1997

A 0-1 integer programming model for the simultaneous allocation of operations of part types and grouping of machine-tool combinations.

Franklin Samuel Jaiselvan. Foulger
University of Windsor

A 0-1 INTEGER PROGRAMMING MODEL FOR THE SIMULTANEOUS ALLOCATION OF OPERATIONS OF PART TYPES AND GROUPING OF MACHINE-TOOL COMBINATIONS

by

Franklin S.J. Foulger

A Thesis
Submitted to the Faculty of Graduate Studies and Research
through the Department of Industrial and Manufacturing Systems Engineering
in Partial Fulfilment of the Requirements for
the Degree of Master of Applied Science at the
University of Windsor

Windsor, Ontario, Canada
1997

0-612-30941-X

ABSTRACT

In today's competitive world, for manufacturers to survive in the market and to compete on a global level, several innovative strategies are being developed and practised. In industries which manufacture a variety of products in lots, one of the well known manufacturing strategies or systems is cellular manufacturing systems (CMS). CMS has several advantages especially for manufacturers who produce a medium variety of products in medium volumes. The tangible benefits are reduction in cycle time of the product, reduced inventory, improved quality, possibility to meet customer demands on time etc.; the intangible benefits are flexibility in the system, increased control of the process, improvement in employee morale etc.,

This proposed research is an attempt to group machines into cells, assign tools to the machines, and then to allocate operations of parts to the machine-tool combinations, simultaneously. In this research a 0-1 integer programming model is developed for the purpose mentioned above. The objective of the model is to reduce operation costs, material handling costs and refixturing costs, taking into consideration tooling, machine capacity and tool life.

I hereby declare that I am the sole author of this document. I authorize the University of Windsor to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Franklin S.J. Foulger

I further authorize the University of Windsor to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Franklin S.J. Foulger

The University of Windsor requires the signatures of all persons using or photocopying this thesis. Please sign below, and give address and date.

DEDICATION

To God Almighty

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my deep gratitude and appreciation to Dr. R.S. Lashkari for his guidance and support during the preparation of this thesis. I would also like to extend my special thanks to Dr. R.J. Caron and Dr. Sourin P. Dutta for serving as committee members.

I sincerely thank the Faculty of Engineering, University of Windsor for providing financial support in terms of teaching assistanship. The financial support from Dr. R.S. Lashkari through his NSERC research grant is gratefully acknowledged. My thanks are due to Jacquie Mummery for her help in my day to day works.

Finally, I would like to express my deepest and heartful thanks to my parents, brother and fiancé for their encouragement and support which constituted ingredients necessary for the completion of this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Backdrop

In the competitive environment of today, manufacturers are constantly updating their technologies, strategies etc. One of the breakthroughs in Manufacturing was Group Technology which emerged and was accepted and implemented by many industries worldwide for its tangible and intangible benefits. One of the applications of group technology and a noteworthy one, is Cellular Manufacturing Systems (CMS). Though the concept of CMS is not very new, only recently it is being implemented and its benefits are being appreciated by many manufacturers. The concept of CMS is to group machines into cells, based on their capabilities to perform operations on the parts, and to allocate part families to these cells, such that each part family is cell complete, i.e, all the required operations of the part family would be performed in the assigned cell.

The cell formation, therefore, consists of a machine grouping problem, and an operation allocation problem. There are several techniques to date to solve the operation allocation and machine grouping problems. The general objectives of these techniques is to reduce operation costs, material handling costs, etc., and to take into consideration such factors as, limitation on the maximum number of cells, maximum number of machines in a cell, capacity of the equipment, etc.,

The model proposed in this research is an attempt to solve the above mentioned problems. In this research, a 0-1 integer programming model is proposed with the objective of reducing operation costs, material handling costs and refixturing costs, considering such factors as tooling of the machines, demand for the parts, capacity of the machines, tool life, etc.

