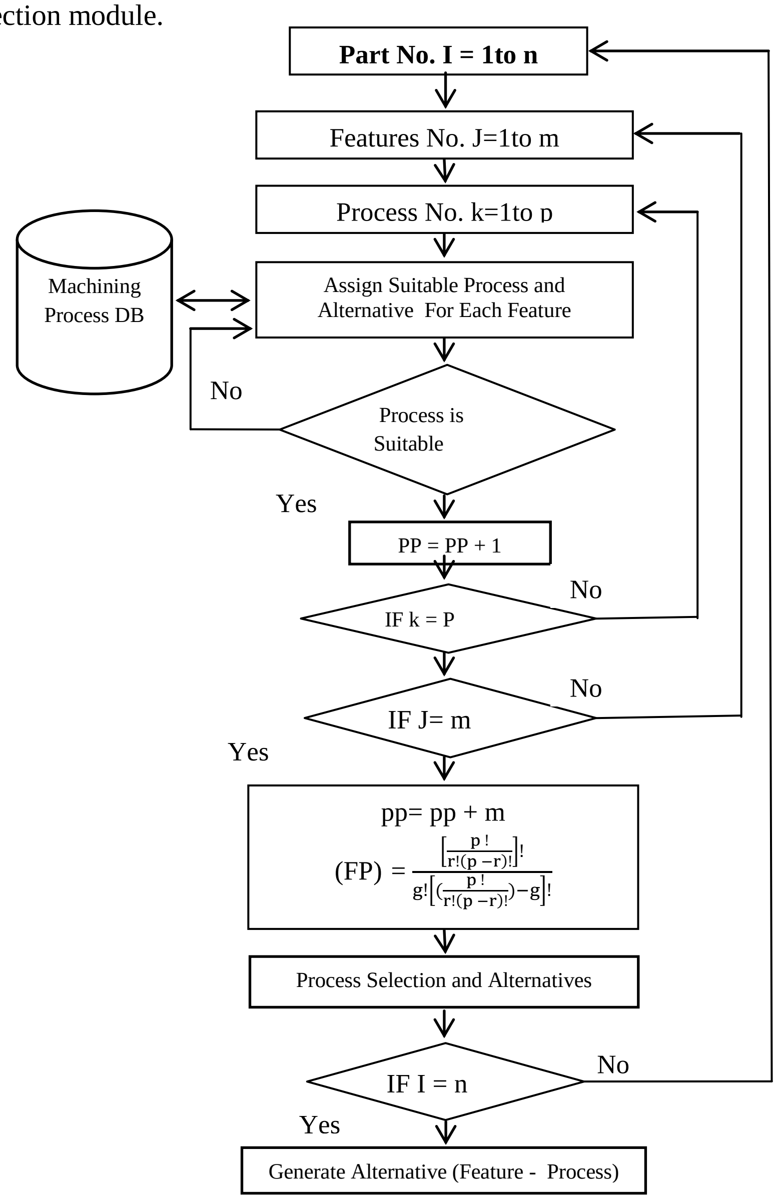


Figure (3): Working Mechanism of Product Design Module.

