COMPUTER-AIDED PROCESS PLANNING FOR SHEET-METAL PART PRODUCTION

by

REHA UZSOY

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ABSTRACT

The trend from mass-production towards batch-oriented flexible manufacturing systems has led to a steady increase in the use of computers in manufacturing , and the integration of computer-aided design (CAD) and computer-aided manufacturing (CAM) systems into computer-integrated manufacturing (CIM) systems . Process planning, occupying a critical position at the crossroads of the design and production activities , assumes great importance in such systems .

In this study a retrieval-type computer-aided process planning system is developed for a multi-plant firm producing sheet-metal parts and a database established and integrated with the firm's existing information system to improve information flow and report-generating capabilities.

The system has been implemented in two of the firm's five plants and results have been encouraging.

SAC PARÇA İMALATI İÇİN
BİLGİSAYAR DESTEKLİ OPERASYON PLANLAMA

ÖZET

Seri Üretim sistemlerinin yerlerini giderek daha küçük partilere yönelik esnek üretim sistemlerine bırakması üretim sistemlerinde bilgisayar uygulamalarının artmasına ve bilgisayar destekli tasarım ve üretimin birbirine yaklaşarak bilgisayarla bütünleşik üretim sistemleri oluşturmalarına neden olmuştur. Tasarım ve üretim arasında bir köprü vaziyetinde olan operasyon planlama faaliyetleri bu sistemlerde büyük önem kazanır.

Bu çalışmada birden fazla işletmesi olan bir şirketin imal ettiği sac parçalar için bir çağırma/düzeltme tipi bilgisayar destekli operasyon sistemi ve şirketin mevcut veri tabanına entegre edilen bir veri tabanı sistemi ile ilgili uygulama ve raporlama programları geliştirilerek şirketin bilgi akışı ve operasyon planlama faaliyetlerine kolaylıklar getirilmiştir.

Tasarlanan sistem şirketin beş işletmesinden ikisinde başarıyla uygulanmaktadır.

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I. INTRODUCTION

During the last three decades , the role of computers in the manufacturing industries has been growing at an ever-increasing rate . The development of NC machinery , followed by DNC and CNC systems led in turn to increased need for computer aid in the design process . Developments in the field of computers , especially the appearanc on the market of mini- and microcomputer systems , database and graphics software and networking and communications technology have led towards the integration of computer-aided design (CAD) and computer-aided manufacturing(CAM) into so-called Computer-Integrated Manufacturing (CIM) systems .

Manufacturing systems are generally acknowledged to be among the most complex and difficult to manage of organizations , - especially since they consist of a number of highly interrelated parts , such as NC machining , MRP , product design and process planning . The trend from the mass-production environment of the pre-1950's towards batch-oriented , flexible systems further aggravates management problems .

Efficient management of such a complex organizational entity in today's changing socio-economic environment requires the integration of many interrelated functions . This , in turn , requires the manipulation of vast amounts of data , rendering computers the only viable alternative for integrating product design , production planning and control and production equipment and processes .

In such a system the function of process planning , defined as "the systematic determination of the methods by which a product can be manufactured economically and competitively" [1] is the intermediate stage between product design and manufacturing . A process plan basically contains descriptions of the operations to be performed in order to manufacture the part , their sequence , the necessary machines and tooling , standard operation and setup times and materials(Fig.1) . Thus the importance of following an optimal process plan is evident .

Manual process planning systems , however , do not easily lend themselves to CIM applications . Since process planners generally rely heavily on their own personal experience , different process planners tend to develop different process plans for

grup No.	Adet	Parça veya grup No.	Adet

Mamul tipi	ARY-5
Girdiği grup No.	9-5
Mamülde kullanılan adet	1

Malzeme cinsi ve özelliği	~~1.20 DIN 1623 st. 12 veya Erdemir 1112 Kalite~~ 9 SO.043-S321	Sipariş ebadından çıkan adet: ~~8~~	Bir parça için malzeme miktarı: ~~2216~~ 2193	Tarih: 20 / 12 / 84
Sipariş ölçüleri	1.20 x 970 x RULO	Kaplama malzemesinin cinsi ve miktarı		Hazırlayan: EMİN
Parçanın açınımı	480 x 480 Bu malzeme 1 Adet MK-040187 1 Adet MK-040188 içindir.			Kontrol eden: [signature]

Operasyon Tarifi	İmalât dairesi no.	Makine veya Tesis cinsi ve no.	Kalıp - Aparat takım no.	Kalite kontrol mastarı	İşçi sayısı	Hazırlık zamanı (dak)	İşçi sayısı	Standart zaman (dak)
~~480 mm lik rulo dilindi~~ -.20 x 970 mm.lik rulodan ~~970 x 1940 mm ebadında levha~~ kesildi. ve tekrar rulo yapıldı	101	DİLME TEZGAHI ~~BOY KESME TEZ.~~						
80 mm.lik ruludan 480x480 mm ebadında levha kesildi.	101	BOY KESME TEZ.						
~~70 x 1940 mm.lik levhadan 480 x 480 mm. ebadında parça kesildi.~~	~~101~~	~~MAKAS~~						
H-300276 kalıbı ile parça çekildi ve form verildi.	101	HİD PRES (315 TON)	KH-300276					
B-300189/1 plakanın üzerine paralel bağlı KB-300189 kalıbı ile parçanın etek kesimi, orta kapak kesimi ve üst yüzeydeki 4 adet oval delik, orta kapaktaki 1 adet Ø 5 mm.lik deliklerin delinmesi, KB-300190 kalıbı ile parçanın orta patlatması ve etek düzeltmesi, KB-300191 kalıbı ile parçanın deliklerinin delinmesi presin bir strokunda komple yapıldı.	101	BÜK PRES (225 - 250TON)	KB-300189 KB-300190 KB-300191					

operasyon .... saatte .... adet imalât miktarına göredir.	Bundan sonra işlem göreceği daire		Toplam zaman (dak)	

parts which are similar or even identical . This leads to a great proliferation of process plans , with a corresponding loss of standardization . Groover[2] cites an example where 42 different process plans were developed for various sizes of a certain part , including 20 different machine tools . The reason was found to be that 9 manufacturing engineers , 2 planners and 25 NC part programmers had worked on the parts . Analysis revealed that two different routings through four machines were sufficient . Different planners may mot be able to communicate ideas effectively , rendering utilization of past experience difficult and leading to unnecessary repetition of errors .

Another aspect of manual process planning systems is the amount of paperwork necessary . Studies cited in the literature[1, 3] indicate that process planners spend up to 30% of their time just writing out process plans and checking them for errors . The retrieval problems of manual systems , with lost documents and long searches through filing cabinets , are also manifest .

The broad information content of process plans also requires the generation of large numbers of reports such as machine workloads , material and tooling requirements and labour requirements for a given production schedule . Preparation of such reports by hand is prohibitively time-consuming and may even result in the report being out of date by the time it is preppared .

Use of computers in process planning permits the creation of a firm-wide database for this purpose , from which information can easily be retrieved and used in the construction of new process plans . This results in a firm-wide "knowledge base" enabling process planners to make use of others' experience , minimizing repetition of errors and promoting standardization . This common database can be updated as production technology evolves , thus ensuring that new process plans reflect the latest available technology . Once established , this database forms the basis for the generation of reports from this data which were previously prepared by hand , resulting in time savings and increasing the cost-effectiveness of the data .

Another extremely important aspect of computer-aided process planning (CAPP) systems is that they act as office automation systems , automating the clerical part of the process planning activity and reducing paperwork to a minimum . The ability of the planner to store complete or incomplete process plans for future editing is also of great value when the iterative nature of process planning is taken into account .

The savings introduced by the implementation of a CAPP system can be expressed in the table below [1]:

Table 1. Estimated Savings from CAPP

Area	Saving(%)
Process Planning	58
Direct Labour	10
Material	4
Scrap and Rework	10
Tooling	12
Work in process	6

A survey by the Committee on the CAD/CAM Interface of the National Research Council[4] leads to the conclusions that major companies have well-structured long-range plans for implementing CIM and that companies will have to adopt this technology in order to remain competitive in their markets . Thus , parallel to this development , it is safe to predict that CAPP systems will become important parts of every major manufacturing enterprise in the near future .

II. LITERATURE SURVEY

In the course of attempts to capture the logic , judgement and experience necessary for process planning and incorporate them into computer programs to automate the process planning function , two alternative approaches , the generative and the retrieval or variant approaches , have been developed . These two approaches to the design of CAPP systems will be described with examples from the literature in this chapter .

2.1 Retrieval-type CAPP systems

The foundation of retrieval type CAPP systems is parts classification and coding and group technology(GT) . The parts to be manufactured are grouped into part families by virtue of their manufacturing characteristics . This classification leads to the members of each part family having similar manufacturing processes . A standard process plan can also be stored for each part family . The parts are coded to reflect this classification and the code serves as a key to enable computer retrieval of appro-

