A KNOWLEDGE BASED DECISION SUPPORT SYSTEM FOR TOOL CHANGEOVER IN CNCs

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ABSTRACT

This paper describes an application of an adaptive planning system for automatic tool changers in flexible manufacturing systems. The conventional models of predictive control usually cannot adapt to a real time dynamic environment. The proposed adaptive control model is capable of self adjusting to changing environments. The algorithm is based on a decision logic, which is constructed by breaking up knowledge and converting them into mathematical form in order to cover all possible conditions that can exist during the implementation phase. Expert thoughts and knowledge from decision logic are stored in the decision tree, which consists of circular nodes, arcs and decision nodes. The suggested system is capable of accepting further rules, new nodes and branches to the tree when additional attributes are needed. This whole knowledge is encoded in the form of production rules and each rule represents a small chunk of knowledge relating to the given domain of tool replacement. A number of related rules collectively respond to highly useful conclusions. The system uses VP Expert development shell, contains an inference engine and, a user interface. The originality of the proposed strategy lies in that a knowledge-based expert system is developed to identify and analyze the current conditions and then readjust the output that reflects the real-time environment. Compared with the various classical models, the approach can synthesize and analyze as many variables as possible to adequately and reliably identify the real-time conditions. Simulation results demonstrate the effectiveness and practicality of this tool-change planning and control strategy.

Keywords: Flexible Manufacturing Systems, Production, Knowledge Based System

1. INTRODUCTION

Industries are pledged with high cost, low profit margins and accelerating competitions, lack of knowledge to deal with flexible demands. Manufacturing cost of the products is comparatively high and application of modern techniques is essential to reduce the lead time by minimizing setup times of the product in order to remain competitive in the market.

All conventional techniques like similarity coefficient, binary ordering and other are applicable to static environment and are unable to give good results where variant has slightly change or addition. These techniques are good for normal manufacturing run, but it fails when sudden event such as urgent dead line, machine tool break down or demand is flexible. Knowledge Based System (KBS) techniques can considerably improve flexibility of the process planning and assist to cope with emergency cases. Tool handling

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and changing systems is main element of Flexible Manufacturing Systems (**FMS)**. Statistics gathered by Rohodes shows that 20% of the time available is lost due to the tool setup, tool change over loading and unloading on the tool magazine. This wastage of time leads to the underutilization of equipments and hence increase of cost. Tool management is having very important role as:

30 – 60% of the tooling is utilized on the shop floor
16% production demand shortage is due to the unavailability of tools
40 – 80%production supervisor time is spent to expedite tooling and materials
20% operator time is spent in the search of tooling

Manufacturing sector and project management both are having similar characteristics, as they both operate in a complex, dynamic and uncertain environments. The development of a specific tool to minimize tooling setup in a manufacturing flexible environment is not yet available, although a considerable number of research have been published on tooling management related topics. To cover the need of dynamic environment, this research work aims to addresses (1) the set of part types that uses identical tooling and (2) provides methodology for expert system development for automatic tool changer and decision logic, which are then to become the core part of KBS further development.

1.1 Automatic Tool Changer of CNC's

Tool changers are different for different applications. For robot application the entire tool set is to be changed in conventional automatic tool changers. For example for in arc welding, the torch is replaced whereas gun is replaced in spot welding. Moreover in mechanical process like grinding, polishing, or deburring, the tool including the spindle is usually replaced. Each time removing spindle with the bit is very expensive as multiple spindles must be prepared. Therefore, this research focuses on the development of an Automatic Tool Changer, where only the bits are changed.