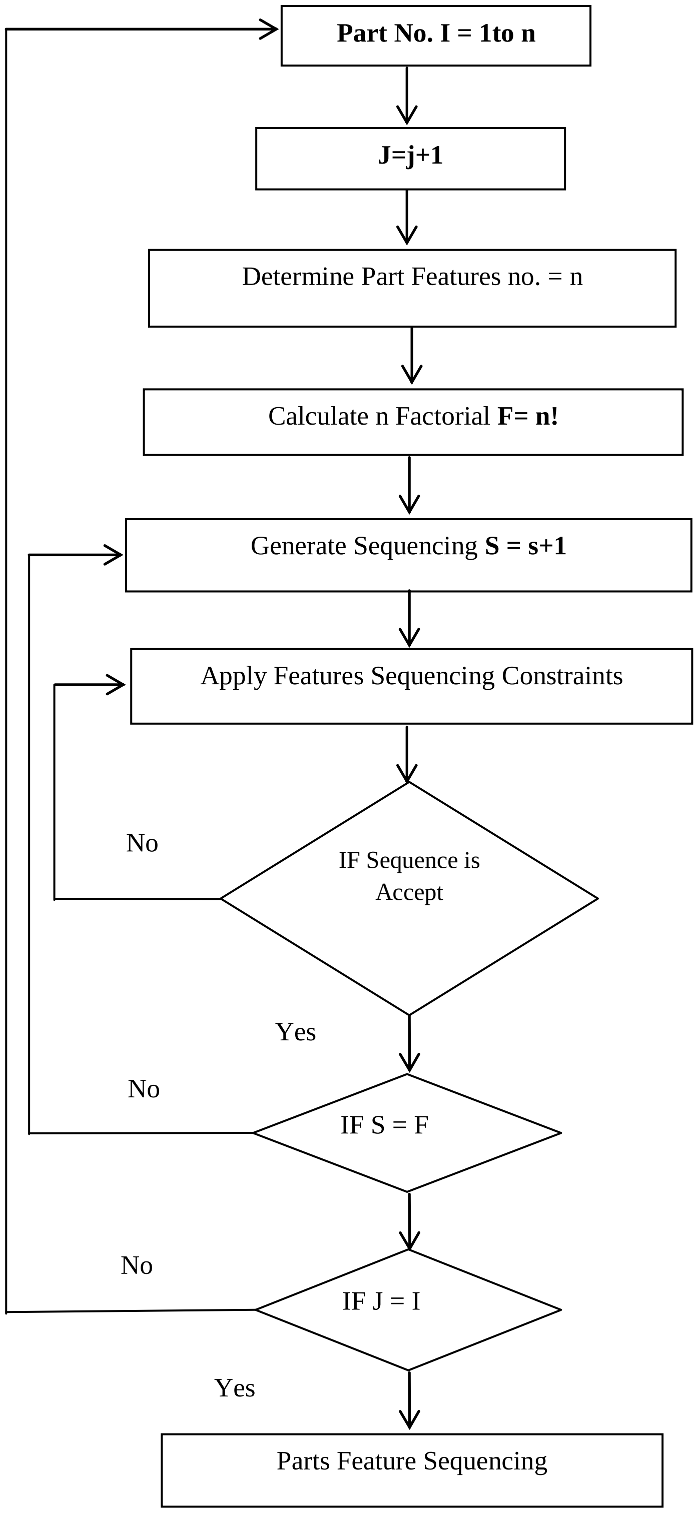


Figure (4): Flow Chart of Machining Feature Sequencing Module.

Machine Tool Selection Sub Module

Machine tool selection module is specifying a certain machine and alternatives that meet the required parameters of (Features - Process) statuses selected in process selection module. Availability of more than one machine to perform the same (feature – process) with the same accuracy is considered important point in process planning flexibility because it is providing alternative choice to select machine tools. Figure (6) shows the flow chart of machining feature sequencing module.