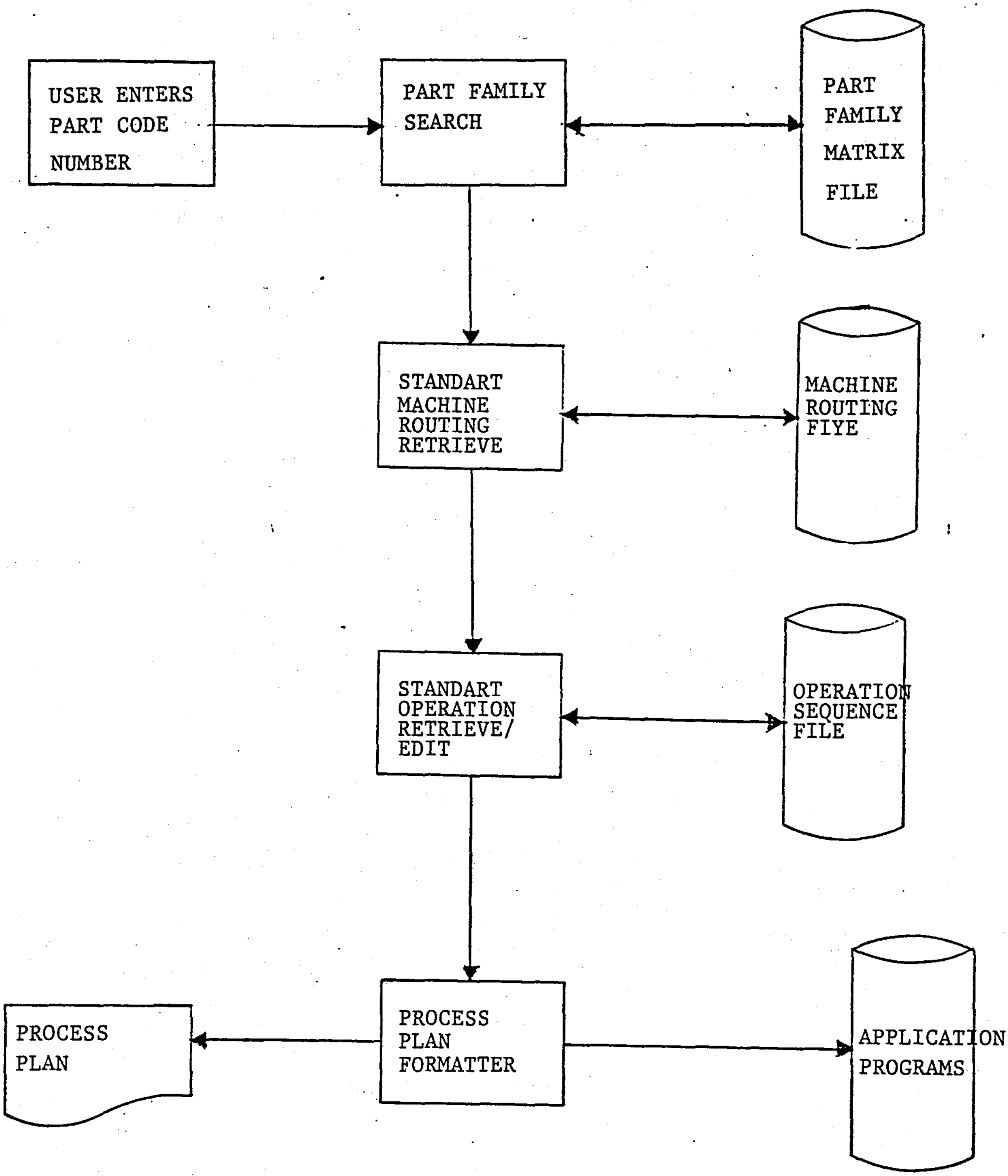


Fig.2 Information Flow in a Retrieval-type CAPP system.

priate process plans for a new part . Some editing of the retrieved process plan may be necessary , which explains why these CAPP systems are also referred to as "variant" systems . The basic structure of a retrieval-type CAPP system can be seen in Fig.2 . It should be borne in mind , however , that most CAPP systems encountered in the literature are for metal-cutting applications , so the part-family maatrix file , which is essentially a group-technological concept , may not be applicable in all cases .

The user of a retrieval-type CAPP system would enter a code containing manufacturing information about the new part to be manufactured . If an exact match is found , it can be displayed to the user . Otherwise , the user can be given a list of "similar" parts , on whose process plans he can base that of the new part . The process plan formatter can then be used to generate the finished document .

One such system is Computer-Aided Manufacturing-International(CAM-I)'s CAPP system . This is a retrieval-type system basically for metal-cutting operations . The basic flowchart can be seen in Fig.3 [4] . In this system the user enters a similarity code , which is used to search the part family matrix . If a match is found , the data is temporaarily stored while the user enters header data , and then a standard operations sequence for the family iss retrieved and edited if necessary . After this ,

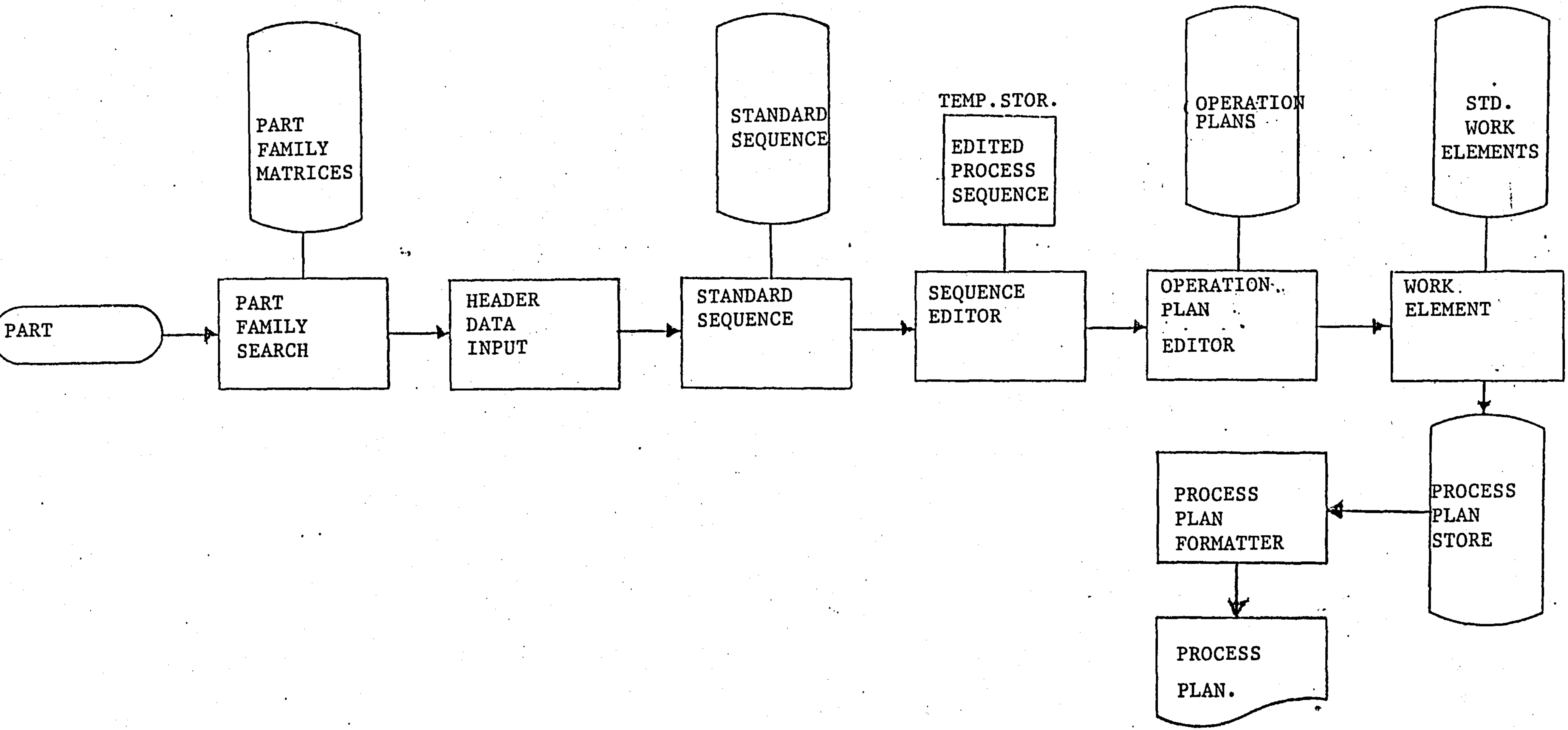


Fig. 3. CAPP System Flowchart

operation descriptions can be retrieved and edited if necessary to be particular to the new workpiece . It is interesting to note that the classification/coding system used is not specified by the CAPP system , which provides for the use of a code of maximum 36 digits provided by the user .

Another widely-used retrieval-type CAPP system is MIPLAN , developed by the Organization for Industrial Research of Waltham , Mass. [1 , 3 , 6] . The basic structure of this system can be seen in Fig.4 . This system , available on various computers such as DEC PDP-11 and IBM OS or DOS systems , has the added advantage that the user can gain substantial benefits without having to first indulge in a vast amount of classification and coding . The user can employ this system at first as a special-purpose word-processor and then gradually build up the retrieval system over time[1 , 6] .

The MIPLAN system consists of modular software which gives the user the followinng options:

i) Creation of a process plan from scratch , using standard user-defined text files .

ii)) Retrieval and completion of an incomplete process plan . This option is extremely useful not only for the many interruptions that planners are subjected to , but also for the construction of process plans where some information is missing and can be added later .

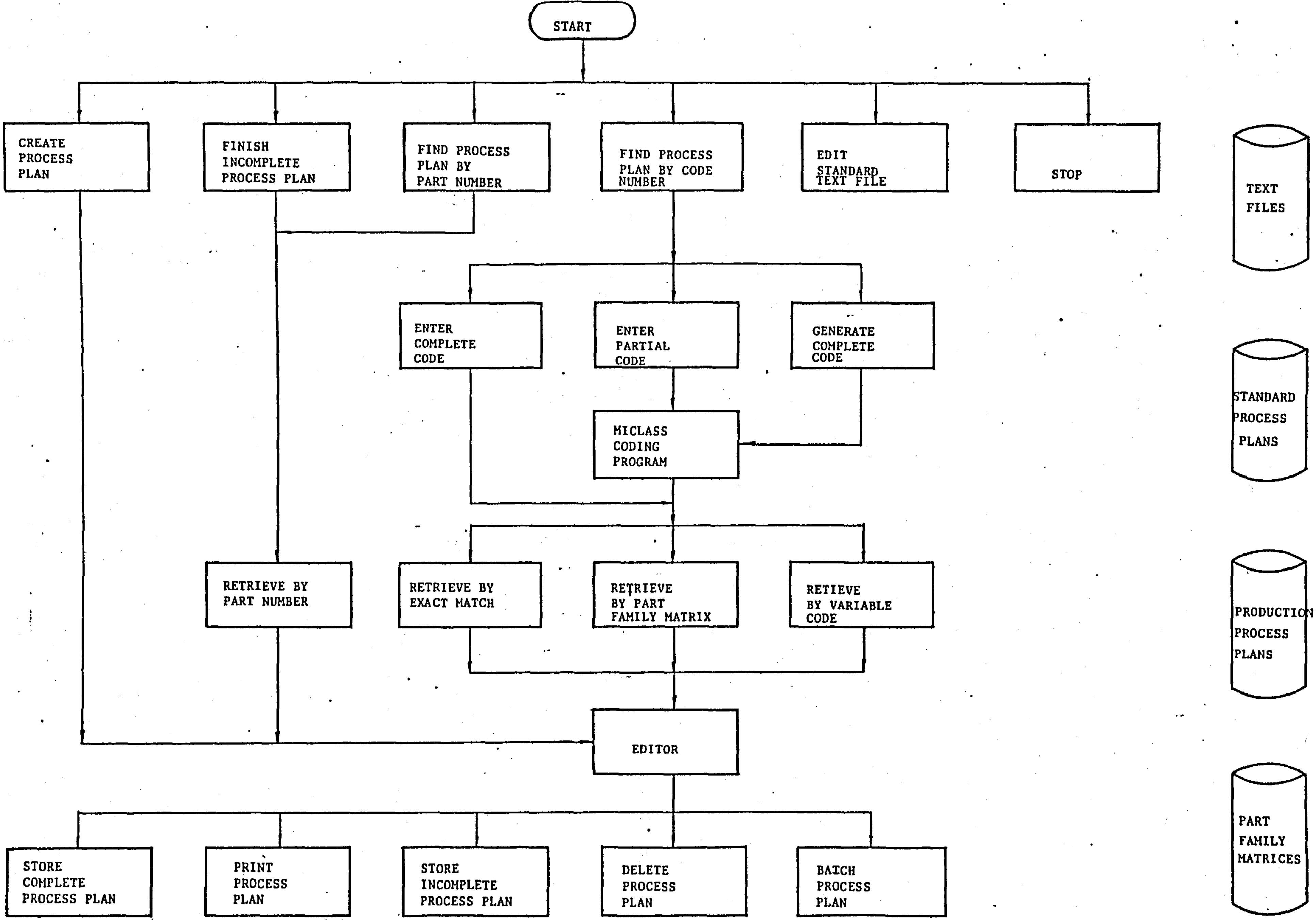


Fig.4.MIPLAN System

iii) Retrieval of process plans by part number . The plan can then be edited if the new part is different from the existing part .

iv) Retrieval of process plans by similarity code . The user can do this by means of a complete or partial code , which can be generated interactively using the MICLASS coding module .