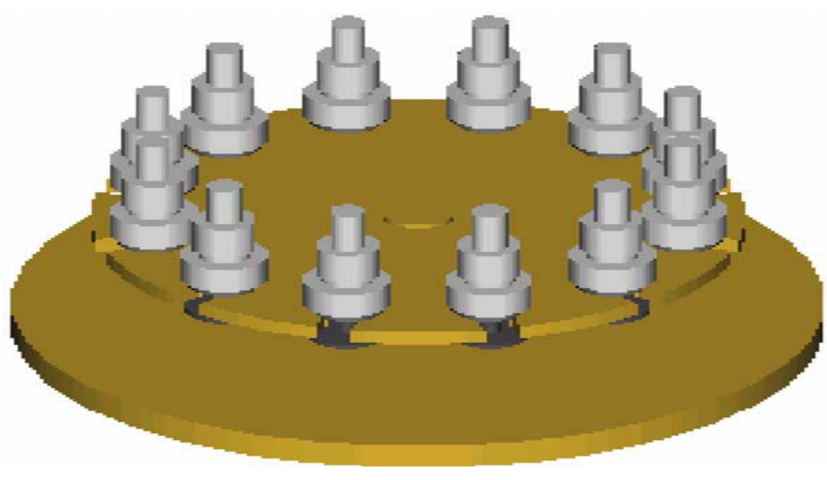

Fig 1. Automatic Tool Changer

1.2 Tool Magazine Arrangement

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The tools required are to be assigned to individual operations and are inserted into the tool magazine for manufacturing desired batch of products. Capacity of tool magazine and available quantities on hand are considered before processing. Certain tools assignment depends upon the operations and it might be assigned more than one operation to a certain tool to introduce tool sharing among the operations. Manufacturing cost is reduced by the reduction of machining time and this may provide a potential gain. Moreover, potential infeasibilities can be prevented by the tool sharing that might incur for the tool magazine capacity constraint due to the initial tool loading. The following framework/algorithm is presented to find the best tool magazine arrangement by considering both tool sharing events and tool duplicates. In this framework, we identify any similar tools by its tool type and the requirement level i.e. challenger tools, which is defined as the number of tools needed to complete a set of operations in manufacturing a batch of parts.