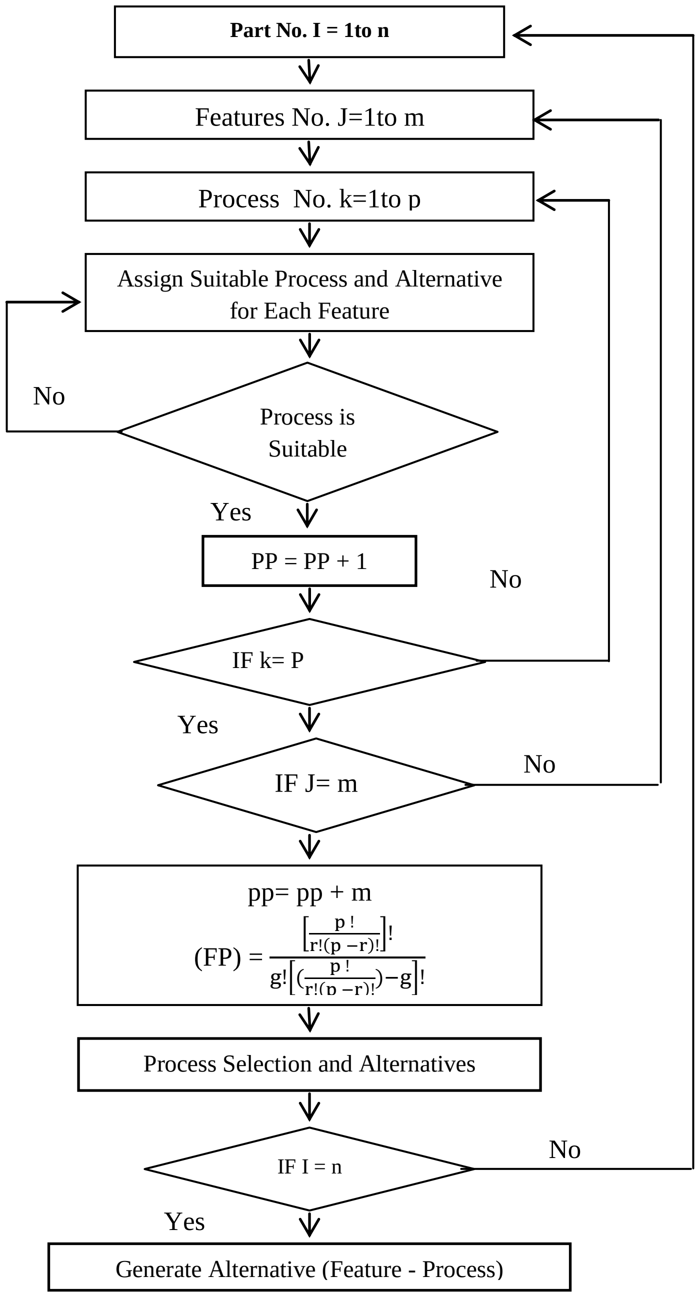


Figure (5): Flow Chart of Machining Process Sub Module.