After work on the process plan has been completed , the user can have the computer print out the finished document , store the completed process plan in the firm's process plan files , delete any unwanted plans or store an incomplete process plan to be completed later .

The system uses four files:the the text file , standard process file , production process plan file and part-family matrices file . The text file contains standard text generated by the user , who is also free to determine how it will be accessed . The standard process plan file contains standard process plans established by the user based on the MICLASS codes , which can be accessed by all retrieval routines . The production process plan file contains the plans used regularly in the plant . The part-family matrix file is used in the case of an exact match of the code of the new part not being found . MIPLAN also allows the user to execute user-defined programs and enter the results on the process plans .

Schaffer , reporting on the application of MIPLAN at General

Electric's Lamp Equipment Operation[6] , gives the savings achieved by the use of MIPLAN merely to eliminate manual writing of process plans at 20% , and estimates a further 10-15% to be gained by the implementation of the retrieval system and modification of existing process plans .

McNeely and Malstrom[7] give a retrieval-type CAPP system for the production of printed circuit boards (PCB) . Their system , based on a program in BASIC , determines the operation sequence , necessary machinery and standard setup and run times from various basic features of the PCB , and also contains information such as documentation revisions and materials . The user enters numerical codes to specify features of the PCB such as drilling and plating requirements and requirements for plated contacts . As the possible operation sequences are known beforehand , the computer gives the appropriate process plan . The authors report reduction of indirect costs to 17% of their former level and preparation time for process plans from four hours to forty minutes on average .

2.2 Generative-type CAPP Systems

Generative-type CAPP systems use the computer to create process plans from scratch , without human interference or use of an existing process plan[2] . The system , given a comprehensive description of the workpart including geometry and materials , synthesizes the design of the optimum process plan , simulating the logic used by a human process planner .

It is generally acknowledged in the literature that although there are several retrieval-type CAPP systems successfully operating , there is no truly generative system in operation as yet . Those generative CAPP systems available to industry still require a trained process planner and have been developed for a somewhat restricted range of manufacturing applications . This may be due to the fact that detailed information on part geometry and materials and sophisticated programming to capture the decision logic involved is required . A considerable effort is being made to develop artificial intelligence systems for CAPP and it is probably safe to say that the main direction of development of generative CAPP systems will be in this direction[19] .

A great deal of effort has been put into the development of generative CAPP systems by the aerospace industry . Boeing and Lockheed have both developed their own generative process planning systems , demonstrating the feasibility of the concept .

The Lockheed system , GENPLAN , as described by Groover[2] , requires the user to enter a part classification code , which it then uses to analyse the characteristics of the part such as material , geometry and other manufacturing data to synthesize an optimal process plan . The systen still requires the planner to make manual additions , but process plans previously designed in several hours can be done in around 15 minutes .

The Boeing generative CAPP system[8] , whose basic structure can be seen in Fig.5 , is based on the Boeing classification structures (the BUCC-1 classification for materials and BUCC-3 for piece parts) and the DCLASS decision handler program developed at Brigham Young University . It was designed to give 80% efficiency on the premise that generation of process plans for one of a kind parts would not be cost-effective , and was tested on sheet-metal parts manufactured in channel form . The basic components of the system are as follows:

i) Classification logic for part shape and raw materials . This is used both for retrieving information and as logic input for the manufacturing process selection routines .

ii) Special parameters . This includes product characteristics which are not attributes of shape or raw material , but are important to the process decisions .

iii) Manufacturing decision logic elements . This contains the identification and relation of drawing characteristics to identify optimal processes within the factory and is limited onlly by the processes it considers . It begins with the most general characteristics and proceeds to the more specific , identifying operations that drive other operations and proceeding from one level to the next until the process is complete .

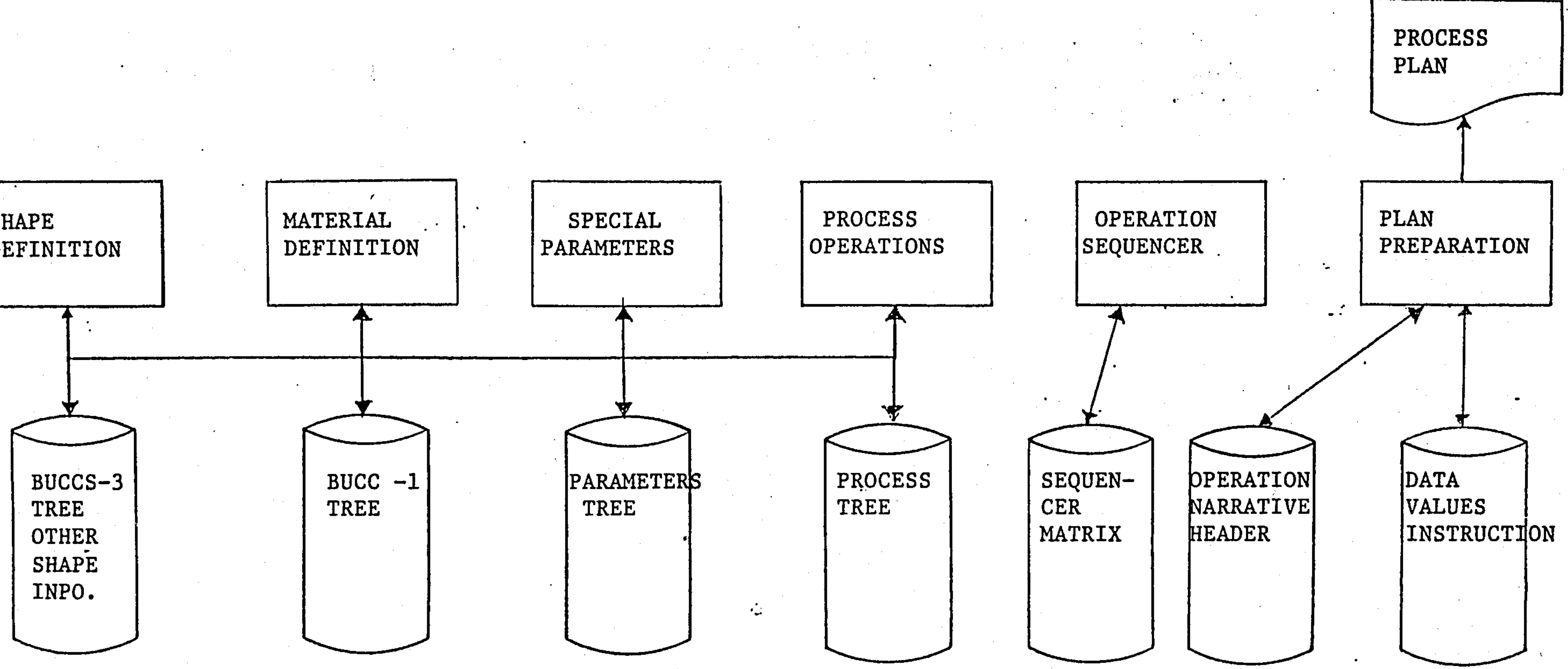


Fig. 5 Boeing Generative Process Planning System.

iv) Operations narrative file . This file contains detailed descriptions of the manufacturing processes performed in the factory , with room , in certain cases , for user additions .

v) Sequencing logic . This uses the operation code to resequence the operations into the proper order .

vi) Plan preparation . This module basically serves the purpose of producing the final document in the form required by the organization .

It should be noted that the above are not artificiall intelligence based CAPP systems . Davies and Darbyshire[9] describe an expert system , EXCAP , for process planning of rotatioonal components . This is an interactive expert system which consists of an inference mechanism and rules on which to base the decisions . The rules serve the purposes of defining available machining operations in terms of the features on which they can be used and the effect they have on the workpiece and the selection of an operation from among a list off candidates . The inference mechanism then forms a tree of all possible sequences and works backward from the finished part to find the best path through the tree according to the rules given .

Halevi and Stout[10] report a generative type CAPP system for cylindrical parts which minimizes production cost or maximizes production . Machine data such as process capability , cutting speeds , feeds and size are input , together with information on the component such as raw material hardness dimensions , tolerances , surface finish and production quantity . The programs incorporate information on items like tool wear and chatter . The program then first calculates maximum and minimum values of each parameter and then selects machines and optimal operation sequences by constructing a matrix which is used to determine a path passing through all required operations while minimizing the number of machines used . The authors make the interesting observation that retrieval-type group-technology based retrieval-type process planning systems do not yield economic processes .

Miaw and Wilson[11] develop an interactive computer program to aid the designer in selecting appropriate manufacturing processes and materials combinations . The user enters a code , which describes characteristics of the part such as bulk , batch size , shape , tolerance , loading mode and structural geometry and the desired criterion of excellence the user wishes to optimize , such as minimum size for constant strength or minimum cost for for constant strength . The program then uses a suitability matrix , a computability matrix and a property matrix to generate possible material-process combinations and rank them according to figures of merit based on the user-defined criterion of excellence . This process also brings the design and manufacturing phases of production together to design a more "producable" product and manufacture it efficiently .