Fig 2. Tool Magazine Arrangement

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2. METHODOLOGY OF STUDY

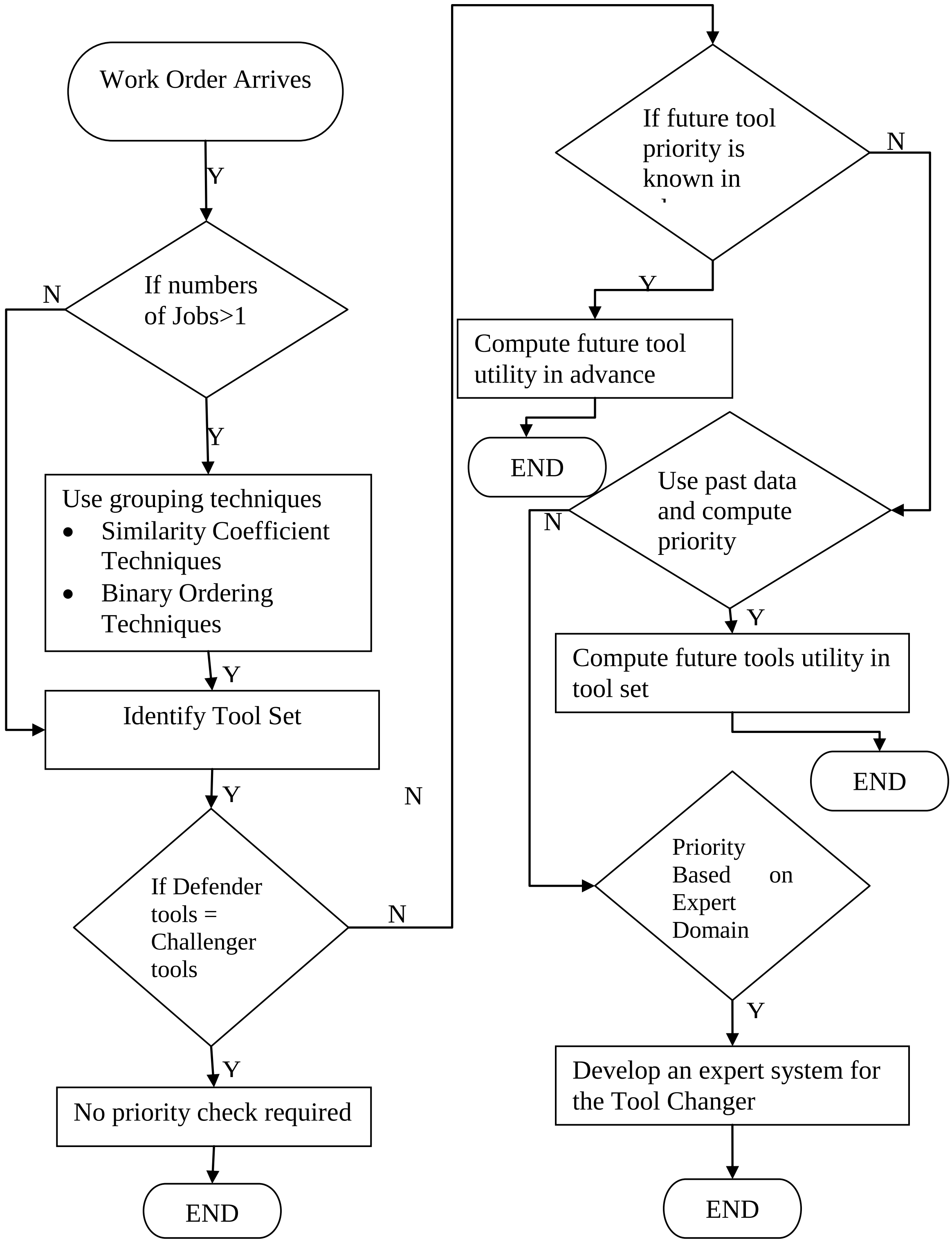

Diagram 1. Methodology of Study

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2.1 Development of an Intelligent System to Ensure Minimum Time Loss in Tool Changes

2.1.1 Problem Statement

To develop an Expert system for the replacement of tools in order to minimize the tool changes in tool slots of CNC's of Flexible Manufacturing Cell for a dynamic job shop environment.

Let the system under consideration consists of CNC machines. Each machine has limited capacity of tool magazine. The system can process a number of part types. Each part type requires limited and different numbers of tool types.

The following assumptions are made:

i) Tools do not fail and remain with the allocated machines for the planning period.

ii) Machines do not fail.

iii) There is no refixturing of parts.

The production-scheduling problem is to develop an Expert system, which helps the machine operator to select and change the tools required for processing different parts so that the tool insertion and tool replacement are minimum. The objective is to maximize the machine utilization and minimize delays in order to reduce the overall cost of the products.

2.1.2 Tool Change over Decision Logic

Notation of Decision logic for an Automatic Tool Changer

Let

Sc **=** Challenger tool set.
Sd **=** Defender tool set.
C = Challenger tool set.
D = Defender tool set.
Ne = Empty tool slot.
Nc = Number of Challenger tools in the challenger tool set.
Nd = Number of defender tools in the defender tool set.
Nc′ = Number of tools belonging to only challenger tool set Sc′.
Nd = Number of tools belonging to only defender set Sd′.
Ncd = Number of common tools in Challenger and defender tool set.
Ni = Number of tool to be inserted
Nr = Number of tool to be replaced
Pri = This is logical notation and stands for priority check.
If **Pri=** Yes, Then make priority check.
If **Pri**= No, Then do not make priority check.

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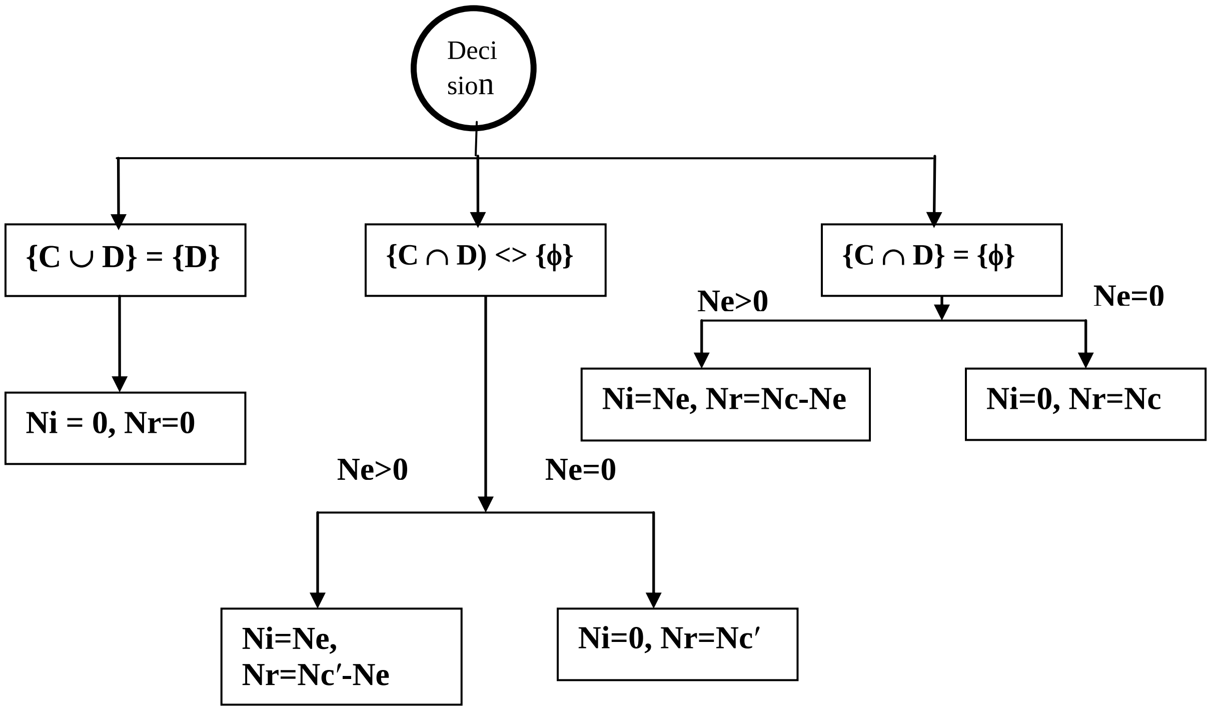