1.2 Framework of the thesis

The framework of the proposed research is as follows. In section 1.3 an overview of the different kinds of manufacturing systems as well as their applications is given. Section 1.4 discusses tools and fixtures in manufacturing. Section 1.5 provides some details about CMS and the various techniques employed for their design. Chapter 2 presents a brief survey of the pertinent literature. In Chapter 3 the proposed mathematical model is presented. The numerical examples are presented in chapter 4 and the results are analyzed. The thesis concludes with some discussions and future directions in chapter 5.

1.3 Manufacturing Systems

The manufacture of products in the modern industrial world requires the combined and coordinated efforts of people, machinery and equipment. Thus a manufacturing system can be defined as a combination of humans, machinery and equipment that are bound by a common material and information flow.

Manufacturing systems in general can be categorized as follows:

a) Job shop:

A job shop is one in which machines within the same or similar processing capabilities are grouped together (Fig.1.1). Job shops find their application in manufacturing systems which have a large variety of parts that are processed in batches of low volume. This layout usually requires general-purpose machines which can accommodate a large variety of parts. In this layout the part types move through the system by visiting different work centers according to it's process plan. The material

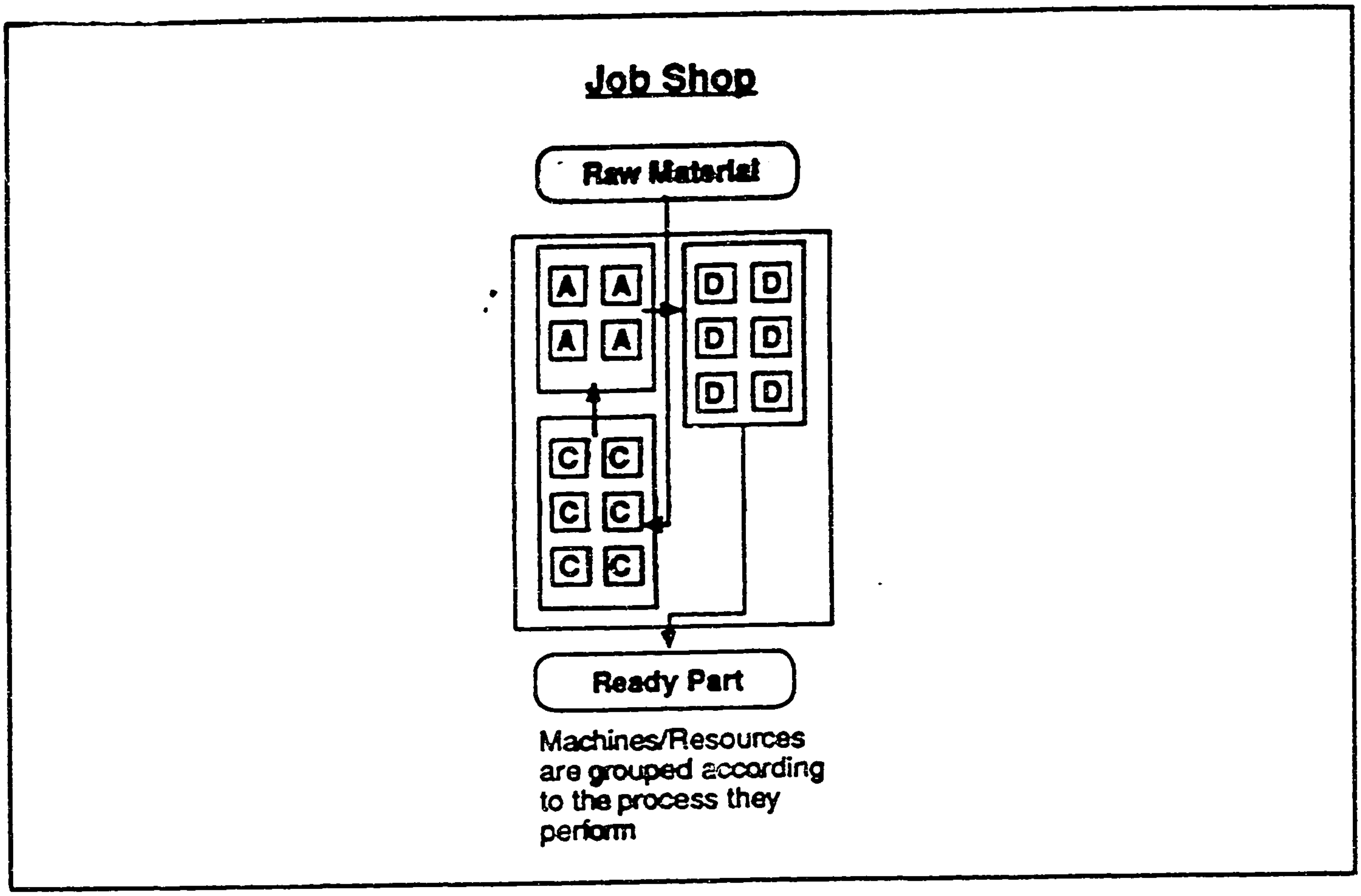


Fig 1.1 Schematic of a Job shop [Chryssolouris, 1992].

handling in these systems has to be very flexible in order to accommodate many different part types. Within each workcenter, a number of machines can be used for a particular operation.

b) Project shop

When the size and or weight of the product to be manufactured is very large and when it is not feasible to move it around a system the materials, people, and machines have to be brought to the product, for processing. This is called a project shop(Fig 1.2), with applications in ship building industries, airplane manufacturing, building constructions, etc.,

c) Cellular Manufacturing Systems

Cellular manufacturing systems (Fig 1.3) are used to process medium variety of products with medium batch sizes. In this layout the equipments and machines are grouped according to the process combinations that occur in families of parts. It can also be said to be a "factory in a factory". Each cell consists of machine-groups that either completely or almost completely process all the operations required for the part family assigned to that cell. Inter-cellular and intra-cellular material handling can be done either automatically or manually.

d) Flow line

In a flow line system or process layout(Fig 1.4), the machines and equipments are placed according to the sequence of operations that are required for the processing of part types. A typical application of a flow line is the transfer line that is used in