Another example of the integration of design and process planning is given in Chang and Wysk[12] . The object of their effort is to integrate a graphic CAD system with a generative CAPP system so that the user , working with a terminal or a workstation , can obtain both an engineering drawing and a process plan without any further coding . The authors interface a CAD system with a generative CAPP system , APPAS , designed by Wysk , capable of planning milling and hole-making operations . The interface is given for hole drilling and chamfering operations only .

The CAPP system used by these authors , APPAS , has the basic functions of process selection and process parameter selection . Process selection selects appropriate machining processes based on surface geometry and tolerances , using process capabilities defined by variables such as tool size , form geometry and tolerances . Processes are arranged in the process boundary file according to precedence relationships aand cost . The CAPP system also includes a cost-estimating procedure . Hughes and Leonard[13] also give a costing procedure for component productionn .

In the integrated system , the user designs the part at the CAD workstation and then APPAS uses the design information to generate process plans and machining data . The user is also given the estimated process cost , for use as design decision information .

The development and increasing use in industry of multi-functional NC machining centres has led to considerable attention being devoted to process planning for such machines . Hitomi and Ohashi[14] give a model for determining the optimal sequence of operations and optimal cutting conditions for a multifunctional NC machinee with automatic tool and work change . These authors develop a mathematical programming model very similar to the travelling salesman problem which they solve with a branch-and-bound procedure to give the optimal sequence and then solve another , non-linear optimization problem to determine optimal cuting conditions . The operations to be performed are input by the user .

The MITURN system developed by the TNO[13] is somewhat more sophisticated . The user inputs the geometry of the starting material and the finished part . The program then uses a group-technology type approach to yield the optimal sequence , expected machine time , tooling and operation instructions and punch an NC tape of the part program .

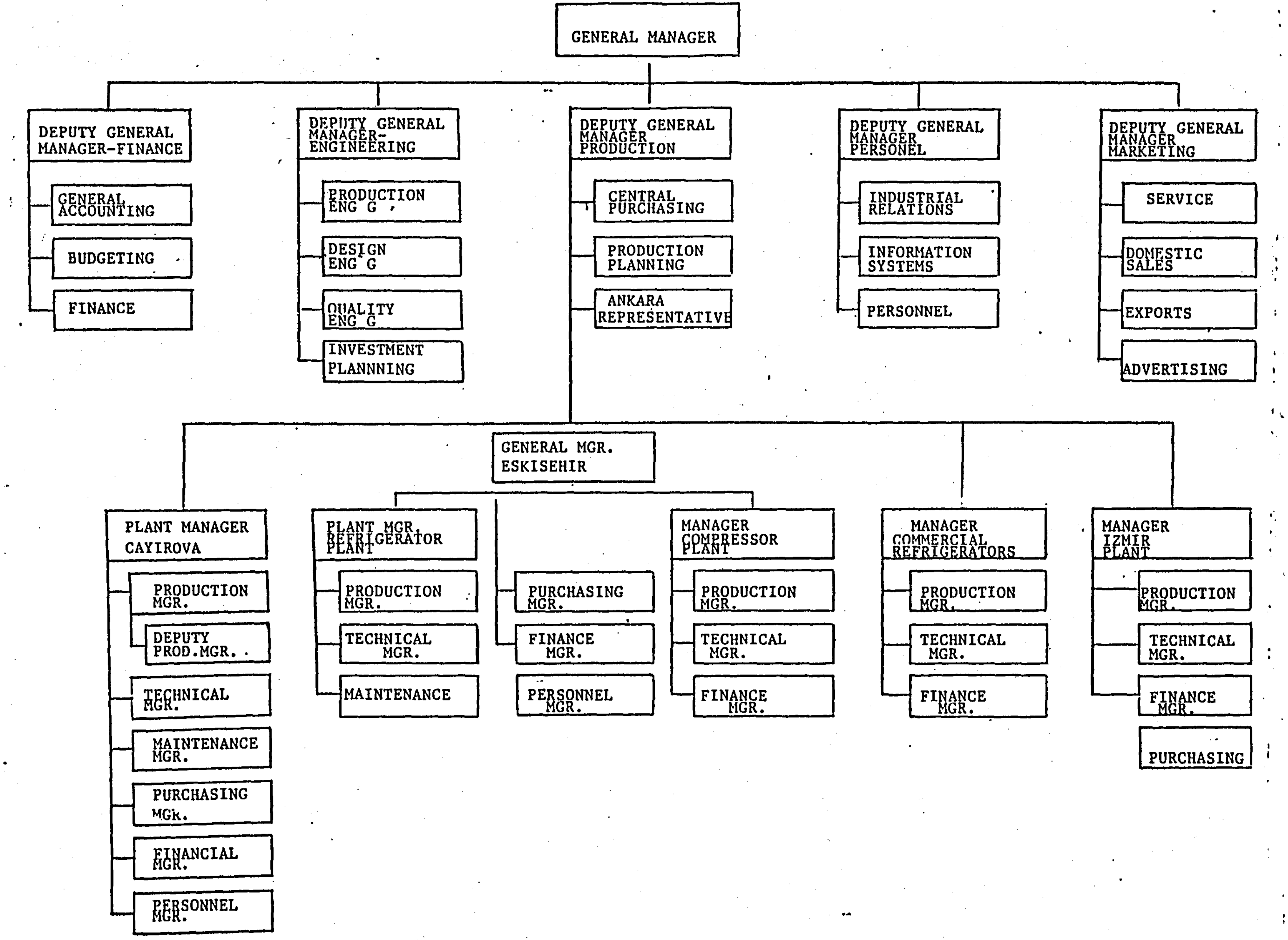
III. STATEMENT OF PROBLEM

The firm under study is Turkey's largest manufacturer of durable household goods , with five plants , each specializing in a different product line . Two of these are in Istanbul , one producing washing machines , dryers and dishwashers and the other commercial refrigerators and air-conditioners;two more in Eskişehir , one producing compressors and the other refrigerators;and another in İzmir producing vacuum cleaners and smaller domestic appliances such as irons and hair-dryers .

In all plants except the one in İzmir , the most important part of the production process consists of sheet-metal forming onn a variety of machines with varying capacities and capabilities . These parts are welded into subgroups and then combined with various plastic and aluminium parts , some purchased and some made in-house , and purchased sub-assemblies such as electric motors and gearboxes , to form the finished products .

As can be seen from the firm's organization chart(Fig.6) , the plants are under the Deputy General Manager for Production and have their own engineering staff . The Central Engineering Departments , Quality Engineering , Design Engineering , Production Engineering and Investment Planning are under the jurisdiction of the Deputy General Manager for Engineering and give technical support to all the plants in general and work on various projects . Of these departments , Design Engineering and Production Engineering are central to this study , which was carried out under the auspices of the central Production Engineering Department .

The Design Engineering Department is responsible for the design of new products , including materials and quality specifications , and technological upgraading of products to facilitate production and lower costs . Thus , this department releases bills of materials and technical change notices to the Production and other central engineering departments , which , after ratifying them or suggesting further revisions(to facilittate assembly , for example) , forward them to the Purchasing and Planning Departments . The engineering staff of the plants are able to introduce technical changes themselves at short notice but have to have them ratified by the Design Engineering Department . The general procedure for technical changes is shown


GENERAL MANAGER
DEPUTY GENERAL MANAGER-FINANCE
GENERAL ACCOUNTING
BUDGETING
FINANCE
DEPUTY GENERAL MANAGER-ENGINEERING
PRODUCTION ENG G
DESIGN ENG G
QUALITY ENG G
INVESTMENT PLANNNING
DEPUTY GENERAL MANAGER PRODUCTION
CENTRAL PURCHASING
PRODUCTION PLANNING
ANKARA REPRESENTATIVE
DEPUTY GENERAL MANAGER PERSONEL
INDUSTRIAL RELATIONS
INFORMATION SYSTEMS
PERSONNEL
DEPUTY GENERAL MANAGER MARKETING
SERVICE
DOMESTIC SALES
EXPORTS
ADVERTISING
GENERAL MGR. ESKISEHIR
PLANT MANAGER CAYIROVA
PRODUCTION MGR.
DEPUTY PROD.MGR.
TECHNICAL MGR.
MAINTENANCE MGR.
PURCHASING MGR.
FINANCIAL MGR.
PERSONNEL MGR.
PLANT MGR. REFRIGERATOR PLANT
PRODUCTION MGR.
TECHNICAL MGR.
MAINTENANCE
PURCHASING MGR.
FINANCE MGR.
PERSONNEL MGR.
MANAGER COMPRESSOR PLANT
PRODUCTION MGR.
TECHNICAL MGR.
FINANCE MGR.
MANAGER COMMERCIAL REFRIGERATORS
PRODUCTION MGR.
TECHNICAL MGR.
FINANCE MGR.
MANAGER IZMIR PLANT
PRODUCTION MGR.
TECHNICAL MGR.
FINANCE MGR.
PURCHASING

in Fig.7 .

The Production Enngineering Department , as the name implies , is primarily concerned with the development of efficient manufacturing methods . Its chief duties are as follows:

i) Design and production of sheet-metal , and , to a lesser extent , plastic dies and the various specialized machines and fixtures which may be necessary for production .

ii) Development of process plans for new products and their update , based on technical changes , for all plants except those at Eskişehir .

iii) Determination of standard process times , assembly line balancing and determination of labour requirements .

iv) Determination of raw material requirements for newly-designed parts , especially sheet-metal parts .

Due to the nature of sheet-metal manufacturing , these functions are intimately related to each other . The shape of the part to be produced and the material deteermine the number and type(progressive , transfer or simple) of dies to be used , which , to a large extent , determines the process plan . The die design also determines the amount of scrap , and thus the material requirements .