Diagram2. Decision Logic

2.3.3 Mathematical Form of Decision Logic (Tool Replacement and Priority Check)

There are three possible states and one state exists at one time. On the existence of a particular state, the decision of tool insertion and replacement is contingent on Ne, Nd/, & Nc/.

1) **Challenger is a Subset of Defender (C Є D),**
   {C ∪ D} = {D}
   Numbers of challenger tools are already present in the defender tool set.
   Ni = 0, Nr = 0, Pri = 0
   No tool change is required.

2) **Challenger and Defender Are Partially Common {C ∩ D) <> {ϕ}**
   Number of common tools between defender and challenger are positive (Ncd >0)

   Case i: Number of empty tool slots are zero (Ne=o).

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a) Defender is completely filled (Ne = 0) & number of challenger tools are equal to the number of defender tools (Nc' = Nd').
Ni = 0, Nr = Nc', Pri = No
Replace all defender tools in set Sd' by challenger tools in set Sc'. There is no need of priority check.

b) Defender is completely filled (Ne = 0) & number of challenger tools in Sc' are less than the number of defender tools in Sd' (Nc'<Nd').
Ni = 0, Nr = Nc', Pri = Yes
Replace challenger tools in Sc' with defender tool in Sd'. While making replacements, check the priority of tools in Sd' and replace those tools having less priority.

Case ii: Numbers of empty tool slots in defender are positive (Ne>0).

a) Defender is Partially filled (Ne > 0) & number of challenger tools in set Sc' are equal to the number of empty tool slots (Nc' = Ne).
Ni = Ne = Nc', Nr = 0, Pri = No
Insert tools Nc' in empty tool slots.

b) Defender is Partially filled (Ne > 0) & numbers of challenger tools in Sc' are less than the empty tool slots (Nc' < Ne).
Ni = Nc', Nr = 0' Pri = No
Insert challenger tools Nc' in empty tool slots.

c) Defender is partially filled (Ne > 0) & number of challenger tools in set Sc' are greater than the empty tool slots (Nc' > Ne).

i) Number of challenger tools in tool set Sc' are equal to defender tools in set Sd' plus empty tool slots (Nc'=Nd+Ne)
Ni = Ne, Nr = Nc'-Ne=Nd' Pri = No

ii) Number of challenger tools in Sc' are equal to the number of defender tools in Sd' (Nc'=Nd).
Ni = Ne, Nr = Nc - Ne, Pri = Yes

Candidate tools for replacement are Nc'-Ne. Replace three tools having lowest priority.

iii) Numbers of challenger tools in Sc' are less than defender tools in Sd' (Nc' <Nd').
Ni = Ne, Nr = Nc'-Ne , Pri = Yes

Inset Nc' challenger tools in empty tool slots and replace Nc'-Ne tools in Sd', having lowest priority.

3. Challenger And Defender Are Mutually Exclusive { C ∩ D } = {ϕ}

Numbers of common tools in defender set and defender set and challenger set are zero (Ncd = o)

Case i: Number of empty tool slots in defender are zero (Ne = 0).

a) Defender is completely filled (Ne = 0) & numbers of challenger tools are equal to the number defender of tools (Nc = Nd).
Ncd = 0, Ni = 0, Nr = Nc, Pri = No
Replace all defender tools Nd' by challenger tools Nc'.