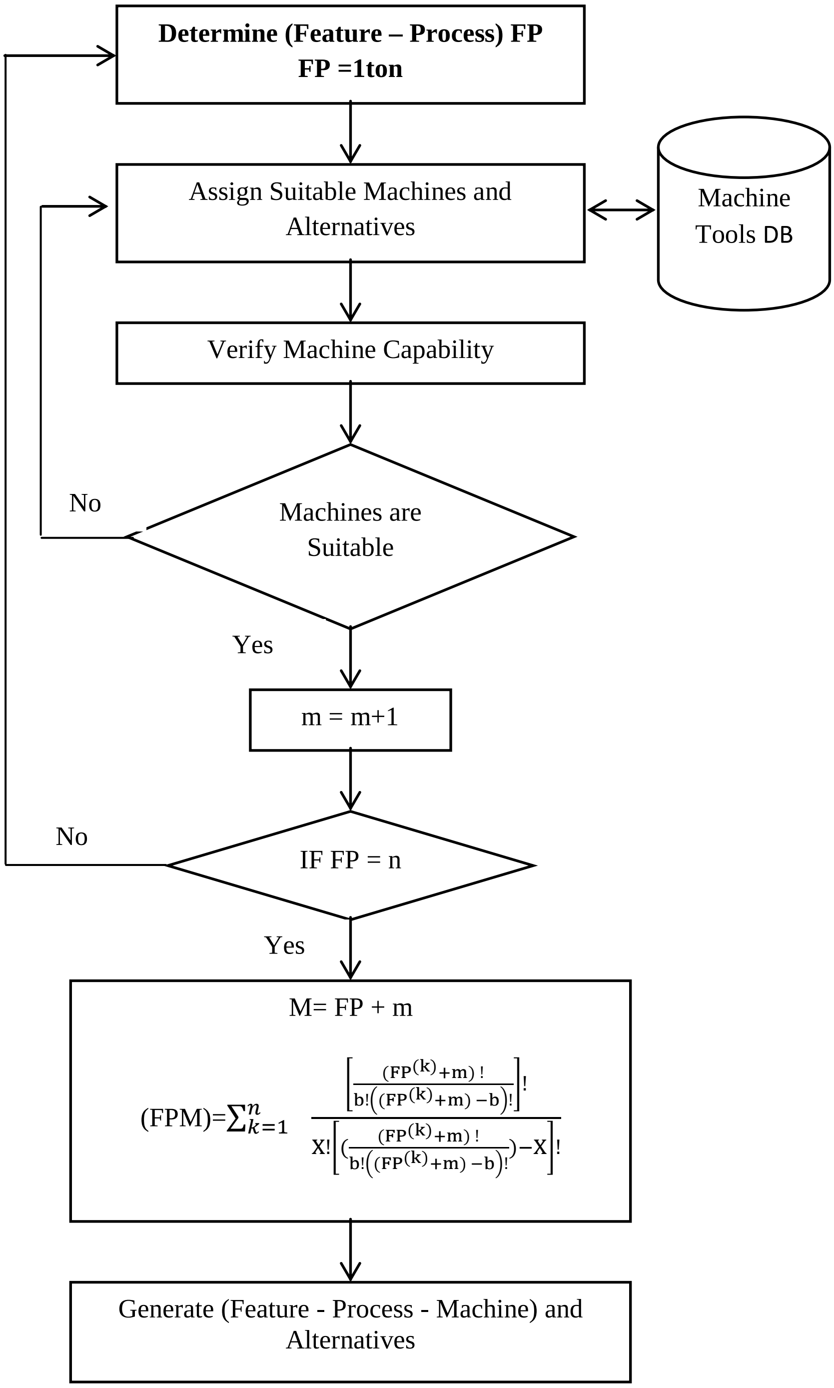


Figure (6): Flow Chart of Machine Tool Sub Module.

Cutting Tool Selection Sub Module

Cutting tool selection is according to some given information including process type (drilling, milling, grinding, etc.), feature properties, cutting types (continues, interrupter), machine properties (cutting speed, feed rate, dimensions) etc. based on this given information the suitable tools will be selected. Figure (7) illustrates the flow chart of cutting tool selection module.

Machining Time Calculation Sub Module

According to alternatives of machine tools, cutting tools, machining processes the machining time is varies depending on these changes increasing or decreasing. Figure (8) illustrates the flow chart of machining time calculation module. Availability of more than one tool different in specifications (cutter dia., no. of teeth, cutting depth) provides a variation in tool selection.

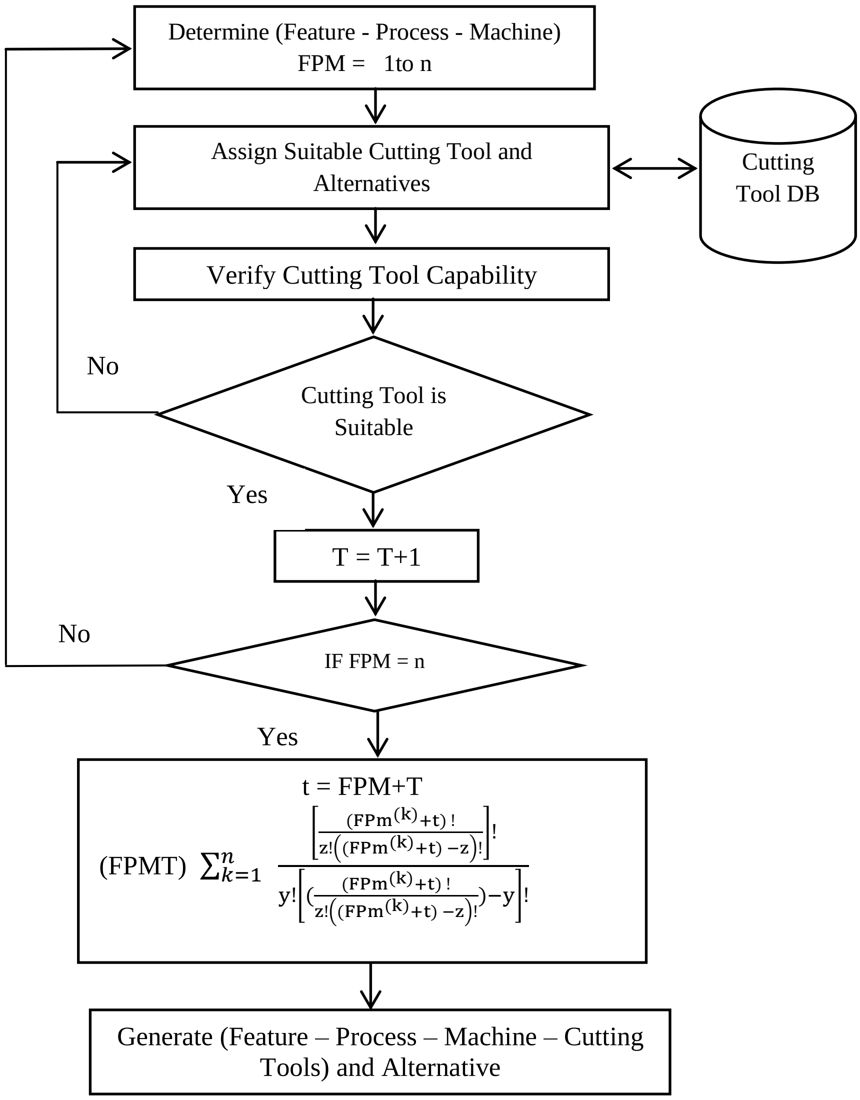


Figure (7): Flow Chart of Cutting Tool Sub Module.