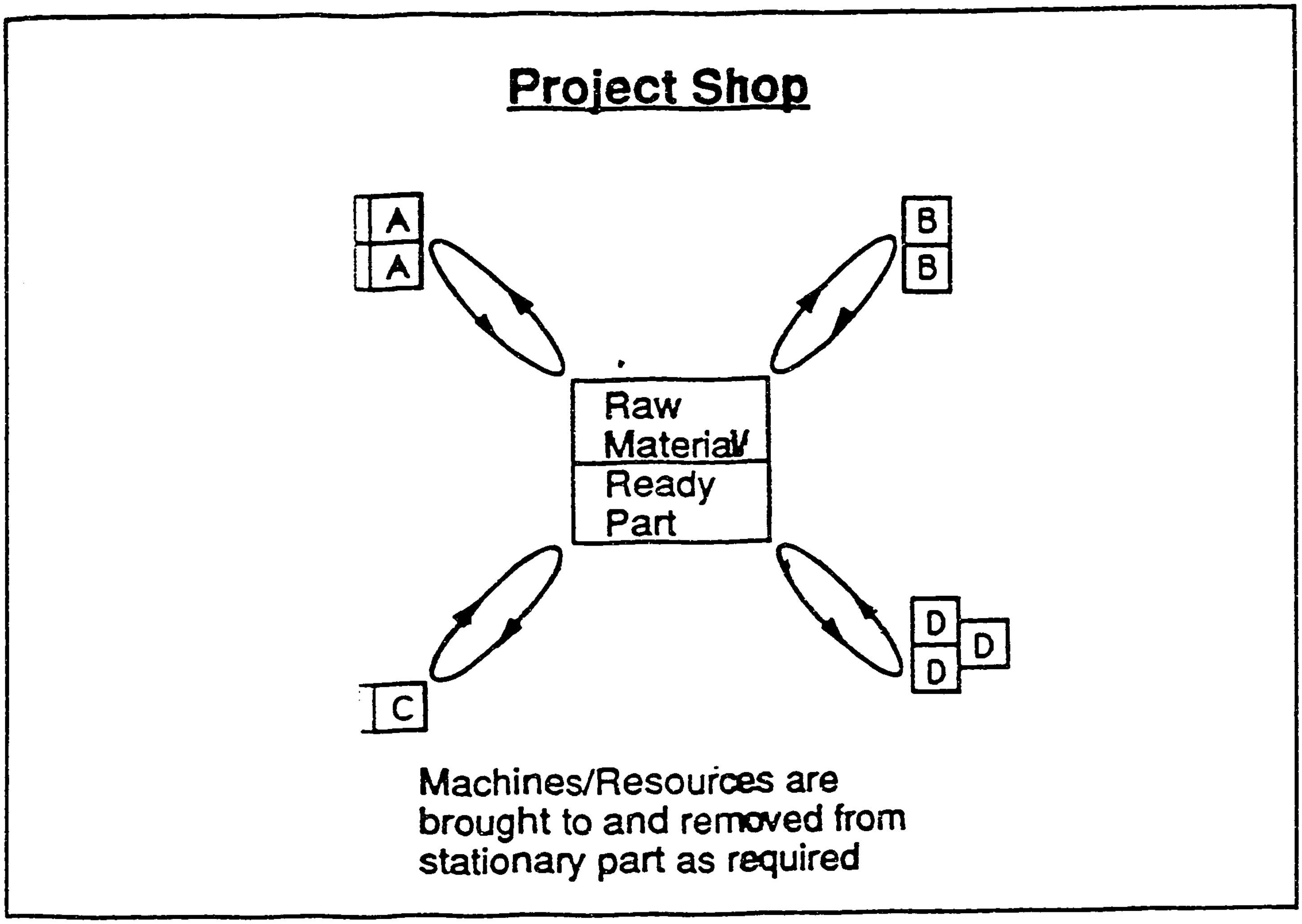


Fig 1.2 Schematic of a project shop [Chryssolouris, 1992].