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b) Defender is completely filled (Ne = 0) & number of challenger tools are less than the number of defender tool (Nc < Nd).

Ni = 0, Nr = Nc, Pri = Yes
From the tool set Sd, select tools equal to Nc having lowest priority from Nd for replacement.

Case ii: Number of empty tool slots in defender are positive (Ne > 0).
a) Defender is Partially filled (Ne > 0) & number of challenger tools are equal to the empty tool slots (Nc = Ne).
Ni = Ne, Nr = 0, Pri = No
Insert challenger tools equal to Ne empty tool slots.
b) Defender is Partially filled (Ne > 0) & number of challenger tools are less than the empty tool slots (Nc < Ne).

Ni = Nc, Nr = 0, Pri = No
Insert challenger tools Nc in empty tool slots.
c) Defender is Partially filled (Ne > 0) & number of challenger tools are greater than the empty tool (Nc > Ne).

i) Number of challenger tools are equal to the defender tools plus empty tool slots
(Nc = Nd + Ne).
Ni = Ne, Nr = Nc-Ne, Pri = No
Insert tools equal to Ne in empty tool slots and replace Nc-Ne, with challenger tools.
ii) Number of challenger tools are equal to defender tools (Nc=Nd).
Ni = Ne, Nr = Nc – Ne, Pri = Yes
Insert tools equal to Ne in empty tool slots and from Sd replace Nc-Ne tools having lowest priority.
iii) Numbers of challenger tools are less than defender tools (Nc<Nd).
Ni = Ne, Nr = Nc-Ne , Pri = Yes
Replace from Sd, tools Nc – Ne having lowest priority.

3.3.4 Tool Replacement Procedure

Considering Decision Logic for an "Automatic Tool Changer", three possible conditions of the tool changes are as following:

a. Only insertion is required
b. Only replacement is required
c. Both insertion is and replacement are required

The condition "a" exists when empty tool slots are more than the challenger tools.
The condition "b & c" exists when only defender tools are greater than the challenger tools.
These conditions can be categorized into following three types:

i) Deterministic Environment

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In the deterministic environment future tool utility is known in advance as all jobs for processing are known.

ii) Probabilistic Environment

Job orders are probabilistic and shop is flexible or dynamic. Work orders suddenly changes due to change in priority.

iii) Uncertain Environment

Jobs order changes suddenly and shop is dynamic. No past data is being kept and decision for the replacement can be made by the knowledge provided by the experts in that particular domain. The above data collected is stored in the knowledge domain and is used in the calculation of priority for replacement and is confidence factor for tool replacement of tool changer.

3.3.5 Tools Priority Assessment

i) Priority Based On Tools Past Utility

The priority of tools for the replacement can be sorted out by studying the past usage of the tool. The tools, which are often used, are not preferred for replacement.

a. Data Collected From Machine Shop.

The following is part of data collected is collected from machine shop and is used for knowledge acquisition by knowledge engineer to assign priorities of tools called Confidence Factor which is similar to tool priority assessment.

S. No	Part No.	Machines Used	CNC Lath Tooling Used	CNC Milling Tooling Used
1	0-33	CNC lath	$T_{f,}$ $T_{r,}$ $T_{b,}$ $T_{g,}$ $T_{F,}$ $T_{i\,t,}$ $T_{p,}$ $T_{2,}$ $T_{1.25}$	
2	0-34	CNC Lath	$T_{f,}$ $T_{r,}$ $T_{b,}$ $T_{g,}$ $T_{F,}$ $T_{p,}$ $T_{2,\,T4}$	
3	0-35	CNC Lath	$T_{f,}$ $T_{r,}$ $T_{b,}$ $T_{g,}$ $T_{F,}$ $T_{i\,t,}$ $T_{p,}$ T_{2}	
4	0-36	CNC Lath, CNC Milling	$T_{f,}$ Tb, T_F	Mer, Mef
5	0-37	CNC Milling	Tr, Tf, Tb, Tot	Mg
6	0-38	CNC Lath, CNC Milling	Tf, Tr, T3.4	Msf, Mer, Mef, Mt, M2.5, M4.5, M5, Mi3
7	0-39	CNC Lath, CNC Milling	Tf, Tr, T3.4	Me

Table1: Data Collected From Manufacturing Facility

3.3.5 Percentage Utility Of Tools Used

Data collected from machine shop is used to assess the frequency of tooling used in the production of a batch of components. Frequency of tools used is number of time that particular tool is utilized in machining by total number of part types.