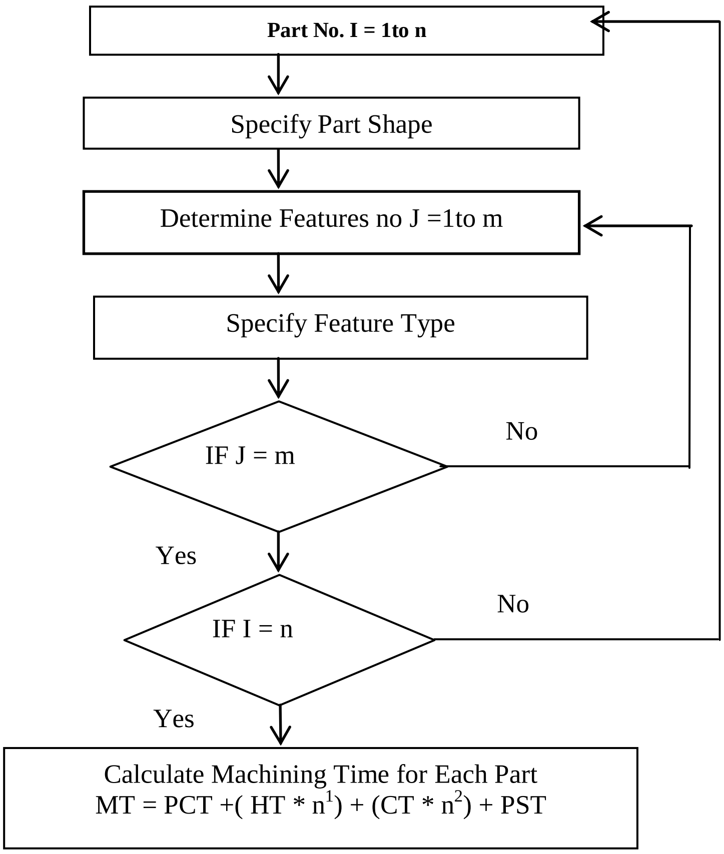


Figure (8): Flow Chart of Machining Time Sub Module.

System Implementation and Testing:

To examine and test the capabilities of the developed system are carried out through a case study. The case study is including five design parts to be manufactured on three machines (Mill, Drill, Mill Drill) and set of cutting tools for testing the system, in this case study a machine tool can process one feature at a time and each part is processed on one machine at time, Figure (9) shows the 3D model of parts design and all dimension in millimetres. The product design module includes two steps; the first is describes and selects the kinds of features included in the design with its parameters such as feature type, sub feature type, feature dimensions, tolerance size and surface finish.