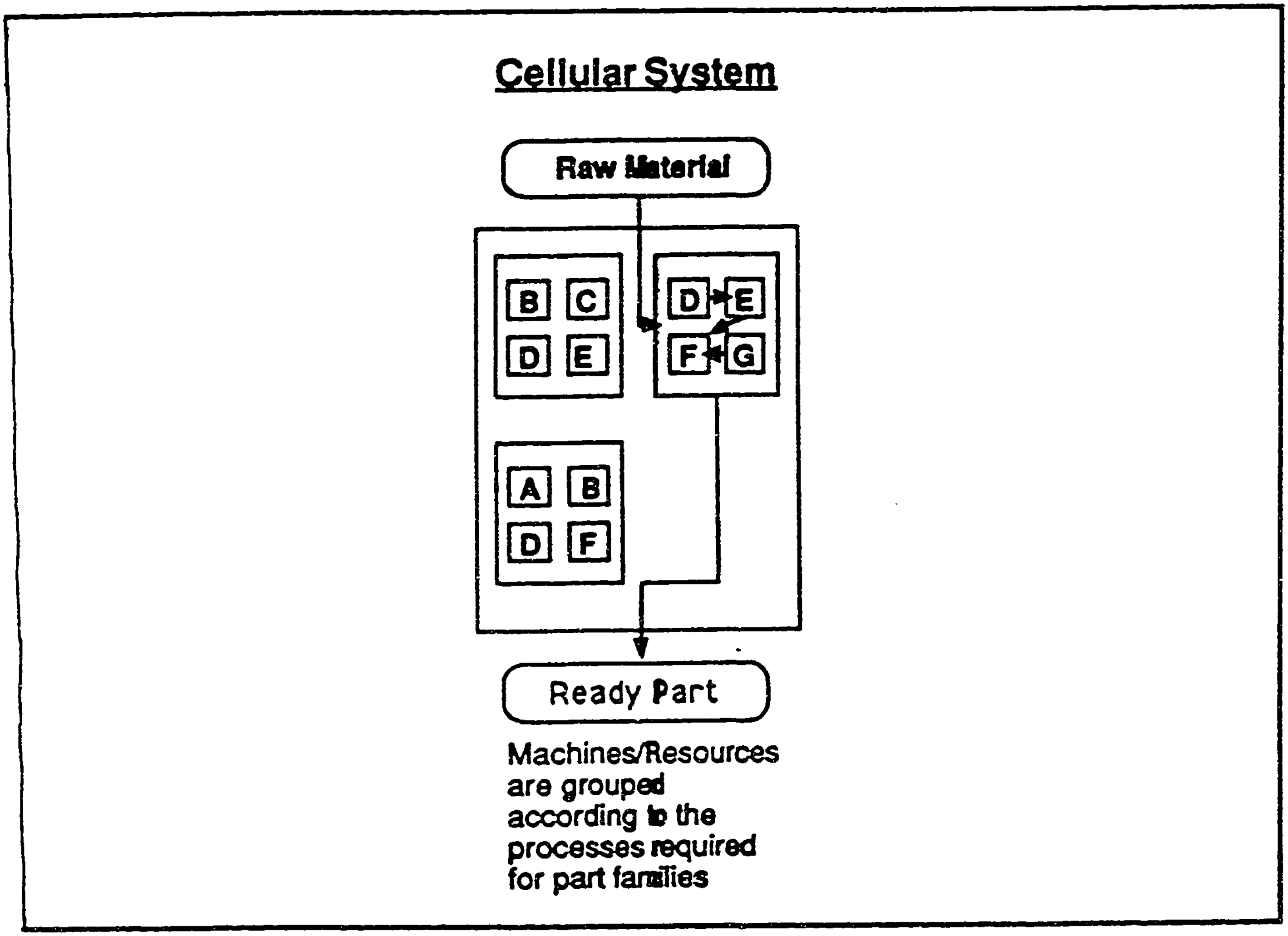


Fig 1.3 Schematic of a cellular manufacturing system [Chryssolouris, 1992].