S.No	**Tool Used**	**Nomenclature**	**Frequency**	**Confidence Factor (%)**
1.	Tf	Facing Tool	40/42 =	95
2.	Tr	Roughing Tool	15/42=	36
3.	Tb	Boring Tool	23/42=	55

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4.	Tg	Grooving Tool	15/42=	36
5.	T_F	Finishing	23/42=	55
6.	Tit	Internal Threading	3/42 =	70
7.	T_P	Parting Tool	7/42 =	17
8.	Tot	Outer Threading Tool	10/42=	24
9.	T2	Dia 2 Drill	4/42 =	10
10.	Tn	Knurting Tool	1/42 =	2
11.	Mer	End Mill Cutter (rough)	23/35=	66
12.	Mef	End Mill Cutter (finish)	10/35=	29
13.	Mg	Grooving Cutter	3/35 =	9
14.	Msk	Slitting Key way Cutter	5/35 =	14
15.	Mts	T Slot Cutter	3/35 =	9

3.3.6 A Rational For Tools Priority Based On Tools Utility

The tooling required for the manufacturing of parts is classified into three categories using following criteria:

Extensively Used: If the percentage utility (confidence factor) is more than 50%, these tools are categorized as extensively used with:

a) High Priority: Priority of retention is high if %age utility is more than 80%.
b) Ave Priority: Priority of retention is average if %age utility is between 60 to 80 %.
c) Low Priority: Priority of retention is low if %age utility is between 50 to 60%.

Moderately Used: If the percentage utility (confidence factor) is between 20 to 50%, these tools are moderately used.

a) High Priority: Priority of retention is high if %age utility is between 40 to 50%.
b) Ave Priority: Priority of retention is average if %age utility is between 30 to 40%.
c) Low Priority: Priority of retention is low if the %age utility is between 20 to 30%.

Rarely Used: If percentage utility (confidence factor) is less than 20%, these tools are rarely used.

a) High Priority: Priority of retention is average if %age utility is between 10 to 15%.
b) Ave Priority: Priority of retention is average if %age utility is between 10 to 15%.
c) Low Priority: Priority of retention is low if %age utility is less than 10%.

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3.3.6 Tools Priority Assessment

i) Machine Shop Tools Priority Based On Tools Utility:

The above tool utility is assigned priority number based upon their usage. High the number represents to high the priority as tabulated following:

	EXTENSIVELY USED			MODERATELY USED			RARELY USED		
	High	Ave	Low	High	Ave	Low	High	Ave	Low
Priority	9	8	7	6	5	4	3	2	1
Tools	If	Mcr	Tb		Tr	Tot	Tp	Msk	Tit
			Tf		Tg	Mef		T2	Msk
									Mg
									Tn

Table2. Calculating Tool Priority

ii) Priority Based on Tools Future Utility (Future work Orders are Known)

When future work orders are known, the future tool utility data may help to assign priority to the tools, in order to decide replacements. Consider an example of ten parts being processed on the CNC Lathe and their respective tooling requirement is shown in the following table against each:

S. No	Part No	Machine	Tools Used
1	4	CNC Lath	Tf, Tb, T2
2	6	CNC Lath	Tf, Tg, TF, Tit
3	3	CNC Lath	Tf, T2, Tg, Tit, Tot,
4	8	CNC Lath	Tn, Tp, Tr, TF
5	9	CNC Lath	Tf, Tr, Tit, Tot
6	5	CNC Lath	Tb, Tf, T2
7	2	CNC Lath	Tp,Tf,Tb,Tot
8	10	CNC Lath	Tg, TF
9	1	CNC Lath	Tf, Tb, Tit, Tr
10	7	CNC Lath	Tg, Tb, Tp

Table 3. Future Tool Utility

iii) Tools Priority Calculation based on Future Tools Utility

Considering the future utility priority is decided by considering the future tool utility and percentage tool utility of the different tools. These priorities help us to decide which tool will enter and which will leave the port at the time of replacement. The tool having fewer priorities is preferred for replacement.