Update of the process plans becomes necessary when technical changes are made by the Design Engineering Department . Due to the steady diversification of products and marketing requirements

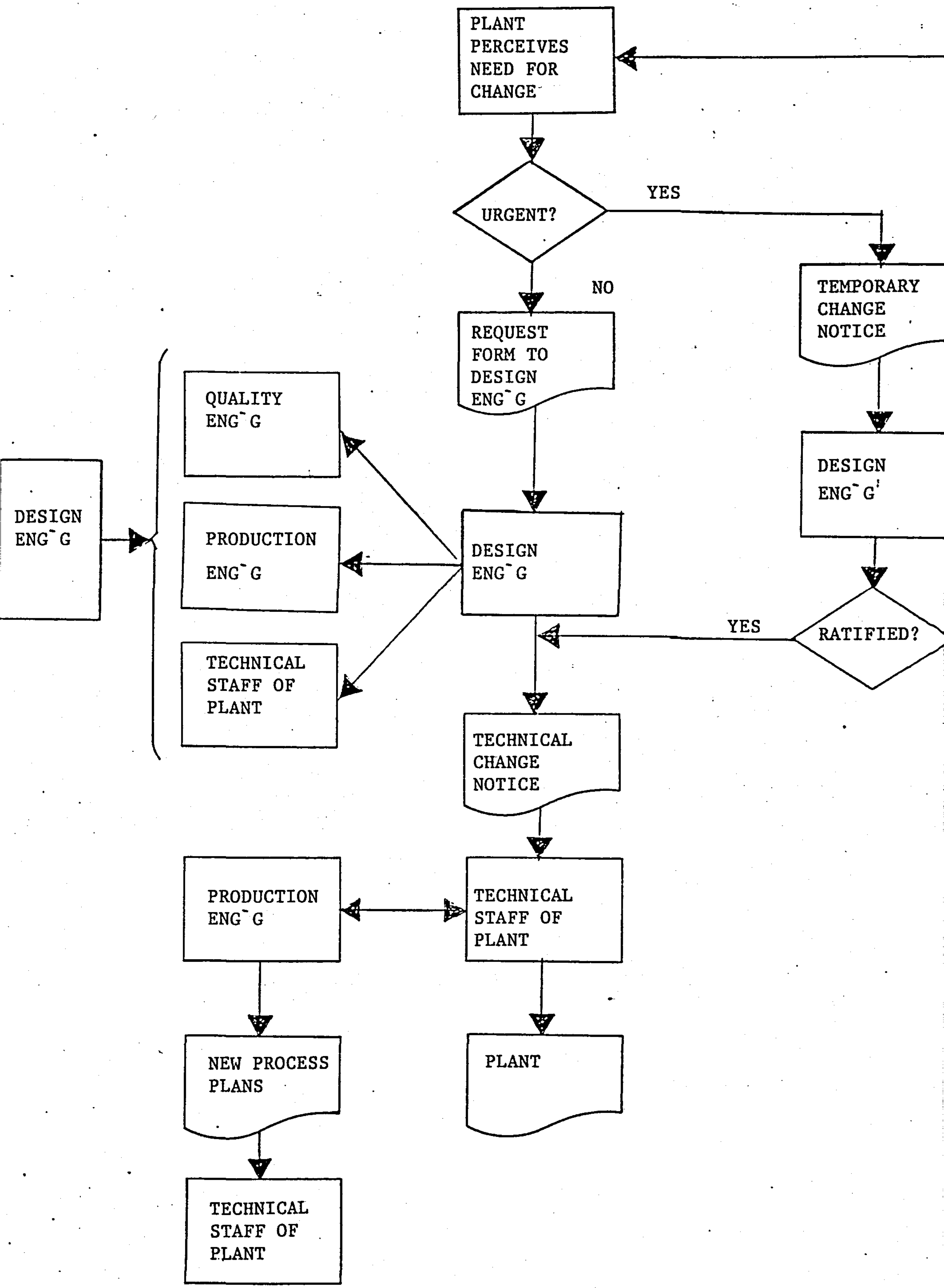


Fig.7 Procedure for Technical Changes.

the volume of such changes is continually increasing and thus consuming an ever-increasing portion of the production engineers' time .

Among the firm's current computer applications , the main source of support for the plants' technical staff is the Materials Management System(MMS) . This system is basically a materials control system based on the open warehouse system where no documents are required to draw materials from the inventory , and performing inventory control , purchasing and accounting functions . Its main components are a catalogue of all parts , materials and products the firm uses or produces and the bill of materials of each product in the form of a tree . The amount of materials used in production is calculated from the daily production figures and the bill of materials and subtracted automatically from the inventory balances on a daily basis .

The validity of the MMS's information clearly depends on its being kept up to date , incorporating the latest technical changes . As mentioned above , technical changes are introduced by the Design Engineering Department and the technical staffs of the plants . While those introduced by the Design Engineering Department are relatively easy to follow , due to problems of distance and communication those stemming from the plants are difficult to keep track of , leading to frequent discrepancies between the Central Engineering Departments' information and the actual state of the plant .

At present the firm produces approximately 2000 parts and sub-assemblies in-house , entailing roughly 12000 operations . As can easily be seen , the firm has far outgrown the capability of the current manual process planning system . Generation of reports and follow-up of technical changes has become extremely time-consuuming , and the number of different personnel working on the process plans has led to a lack of a common firm-wide knowledge base for process planning , with a corresponding lack of standardization .

Viewed from the CIM point of view , the firm has taken the first step towards realising CIM with the installation of the MMS . This study , constituting a second step towards CIM , will integrate with the MMS to form a starting point for the construction of a full-scale engineering database and lead to considerable improvement in engineering performance . The fact that the CAPP system designed requires only software effort and no hardware investment was also an important factor in the choice of approach .

The available database and programming resources rendered a retrieval-type CAPP system the only feasible alternative , since the geometric data required for a generative-type CAPP system were not available .

IV. DATABASE SYSTEM AND COMPUTER IMPLEMENTATION

4.1 Database system

After the decision to implement a CAPP system had been taken , the requirements that the database system would have to fulfil were investigated and it was decided that the database would have to meet the following requirements:

i) Efficient interfacing with the existing MMS database system

ii) Potential for growth and development of new systems , especially on-line production control ,

iii) Efficient generation of reports to save time and increase the cost-effectiveness of the data

iv) Information content equal to that of the current manual system , with minimum redundancy

v) Ability to keep track of dies and machinery , both in-house and at vendors' premises

vi) Facilitate information flow between plants and central engineering departments .

As was briefly mentioned in Chapter I , the process plans basically contain information on the nature and sequence of the operations and the tooling , machinery and time needed to manufacture the part . Thus , as a first step , a study of the information content of the manual system was made in order to eliminate redundant items and include new items as necessary .

The generation of reports from the process planning database was found to require considerable informmation that was available in the MMS . The parts catalogue was used to retrieve part descriptions , eliminating the need for storing these again in the process planning system . Where-used data was accessed where necessary from the bill of materials , leading to further memory economies . Data on vendor firms and depreciation were also found to be available in the MMS .

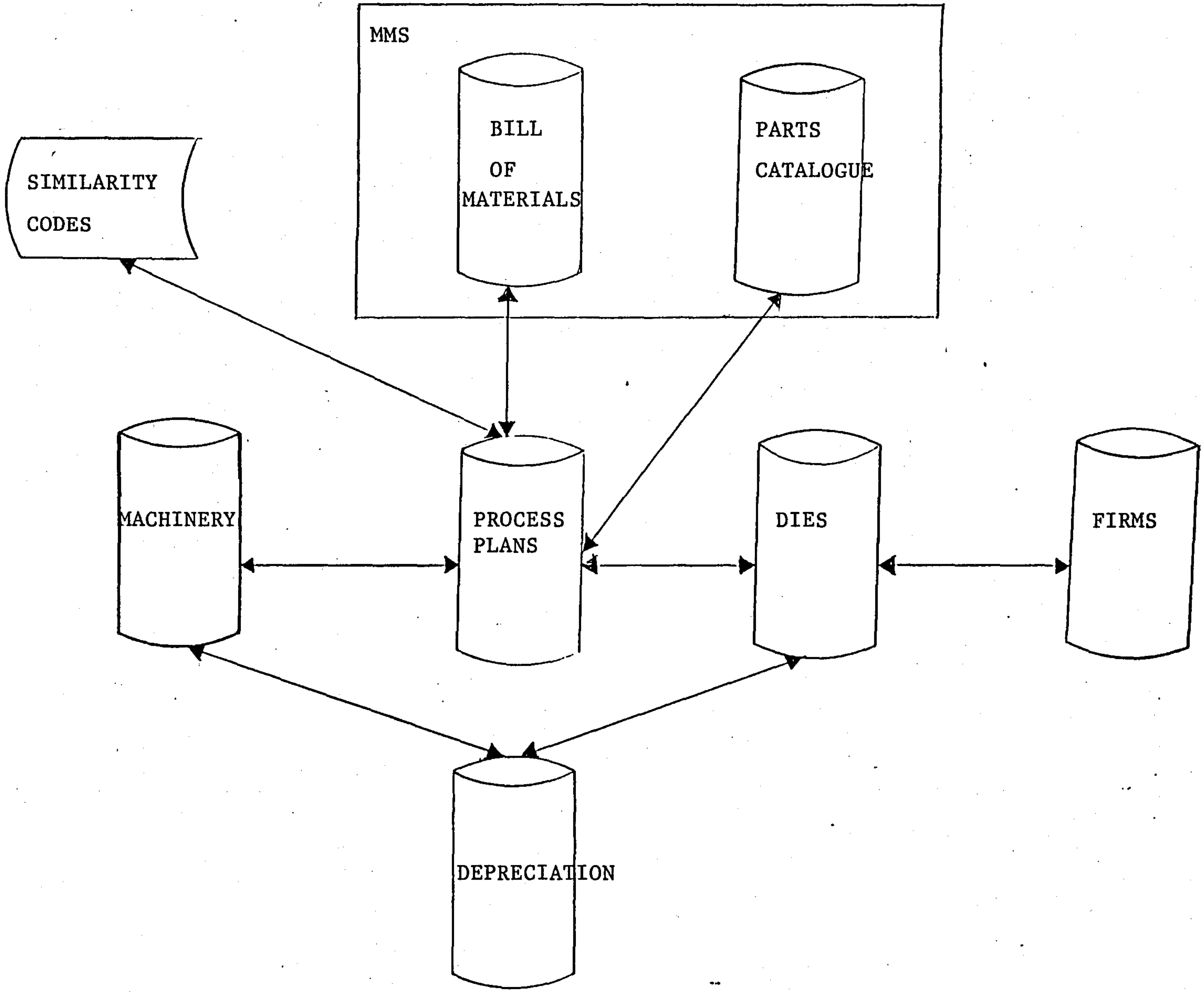
As the firm under study has several different plants and two subsidiary firms , all of which may be expected to come under the jurisdiction of the Production Engineering Department in the future , firm and plant codes were used as keys in all databases except the similarity code file . This has the added advantage of increasing database security , since the user is asked to enter his firm and plant codes and a password , which restrict his access to the information belonging to his plant or firm . Only firm codes are restrictive in the similarity file , enabling planners to view similar parts even if they are produced at different plants .

These factors being taken into account , the decision was taken to delete several redundant items such as quality control gauges which were unused and record of all technical changes except the latest . Where-used information was eliminated from the process planning system as it was already available in the MMS . The number of parts per unit of ordered quantity was also deleted since it is not applicable to coil stock .