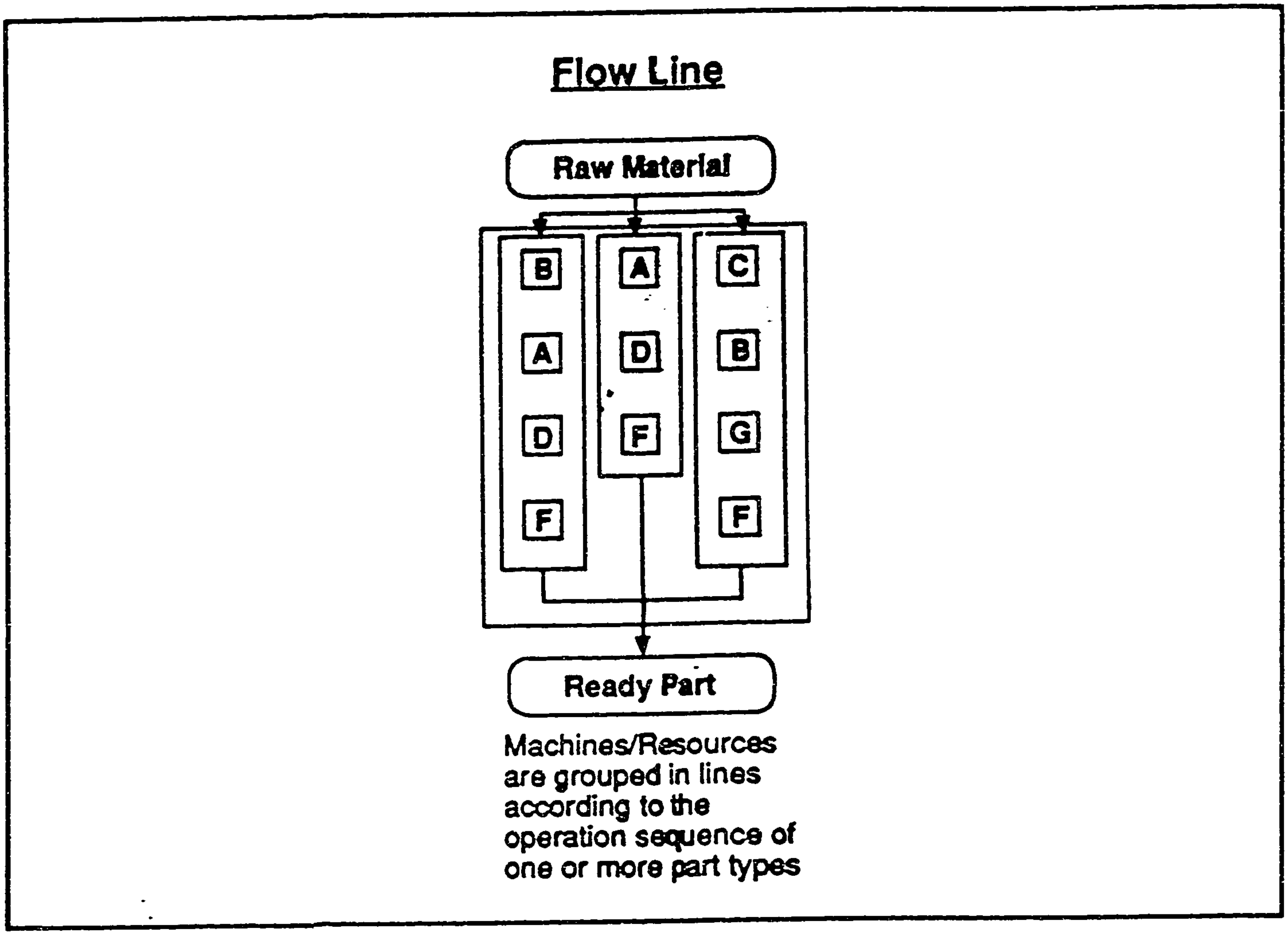


Fig 1.4 Schematic of a flow line [Chryssolouris, 1992].

automotive industry. A flow line consists of a sequence of machines which are typically dedicated to one particular part or at most a few very similar parts. The machines in a flow line are linked by automated and dedicated material handling devices.

e) Continuous system

The manufacturing systems discussed earlier, i.e, job shops, project shop, CMS and flow line, are all systems which perform discrete part manufacturing. A continuous system (Fig 1.5) is one which produces non-discrete products such as liquids, gases or powders, etc. In a continuous system the equipment is arranged according to the processing sequence of the products. The continuous system is the least flexible of all the types of manufacturing systems.

The above mentioned standard manufacturing systems often appear as a combination of one or more systems or with slight changes.

Figure 1.6 shows the difference in the applicability between a product shop, CMS and a process layout.

1.4 Tools and Fixtures in Manufacturing Systems

1.4.1 Tools in manufacturing systems

Tools play a vital role in manufacturing systems; they are the interface between the workpiece and the machine tool. There have been several varieties of tools invented and used for various operations in machines and on various materials of parts. Tools come in different shapes, diameters, lengths, number of teeth and alternative tool materials. The most popular tools are those made of high-speed steel (HSS) and tungsten carbide. Usually tungsten carbide tools can be operated at higher cutting speed than HSS , but are more costly and are sometimes difficult or impossible to regrind.