S. No	Tool Name	Tool Usage Freq	% Utility used	Priority

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1	Tf	4	40	4
2	Tg	9	90	9
3	Tr	8	80	8
4	Tb	3	30	3
5	Tit	7	70	7
6	Tot	4	40	4
7	Tn	5	40	5
8	Mer	4	40	4
9	Mef	1	10	1
10	Mg	4	40	4
11	Msk	2	10	2
12	Mts	6	90	6
13	T2	2	20	2
14	TF	1	10	1

Table 4. Priority of Future Tool Utility

iv) Priority Based on Expert Domain Knowledge

In this situation no data is available and is in particular relevant to dynamic shop. The priority allotment to the tools can be decided based on:

a) Interviews with shop supervisors, Foreman, Machine Operators, and Tools store supervisors.

b) Tool manufacturers and Vendors.

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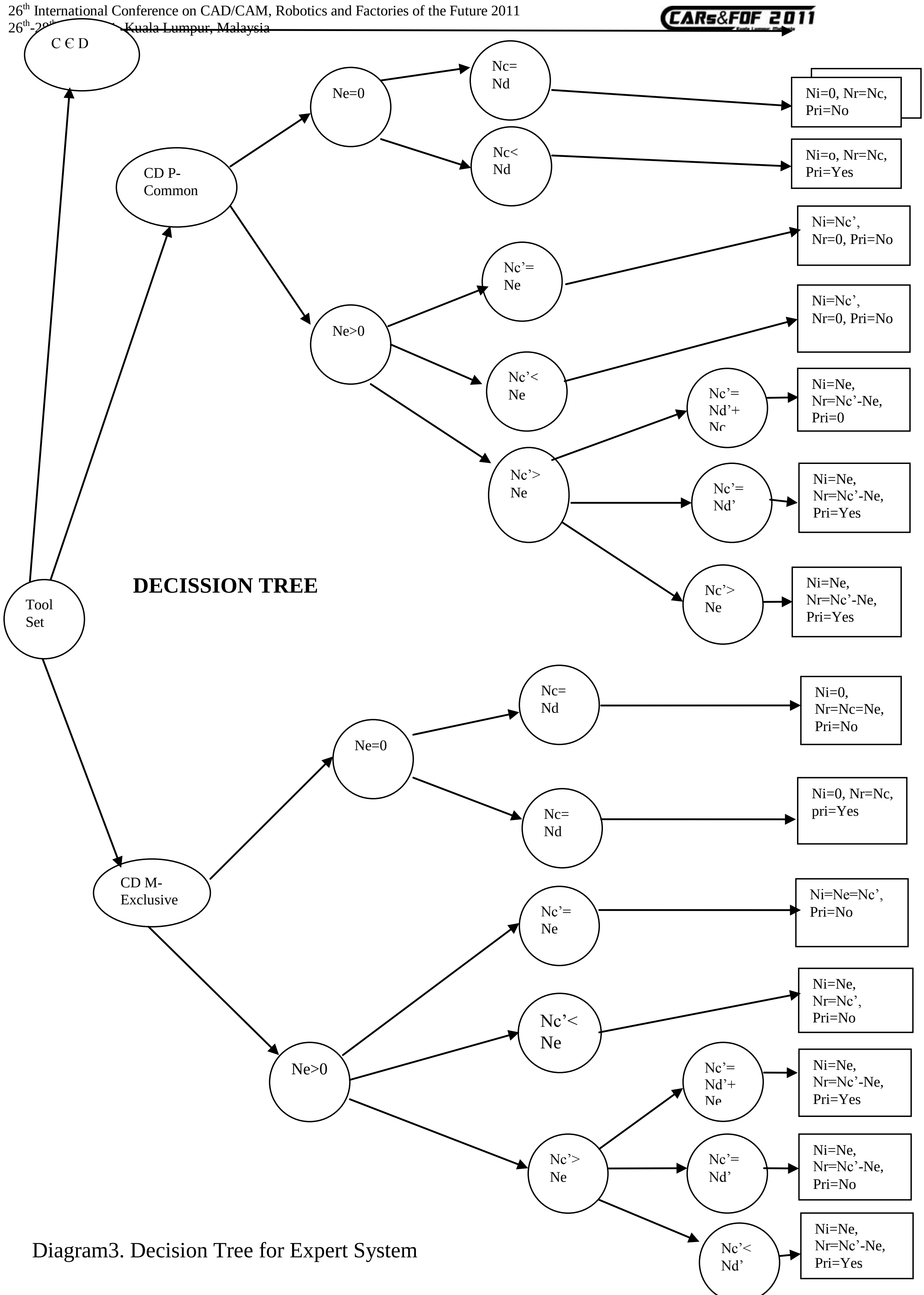