The system was implemented on the firm's Burroughs B5900 mainframe using Burroughs DMSII database management software . This database management system defines "data sets" which can be accessed via different key sets , called simply "sets" . Thus the database system as was finally decided upon consists of the following data sets , some of which were already in existence in the MMS (Fig.8)

4.1.1. Parts catalogue

This data set , already existing in the MMS , contains the description of all parts , products and sub-assemblies the firm uses or produces , price , units of order and various other data


MMS
BILL
OF
MATERIALS
PARTS
CATALOGUE
SIMILARITY
CODES
MACHINERY
PROCESS
PLANS
DIES
FIRMS
DEPRECIATION

on purchasing . The process planning system uses this set to retrieve part descriptions . Keys are (firm code , part number) .

4.1.2. Bill of materials

In the MMS , the bill of materials daata is not stored as a data set but as seven indexed sequentiial files , in order to facilitate on-line inquiries . One of these files contains the basic data as a tree structure , the so-called "father-son" file , which has records of all parts and assemblies making up another part . Each record contains the number of the parent part , the number of the component and the amount of the component used in the parent . The other six files are of similar structure and include "son-father" , i.e. , the reverse of father-son , products used(lowest level of tree to top level) and so on . The process planning system uses this data to determine which components are used , and how many , in a given part in order to calculate material requirements and machine workloads .

4.1.3 Process plans

This is the central module of the process planning systeem and , in fact , can stand alone with only the parts catalogue for the purpose of storing and retrieving process plans . However , its full potential only begins to be realized when it is linked to the machinery and dies data sets and the bill of materials . It contains , for each part three master records , one of which contains the raw material number , standard and requirement , flat pattern of the part(if any-this area is not applicable for assemblies) , the number and date of the latest technical change and the name of the person who added it , the production centre the part will go to after the process plan has been completed and the other two any notes the planner may wish to add . Since the process plans are used during actual production , the notes are extremely useful for drawing the workers' attention to possible problems(e.g. , "remember to remove the 5mm punches from the die for operation 20")thus saving a great deal of trouble and wasted production .

For each operation , the data set contains the sequence number of the operation , its description , die or fixture used , alternative die or fixture , machine used , alternative machine , production centre where the operation is performed , standard operation and setup times and worker requirements .

With such a broad information content , this data set has to be accessed in several different ways . The following sets were defined:

4.1.3.1 By operation (keys [firm , plant , part no. , oper.no])

This set is used to access process plans by part number .

4.1.3.2. By machine (keys [firm , plant , machine , pat no])

This set is used to find the operations performed on a given machine for the purposes of calculating machine workload .

4.1.3.3 By die (keys [firm , plant , die , part no. , op.no])

This set is used to find the operations performed by each die or the part it is used for . This will be used with thhe dies data set to determine which part is made where , in-house or at a vendor .

4.1.4. Dies

This data set contains information on dies needed by the technical staff , such as where the die is(in-house or at a vendor's) , price , maker , depreciation account number and theoretic lifetime in number of hits . It can be accessed by the following sets:

4.1.4.1 By die (keys [firm , plant , die number])

This is used to retrieve the die by number .

4.1.4.2 By firm the die is used at (keys [firm , where-used])

This enables the plants to check which die is used at which firm or plant and thus keep better track of depreciation payments .

4.1.5. Machinery

As the process planning activity is intimately related to the available machinery , it was necessary to include this data set . It contains the code of the machine , description , depreciation account number , the production centre and plant where the machine is used and its pprice and maker . This data set is accessed by machine code .

4.1.6 Firms catalogue

This data set existing in the MMS contains a list of all vendor firms the firm does business with , and is accessed by firm code . It can be used with the die data set to keep track of dies at vendors' premises .

4.1.7 Depreciation

This data is outside the MMS and part of the accounting system . It records the purchase and remaining depreciation of machinery and equipment . Access is by account number .

4.1.8 Similarity codes

This data set contains the similarity codes used in the retrieval-type CAPP system . It can be accessed by part number or similarity code .

4.2 Technical Information Syystem

One of the most important requirements the database system is required to meet is to facilitate inforrmation flow between the central engineering units and the plants . Since technical changes may require materials purchases , modifications to existing dies or the design and manufacture of new dies , there is a considerable time lag between a technical change being accepted by the technical staff and its actually going into production . This leads to discrepancies between the information of the central engineering units and the plants' actual state . It is important to note that , however , that after a change has been accepted by the technical units it has become an integral part of the product design , and , as such , must register in the technical departments' records . It is also important , especially from the materials point off view , to know the actual state of the product as it is being produced by the plant at the moment .. The problem can be solved by storing both sets of data and updating nthe plants' state from the technical departments' recors as the changes go into production .

It thus becomes necessary to store both the technical departments' information and the current state of the plants separately , storing a bill of materials and a set of process plans for each , since keeping both sets of data in the same files will lead to problems of update and security . Hence , the technical departments will update their own records as technical changes are made , and the actual state of production will be updated from these files as the changes go into production .

At present , as the central engineering departments examine each technical change to see if changes in process plan or die design are necessary and to keep track of its implementation , the daily volume of technical changes takes up a great deal of the engineers' time . On the other hand , the technical staff of the plants have more accurate , on the spot information on available machinery and dies . Thus , the suggested database system would function more effectively if the daily changes were followed up and entered into the technical records by the technical staff of the plants themselves , thus releasing the central engineering departments for project work and increasing the reliability of the data by capturing it at its source(Fig.9) . The various plants can send their data to the mainframe by means of tapes or diskettes periodically , to make the information available t1 the central departments , and eventually some form of networking will render this data transfer easier .

The programming of the first phase mentioned above , the the process plans and machinery data sets and their interfaces with the MMS was carried out in COBOL . The programs were designed to run on-line , except for certain report generators , in order to speed up the clerical work and capture data at its source . All data entry and update programs have extensive error checks in order to screen out bad data . In order to make sure that only authorised personnel can make changes , the update and inquiry programs have been separated and all programs further protected by plant and firm codes and passwords .

4.3 System Programs

The backbone of the system is the data entry and update program for the process plans which is in fact a highly specialized text editor . It uses a window approach in which the

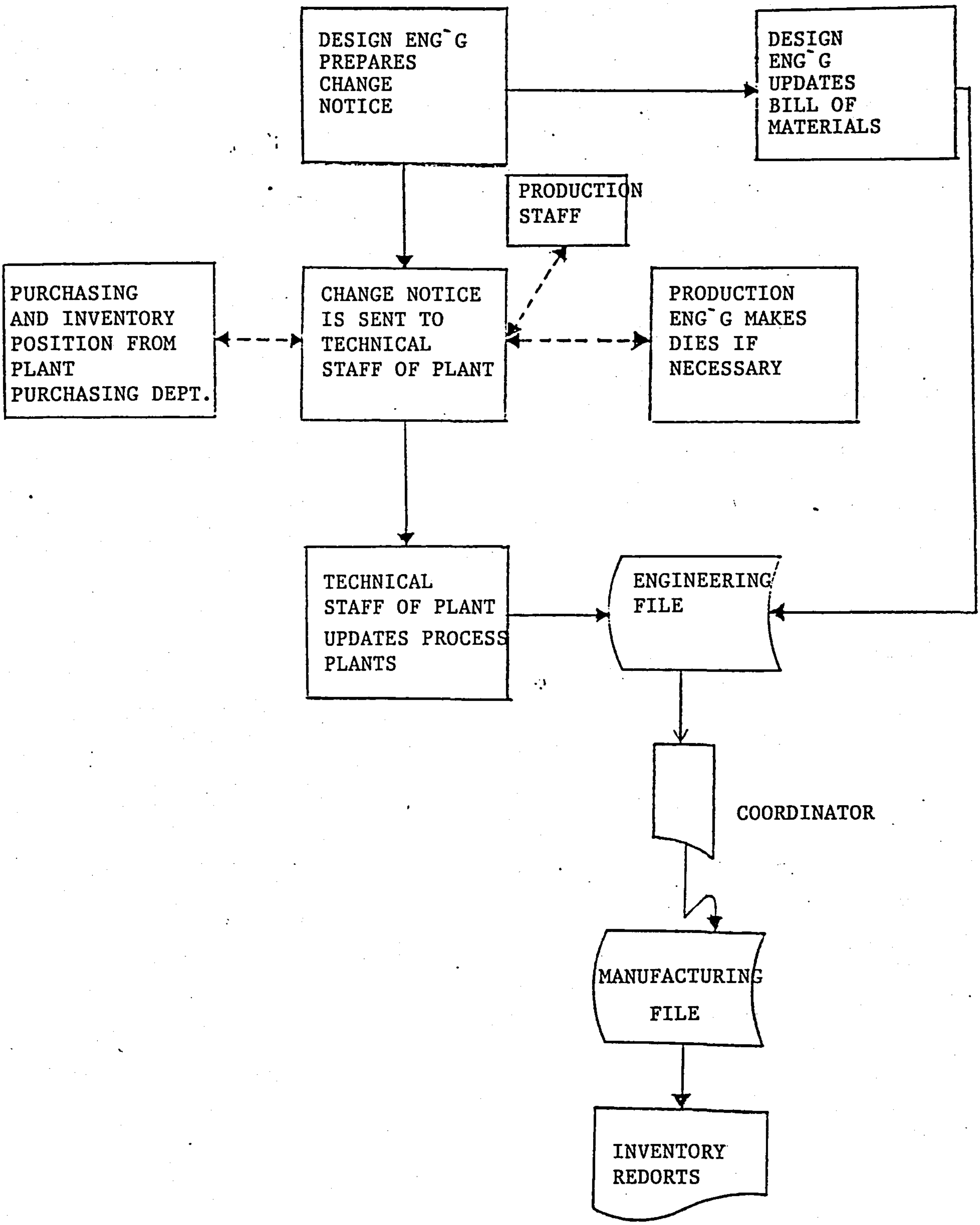


Fig. 9 Suggested Procedure for Technical Changes.

user enters and updates data via a window and sees what he has written , enabling errors to be corrected without going any further . The program also contains a machinery check to ensure that the machine the user specifies actually exists at that plant . The user is guided by a series of menus and if necessary can call a help option which gives information about program options and commands . The similarity codes are treated as an integral part of the process plans , but can be added later if desired . The program has the following options:

i) Data entry . Creation of a new process plan from scratch .

ii) Update . The user can make changes and add or delete operations on existing process plans .

iii) Delete . This option deletes the whole of a process plan .

iv) Copy . This option enables the user to copy existing process plans from one part to another . Thus the user can copy similar process plans found via the similarity codes , saving a great deal of clerical work .

v) Help . This option gives the user information on the programs options and commands .