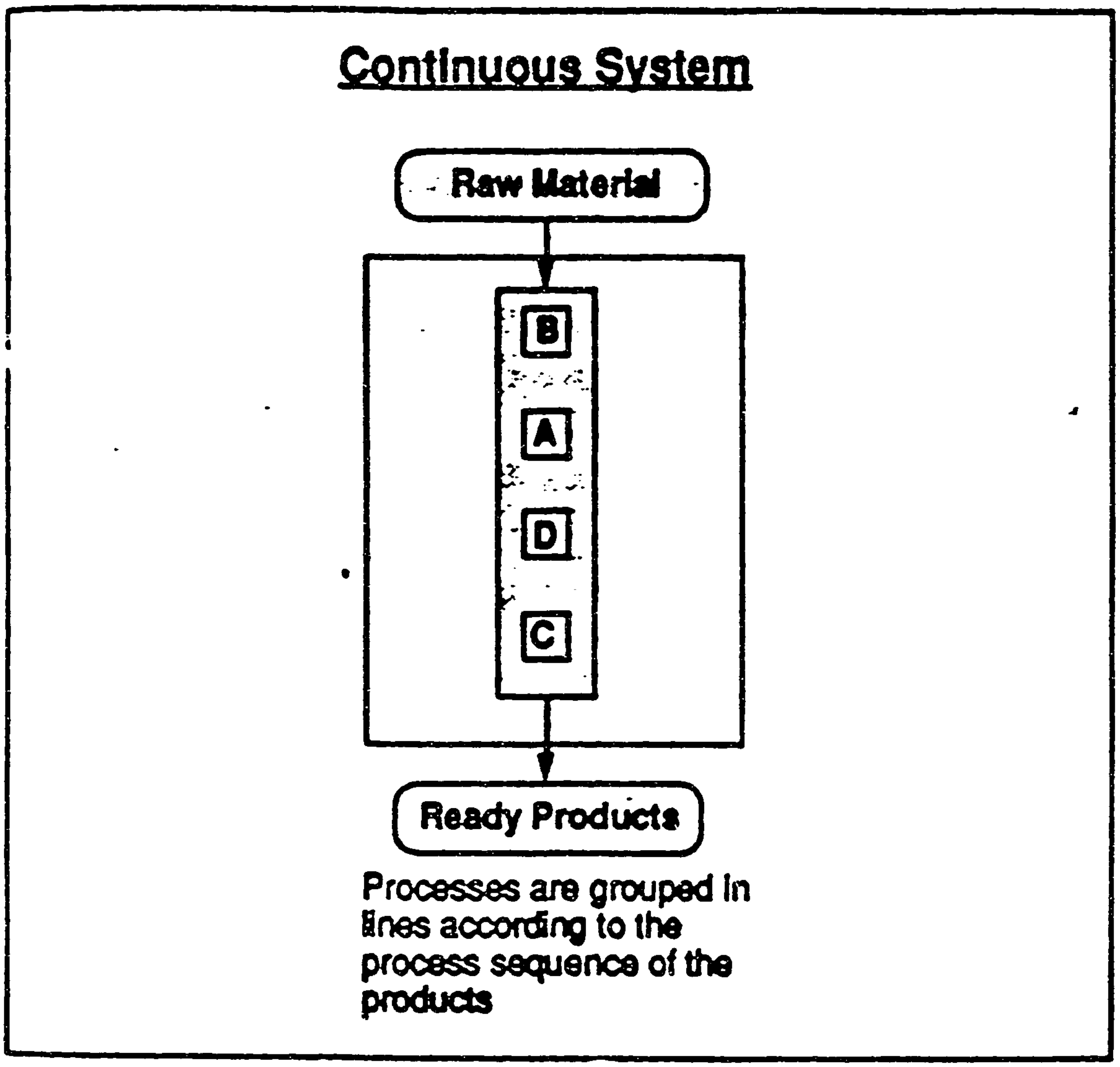


Fig 1.5 Schematic of a continuous system [Chryssolouris, 1992].