Diagram3. Decision Tree for Expert System

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3.3.7 Writing the Rules

The system developed can be used to select the challenger tools for insertion in the tool slot. The system is constructed by extracting knowledge. Decision logic is constructed mathematically by breaking up knowledge and converted them in to mathematical form in order to cover all possible conditions that can exit during the implementation phase. Expert thoughts and knowledge from decision logic is stored in the decision tree, which consists of circular nodes, arcs and decision nodes (rectangles). For further addition of rules, new nodes and branches can be added to the tree when additional attributes are needed. This whole knowledge is encoded in the form of production rules and each rule represents a small chunk of knowledge relating to the given domain of tool replacement. A number of related rules collectively responds outcome of some useful conclusions
Path 1: 1, 3, 6, 11, 21. Part 2

he **IF-Then** is made up of the two parts. The **IF** part is comprised of conditions called clause and connected to one another by logical operators **AND, OR.** For example the path leading to conclusion 21 contains decision nodes 1, 3, 6, 11. The rule that generates this path is

IF 1
AND 3
AND 6
AND 11
THEN 21

IF	tool capacity = yes
AND	CD –relation = challenger defender common
AND	tool slots status = fully filled
AND	quantity tool challenger < quantity tool Defender
THEN	quantity tool replaced = quantity tool Challenger Quantity tool inserted = 0

Similarly the following 9 paths can be drawn from the decision tree.

Path 1	1, 2, 5	Rule 9
Path 2	1, 4, 8,15, 25	Rule 10
Path 3	1, 4, 8, 16, 26	Rule 11
Path 4	1, 4, 9, 18, 28	Rule 12
Path 5	1, 4, 9, 17, 27	Rule 13
Path 6	1, 4, 9, 19, 29	Rule 14
Path 7	1, 3, 6, 10, 20	Rule 15
Path 8	1, 3, 6, 11, 21	Rule 16
Path 9	1, 3, 7, 12, 22	Rule 17
Path 10	1, 3, 7, 13, 23	Rule 18
Path 11	1, 3, 7, 14, 24	Rule 19

From these paths we can write the corresponding rules for the knowledge base.

RULE 6
IF qty_tools_defender – (qty_tools_slot)
THEN qty_empty_slots=0
ELSE qty_empty_slots=(qty_tools_slot_qty_tools_defender);

Rule 11
IF CD-Relation = Chlgr_Dfdr_ME AND
Tool_slots_status = Fully_Filled AND
qty_tools_defender > (qty_tools_challenger)
THEN qty_tools-replaced = (qty_tools_challenger)
qty_tools_inserted = 0
qty-empty-slots = 0
Replacement_Made = True
Insertion_Made = False
Make_Priroity_Check = Yes
Message = (message 2)
PrintResult = Yes;

4. CONCLUSION AND FUTURE RESEARCH

This research work provides methodology for making an expert system for Automatic Tool changer of NC/CNC machines and comprises of mainly three parts, Introduction to tool management in FMS, AI and Expert Systems, Methodology Expert System and Decision Logic for ATC and software development and rules for VP Expert Shell. This research work will provide basis for: Reducing idle time on the cell/machines and is very suitable for real-time dynamic environment and will minimize set up time and maximize machine utilization. All conventional techniques are applicable to static environment and fails where the variant has slight exception or addition. This paper presents the development of a knowledge-based system for expert system for the Automatic Tool Changer of NC/CNC machines and is capable of assisting in minimizing tool setup times. The research work opens new avenues for future work. This field is new and study can be extended in several ways. Modification is easy and new information can be added which are available for future reference. The research work is based on the condition that tools and machine do not fail and part will not be removed during processing. Unexpected breakdowns and refixturing of the jobs could be extended by the addition of new dispatching rules. Research work will improve full utilization of manufacturing resources by having correct tools for the job at right time, and will minimize delays in production schedule, improve product delivery time, and will reduce costs associated with lower tooling inventory. The system uses VP Expert development shell; it contains an inference engine, a user interface. It unable to process the strings but having ability to call programs made by procedural languages like, C++, C, and Basic. The inputs to the system developed are the part and tool files, which include the representation of the part features and cutting tools. This paper describes the application of the system developed using a typical example.

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