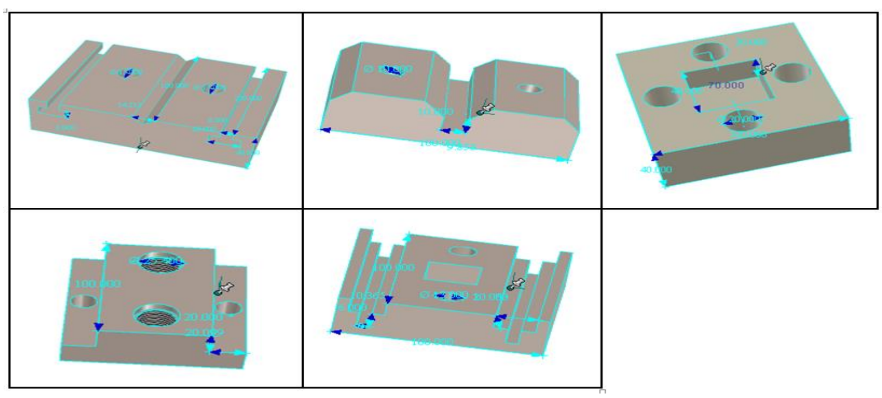


Figure (9): 3D Model Parts Design of the Case Study

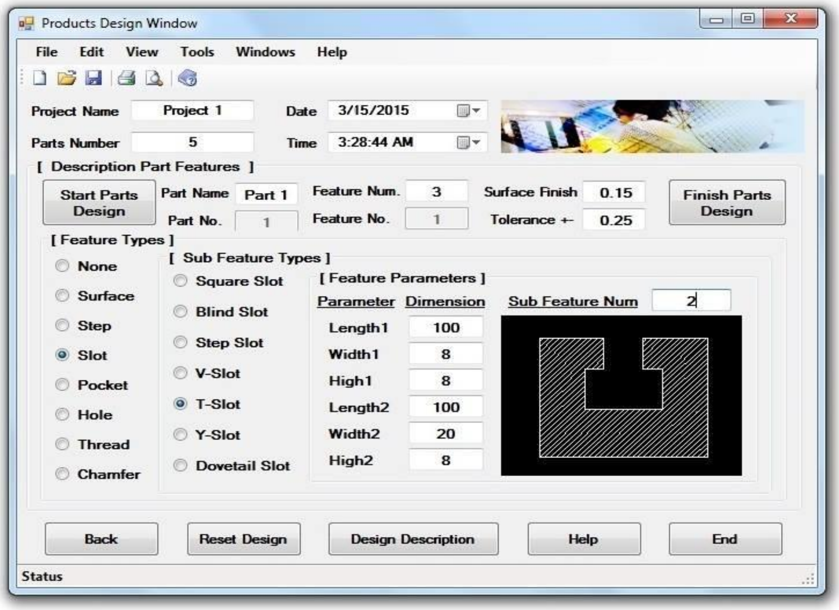
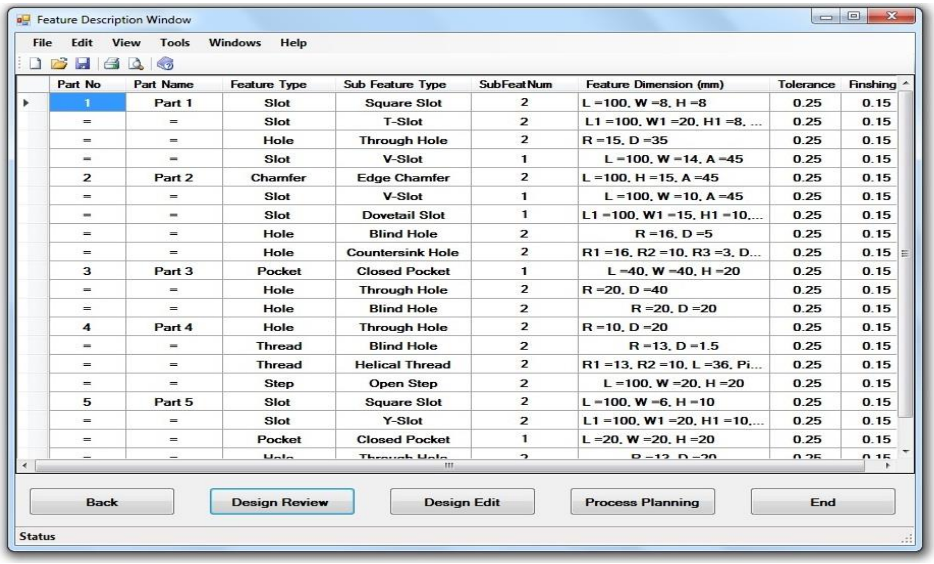


Figure (10): Input Information Window of Product Design Module.

The second step of product design module includes the representation of all information relates to design required in process planning stage obviously and significantly as shown in figure (11).