Another program performs the same functions for the machinery data set but is much simpler in nature .

4.4. Reports and Application Programs

The user can make inquiries about process plans and machinery via inquiry programs that permit access to the data but no alterations . The similar parts classification , which forms the main part of the retrieval-type CAPP system , is used via another program and will be more fully treated in the next chapter . Another on-line program is available to enter and update descriptions of the various digits of the similarity code , rendering the system extremely amenable to future development .

The report-generating applications programs are of critical importance to the savings potential and the acceptance of the database system by the company . Reports which were previously available only after prohibitive amounts of time and effort can now be generated economically and accurately .

One of the most important reports generated is the raw materials requirements report for sheet-metal parts . This report is prepared by the Production Enginering Department and sent to the Central Purchasing Department which uses it to plan sheet-metal purchasing policy for the year . This report , when prepared manually by finding the sheet-metal components of each product from the bill of materials , searching manually through the process plans , making sure that the plan was up to date and calculating the materials requirements by hand took approximately 2 man/weeks to prepare . The accuracy of these figures is also extremely important , since they are used in the bill of materials for the automatic stock reductions . The availability of the process plans and the bill of materials enables the user to generate reports from both the technical departmets records (the process plans) and the production figures(bill of materials) in a variety of formats and to eliminate discrepancies by checking the two against each other . Two programs generate materials requirements from the bill of materials files by product and by material , and two others perform the same function using the process plans . Another program compares the two sets of figures and lists discrepancies .

Another extremely useful area is opened to use by the inclusion of the machinery in a database . The parts being processed on a given machine and the dies used on the machine can be seen immediately via an on-line inquiry program . Thiss enables die design to take machine workload into account . The user can also inquire as to the machinery available in a given plant . Two other programs calculate the machine workload of a given production schedule at varying levels of detail , using the machinery database and the bill of materials in conjunction .

4.4 Remarks on Implementation

The experience gained to date with the implementation on these programs has proved that they are easy to use , personnel totally lacking in computer background having become quite at home in a week . This also helps eliminate errors by having the process planner do his own entry , thus checking his work at first hand .

It can be seen that the full-scale implementation of the system requires a great deal of time and effort . The process planning system and the machinery , together with their interfaces with the MMS , were selected as the first stage of implementation , after which the programs were to be adapted to run on the smaller computers of the plants . As the dies require a study of their numbering system , they were set as the final stage . At present the two plants at Istanbul are fully converted to the first stage , process plans , machinery and MMS interfaces and results have been encouraging . It should be borne in mind that as the dies subsystem is brought into operation and the system begins to run on the plants' computers , the benefits of improved interdepartmental communication and cost-effective report generation will continue to increase . Adding to this the increased accuracy of the information and the firm-wide standardization of procedures it leads to , and the fact that it depends solely on programming and classification and coding , the database system appears in the light of an extremely cost-effective tool for the enhancement of manufacturing management .

V. CODING SYSTEM AND RETRIEVAL-TYPE CAPP SYSTEM

After the decision to bbring a form of computer support to the process planning activity had been taken , a survey of the available information and programming resources was made in order to determine the form this support should take . The fact that a generative CAPP system would require sophisticated information about part geometry and advanced programming techniques which would take a considerable period of time to become usable , it was decided to develop and implement a retrieval-type CAPP system which could become operational in a much shorter time and thus lead to a reasonably quick solution to the problems of the process planning staff .

As a majority of the firm's components manufactured in-house are sheet-metal parts it was decided to implement the CAPP system on the sheet-metal parts first . Thus , as retrieval-type CAPP systems rely on classification and coding , the need arose to develop a classification and coding scheme for sheet-metal parts .

Classification and coding systems used in industry can be described as monocodes , where each digit of the code classifies the next , and polycodes , where the meaning of each digit is independent of the preceding digits . A detailed description of classification and coding systems can be found in Hyde[16] .

In order to develop the necessary coding scheme , a team wasformed consisting of the author , Doç.Dr.Gündüz Ulusoy , two of the process planning engineers and one of the die-design engineers . This team met twice weekly for four months in order to discuss possible schemes and bring to bear the necessary mechanical engineering and computer background . During these sessions the common characteristics of sheet-metal parts produced by the firm were discussed and at length , after considerable effort , a coding system in the form of a 36 digit polycode was agred upon and tested on the sheet-metal parts produced in the Istanbul washing-machine factory . The first digit contains information on material , the next seven on shape and the others on various critical factors which will be discussed in detail later in this chapter .

Any manufacturing-oriented code for sheet-metal parts must necessarily take into account the various die-design aspects of the parts . For example , if a part has two holes to be pierced very close together , it may not be possible to pierce them both on the same die as the material between may tear . Thus , the classification system developed takes both part shape and these die-design deteermining factors , which we will call "critical factors" since they are critical to die design and thus play a large role in determining the process plan .

The first group of characteristics contains information on material and part shape . Part shape is definedd in terms of the basic sheet-metal forming operations , which were taken to be piercing(including blanking and extrusions) , shearing , forming , bending and drawing . Bending was further decomposed according to whether the bend was on the edge of the part , bent the part as a whole or involved only a portion of the part . Material is classified by quality , such as stainless steel , deep-drawing steel etc. , and thickness . A detailed description of the basic forming characteristics as used in the code developed is given below:

5.1 Shaping Characteristics

5.1.1. Piercing

i) Simple extrusions

Extrusions where the angle of extrusion is less than 90 and the regularity of the flange is unimportant .

ii) Complex extrusions

Extrusions with angle of extrusion less than 90′ and regularity of the flange edge is required .

iii) Round holes , pierced or blanked

iv) Holes other than round , pierced or blanked

5.1.2 Shearing

i) Flat pattern shearing

Shearing operations where the entire flat pattern of the part is obtained

ii) Notching along edges

iii) Notching at corners

The above notching operations are separated because it is possible to combine the latter with bending operations on a single die , but not the former.

5.1.3 Forming

i) Stiffening ribs across bends

ii) Form along edge

Shallow forms of depth less than 2t along an entire edge .

iii) Forms

Formed shapes with closed contour of depth less than 5t , and shapes deeper than 5t with one or more edges on the edge of the part ..

iv) Welding projections

Round projections of diameter less than 10 mm for projection welding .

v) Stiffening rib along bends

5.1.4 Bending on Edges

i) 90' bend

ii) Bends other than 90'

iii) U-bend

iv) Z-bend

v) Edge hem

vi) Curling

vii) All others

5.1.5 Bending of entire part

i) 90' bend

ii) Bends other than 90'

iii) U-bend

iv) Circular bend

v) Pipe clips

vi) More than one 90' bend

vii) More than one bend other than 90'

viii) More than one U-bend

ix) All others

5.1.6 Detail bending

i) Lanced tabs with angle 90'

ii) Lanced tabs with angle not 90'

iii) U-bends in centre of part

iv) Z-bends in centre of part

v) All others in centre of part

vi) Bending 90′ tab on edge

vii) Bending tab on edge with angle not 90′

viii) U-bending of part of an edge

ix) Z-bending of part of an edge

x) All others bends on part of an edge

xi) Both centre and edge operations

5.1.7 Drawing

Shaping the part to a depth greater than 5t along a closed contour in one or more operations .

Obviously , combinations of these basic operations are also possible . The number of these was reduced by the elimination of the manifestly impossible , but still required the use of alphabetic characters , especially for the bending digits . A detailled breakdown of the digits of this part of the code and the various conventions adopted can be found in the Appendix .

5.2 Critical factors

The second group of characteristics is the critical factors . These are generally due to the interaction of the elements defined in the first eight digits of the code . This interaction may be of the following forms:

i) The two operations may be superimposed , for example a hole pierced on the wall of a drawn part .

ii) The two operations may be closer to each other than a certain minimum distance , leading to complications in the die design . For example , if a hole is too close to an edge it is impossible to perform both shearing and piercing operations on the same die . These minimum distances are given in the die design literature as an absolute minimum for sheet metal below a certain thickness and as a function of the material thickness for thicker sheet . Thus we have the following three types of critical factors:

i) Those due to superposition

ii) Those due to two operations being closer than the minimum distance

iii) Those due to two operations being closer together than the minimum distance for that thickness of sheet

These factors are intimately related with die design , manufacture and press technology and may change with advances of the said technology . They play an important , sometimes decisive role in determining the number of dies needed to produce a part .

Thus , explicit inclusion of both the presence and type of the critical factors in the code is essential to its usefulness . This will enable the user , when faced with a given critical factor , to retrieve and examine parts with the same critical factor to glean methods of solution to his problem from them . This will also lead to increased utilization of past die design experience , reducing the possibility of repeating costly errors .

Another important advantage due to explicit inclusion of the critical factors is that it enables the factor of technological change to be taken into account . If at some date in the future new technology enabling holes to be pierced closer together than possible today should become available , the user can retrieve parts having that type of critical factor automatically and update them , thus ensuring that the CAPP system always reflects the latest available technology .

The critical factors being in three types , it is clear that in case of two types occurring on a part simultaneously some form of ranking is necessary . After discussion with the die engineers it was decided that superposition was the most dominant , followed by absolute minimum distance and distance as a function of thickness in that order .

The critical factors , 28 of which are possible , are defined in digits 9 to 36 of the polycode . Possible criteria for different operations to cause critical factors were found from the die design literature and are given in the Appendix .

5.3 Use of the CAPP System

Based on the code described above , the retrieval-type CAPP system was developed to enable retrieval of process plans and their editing . The system was programmed in COBOL and integrated with the database described in the previous chapter . A flowchart of the system is given in Fig.10. The main program for this purpose , called URR11 , enables the user to retrieve process plans by part number , to obtain list of similar parts and to copy a process plan for editing if an exact or close match is found .

In order to render the search time shorter , material was used as a key in the similarity codes data set . Thus , the user has to specify material but nothing else is obligatory enabling searches with partial codes to be made . For example , the user can search for all deep-drawing steel parts with a given critical factor , without specifying any other particulars .

5.4.1 Options of the CAPP System

5.4.1.1 Creation of a process plan from scratch

This is done using the editor for process plans .

5.4.1.2 Completion of an incomplete process plan

The process plan is rretrieved by part number using the system editor and then updated .