Part No	Part Name	Feature Type	Sub Feature Type	SubFeatNum	Feature Dimension (mm)	Tolerance	Finshing
1	Part 1	Slot	Square Slot	2	L =100, W =8, H =8	0.25	0.15
=	=	Slot	T-Slot	2	L1 =100, W1 =20, H1 =8, ...	0.25	0.15
=	=	Hole	Through Hole	2	R =15, D =35	0.25	0.15
=	=	Slot	V-Slot	1	L =100, W =14, A =45	0.25	0.15
2	Part 2	Chamfer	Edge Chamfer	2	L =100, H =15, A =45	0.25	0.15
=	=	Slot	V-Slot	1	L =100, W =10, A =45	0.25	0.15
=	=	Slot	Dovetail Slot	1	L1 =100, W1 =15, H1 =10,...	0.25	0.15
=	=	Hole	Blind Hole	2	R =16, D =5	0.25	0.15
=	=	Hole	Countersink Hole	2	R1 =16, R2 =10, R3 =3, D...	0.25	0.15
3	Part 3	Pocket	Closed Pocket	1	L =40, W =40, H =20	0.25	0.15
=	=	Hole	Through Hole	2	R =20, D =40	0.25	0.15
=	=	Hole	Blind Hole	2	R =20, D =20	0.25	0.15
4	Part 4	Hole	Through Hole	2	R =10, D =20	0.25	0.15
=	=	Thread	Blind Hole	2	R =13, D =1.5	0.25	0.15
=	=	Thread	Helical Thread	2	R1 =13, R2 =10, L =36, Pi...	0.25	0.15
=	=	Step	Open Step	2	L =100, W =20, H =20	0.25	0.15
5	Part 5	Slot	Square Slot	2	L =100, W =6, H =10	0.25	0.15
=	=	Slot	Y-Slot	2	L1 =100, W1 =20, H1 =10,...	0.25	0.15
=	=	Pocket	Closed Pocket	1	L =20, W =20, H =20	0.25	0.15

Figure (11): Output Result of Product Design Module.

The second stage of the developed system is the process planning module at this stage the selection and generation of process planning activities has been done which includes machining processes, machine tools and cutting tool selected to machine part as well as sequence are generated. At this stage the result of concurrent working of sub modules to generate suitable process plan and alternatives figure (12) shows the initial solution of process planning module.

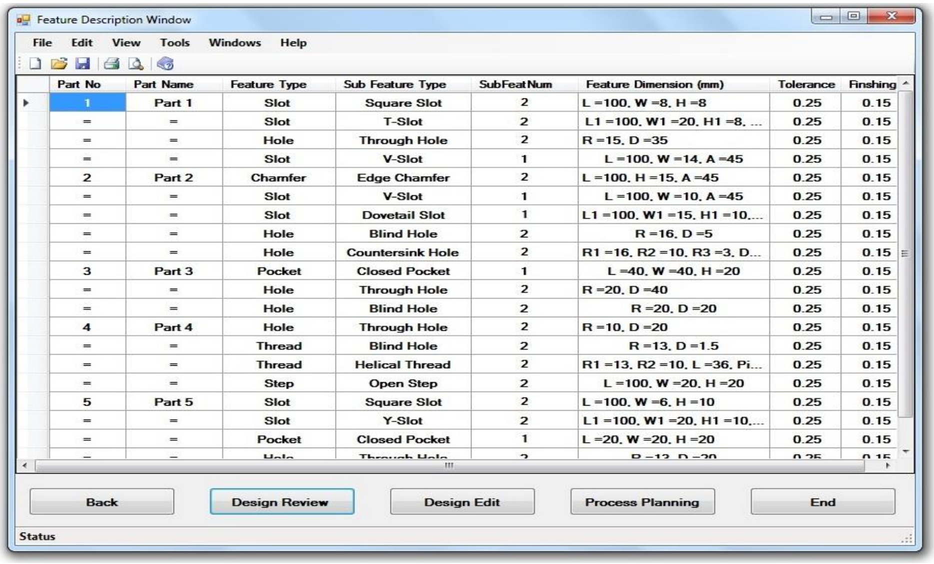


Figure (12): Initial Output of Process Planning Module.

Figure (13) shows the final result of process planning module which is represent as work sheet includes generation of optimal process planning and machining time for each one.

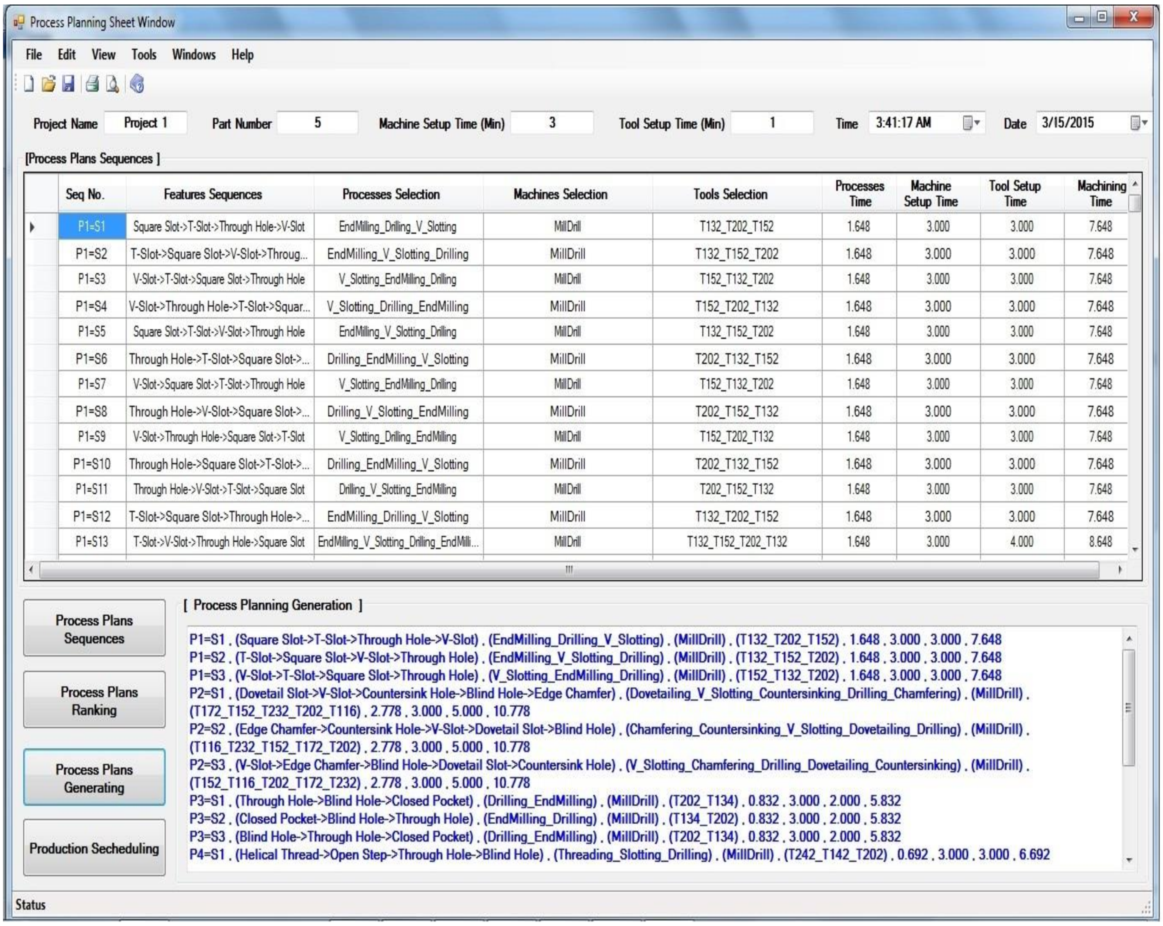


Figure (13): The Final Result of Process Planning Module.

Result and Discussions:

The two modules of the developed system are designed to work relatively where the product design module describes the part design based on feature library, the output results from product design module are represent as an input that contains all information about designs to generate suitable process plan for each one. In process planning module is assign suitable cutting tool with suitable machine tool and alternatives for each feature included in the part design as well as generating of multi machining sequence and calculation of machining time, based on these varying in flexible selection and generating a flexible process planning can be produced that is able for integrating with other activities ;therefore it is considered better than fixed process plan because of flexible process plan provides alternative options to be to work compatibility with other manufacturing system activities.

CONCLUSION:

The main conclusions obtained from the work is researcher tried to develop a system for generating flexible process planning by Using of non-linear process planning approach with the mathematical models created and group selection constraints is considered a useful method for generating alternative process plan. The results have shown previously for the proposed method and system explained the ability to give optimal solutions for manufacturing components problems that have alternative processes, sequences, cutting tools and alternative machine tools. Further future is needed as an extension to the work presented in this research such as extending the capability of the system by linking with automatic feature recognition and integration of automated assembly planning (AAP) or production scheduling concurrently with the system as well as proposes the using of closed loop and distributed approaches to generate process plan simultaneously.

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