5.4.1.3 Retrieval of process plan by part number

This is done via the system editor for purposes of update

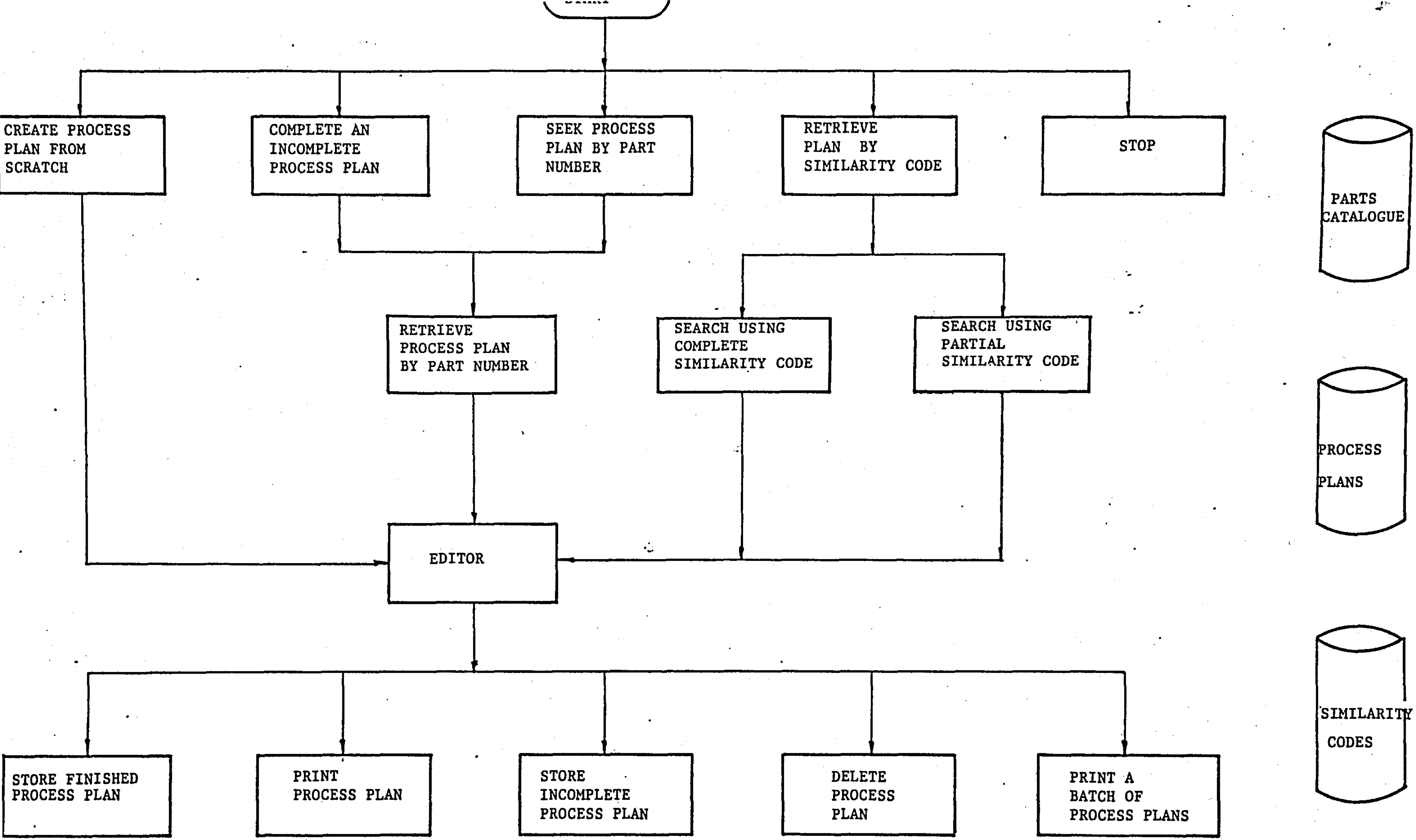


Fig.10 Flowchart of. Developed CAPP System

or copying .

5.4.1.4 Retrieval of process plan via similarity code

This is performed by the program URR11 , which enables the user to search for parts with similar process plans , view selected process plans and , if he so desires , copy a suitable process plan .

5.4.2 Editor of the CAPP System

After the user has retrieved a process plan and worked on it , he has the following options;

i) Store a completed process plan

ii) Store an incomplete process plan

iii) Delete an undesired process plan

iv) Print the process plan on a slave printer

v) Use a separate program to print a batch of process plans

VI. CONCLUSIONS AND EXTENSIONS

The CAPP system and database system described above have been implemented in two of the firm's five plants , and results to date have been encouraging . The time necessary for the preparation of process plans has been considerably reduced , especially by the copy facility and the ability to store incomplete process plans and update them later . The similarity code has been implemented in the İstanbul washing-machine factory and results have been encouraging .

The system has led to a considerable standardization of information in the Production Engineering Department . The process plans now contain standard time data that was not previously entered due to the fact that time study and process planning were done by separate teams . The increased cooperation has the added advantage of leading to more up to date process plans due to feedback from time studies .

Comparison of the flowcharts in Figs. 4 and 10 leads to the conclusion that the system developed in this study has the same capabilities as MIPLAN,with the exception of the standard text files , part family matrix files and use of user-defined routines . The standard text could be developed with time , and its function is fulfilled to a certain extent by the copying option which will result in stansardization of texts over time . The part-family matrix is a group-technological concept which is not applicable to sheet-metal manufacturing as studied here as a die can only perform operations on one part , rendering grouping of part families to process on a group of machines irrelevant . The use of user-defined routines in the CAPP system would require the investment of a great deal of programming effort , and since the process plans contain no information that could require the use of such modules was not considered worthwhile.

The extensions possible are , first of all , the introduction of the dies into the database after solving the associated coding problems and linking this subsystem to the vendors files to allow tracking of dies and easier calculation of depreciation . After this , development of process plans for plastic parts and their inclusion in the classification/coding scheme would also lead to substantial benefits .

Ultimately , it might be possible to develop a full-scale generative process planning system , but this would require the generation of a vast amount of information on part geometry and a corresponding investment of time and effort to capture the logic involved . Thus , it would seem that this is still only a long-term possibility .

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APPENDIX I

STRUCTURE OF THE SIMILARITY CODE

Digit 1 Materials

1- Stainless steel

2- Coated steel

3- Deep drawing steel

4- Standard quality (t<1.5 mm)

5- Standard quality (1.5mm < t < 2.5mm)

6- Standard quality (t>2.5mm)

Digit 2 Piercing operations

A- Normal extrusions

B- Extrusions with regular flange

C- Round piercing or blanking

D- Piercing or blanking other than round

E- (A + B)

F- (A + C)

G- (A + D)

H- (B + C)

I- (B + D)

J- (C + D)

K- (A + B + C)

L- (A + C + D)

M- (A + B + D)

N- (B + C + D)

O- (A + B + C + D)

Digit 3 Shearing operations

1- Flat pattern shearing

2- Notching at corners

3- Notching at edges

4- (1 + 2)

5- (1 + 3)

6- (2 + 3)

7- (1 + 2 + 3)

Digit 4 Forming operaations

A- Stiffening rib across bend

B- Shallow form along edge

C- Welding projection

D- Form

E- Stiffening rib along bend

F- (A + B)

G- (A + C)

H- (A + D)

I- (A + E)

J- (B + C)

K- (B + D)

L- (B + E)

M- (C + D)

N- (C + E)

O- (D + E)

P- All others

Digit 5 Bending operations on edges

A- 90′ Bend

B- Bends other than 90′

C- U-bend

D- Z-bend

E- Edge hemming

F- All others

G- Curling

H- (A + B)

I- (A + C)

J- (A + D)

K- (A + F)

L- (B + C)

M- (B + D)

N- (B + F)

O- (C + D)

P- (C + F)

Q- (D + F)

Curling and edge hemming can only occur by themselves.Here it is possible to describe at most two edges of a part,interpreting the combinations in this fashion.

Digit 6 Bending operations of part as a whole

A- 90′ Bend

B- Bends other than 90′

C- U-bend

D- Circular bending (360′)

E- Pipe clips

F- More than one 90′ bend

G- More than one bend other than 90′

H- More than one U-bend

I- All others

Digit 7 Detail bending operations

A- Lanced tab with bend 90′

B- Lanced tab with bend other than 90′

C- U-bend in centre

D- Z-bend in centre

E- All other detail operations in centre

F- 90′ bend on edge

G- Bend on edge other than 90′

H- U-bend on edge

I- Z-bend on edge

J- All other detail operations on edges

K- Both edge and centre detail operations

Digit 8 Drawing Operations

1- Drawing of entire part in one stage with flange removal

2- Drawing of entire part in one stage without flange removal

3- Drawing of entire part in more than one stage with flange removal

4- Drawing of entire part in more than one stage without flange removal

5- Drawing operation on part of the workpiece

6- (1 + 5)

7- (2 + 5)

8- (3 + 5)

9- (4 + 5)

ii. Critical factors

After discussions with the die engineers and study of the die design literature, five basic criteria for critical factors emerged which covered all possibilities. The criteria are listed according to the two operations whose interaction they result from. The letter "t" is used to represent sheet thickness.

i. Piercing-piercing or shearing-shearing

In order not to be critical, these operations should at least 1.5t apart and never closer than 3.2mm .

ii. Forming-piercing

At least 3t apart,never closer than 5mm .

iii. Piercing-shearing

At least 3t apart,and never closer than 3mm.

iv. Bending operations

The minimum distance between two bending operations should be at least 5t , with a minimum bending radius of 2.5t

v. Drawing operations

The minimum distance between a drawing operation and any other operation should be at least 15t.

The possible ccritical factors and the criterion which applies to them are shown in Table 2 . A critical factor due to superposition is indicated by 1,one due to absolute minimum distance by 2 and one due to the material thickness criterion by 3 . The encircled number represents the which of the above five criteria is applicable to the critical factor formed by the interaction of the operations given in the row and column.The number in the upper right-hand corner is the digit of the polycode representing that particular critical factor.

	PIERCING	SHEARING	FORMING	EDGE BENDING	PART	DETAIL	DRAWING
PIERCING	(1) 1	(3) 2	(2) 3	(2) 4	(2) 5	(2) 6	(2) 7
SHEARING		(1) 8	(2) 9	(2) 10	(2) 11	(2) 12	(2) 13
FORMING			(4) 14	(4) 15	(4) 16	(4) 17	(5) 18
EDGE BENDING				(4) 19	(4) 20	(4) 21	(5) 22
PART BENDING					(4) 23	(4) 24	(5) 25
DETAIL BENDING						(4) 26	(5) 27
DRAWING							(3) 28

Table 2. Critical Factors