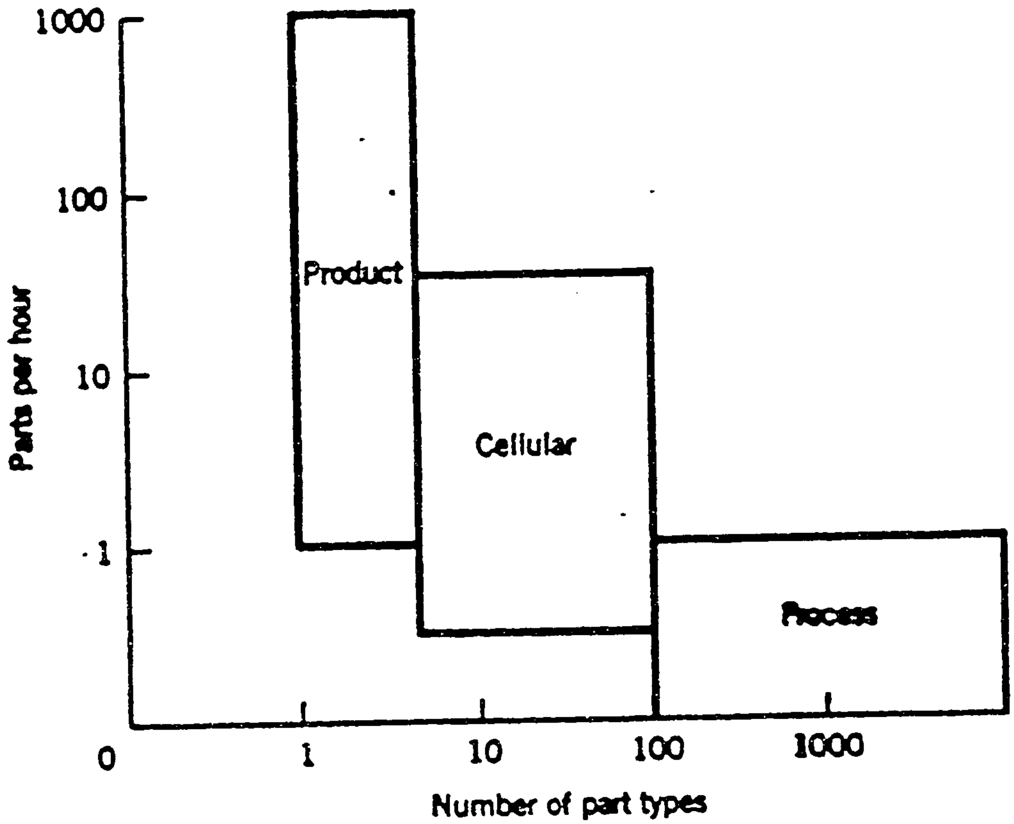


Fig 1.6 Difference in the applicability between a product, cellular and process type of layouts [Askin and Standridge, 1993].

Tungsten carbide is brittle and is therefore not suitable for interrupted cuts. Traditionally, tooling in manufacturing systems was not accorded the proper importance it deserved; however, in recent times, with the advent of high technology tools and improved strategies in manufacturing, tooling has been gaining considerable importance.

1.4.1.1 Tool Management

According to Keith Bird (Plant Manager at Van Dorn Plastics Machinery Co.) tool management is the key item in CMS [Martin, 1989], which probably has a major impact on the productivity of the cell. The objectives of Tool Management Systems (TMS), in general are given in Figure 1.7, and an example of a TMS is given in Figure 1.8. The general objectives of a TMS are as follows:

i. The primary objective of any TMS is to reduce the unescessary cost incured in the procurement, storage and use of tools.
ii. Optimization of the selection of tools required for the manufacture of the products. Reduction, in the variety of tools being used, as well as in the volume or number of tools being procured.
iii. Determination of the tool requirements and tool use.
iv. To implement just in time supply of tools.
v. Reduction of the idle time caused by the tools.
vi. Exploitation of the performance of the tools.

In addition to the above objectives there are other objectives such as acheiving an optimum trade-off between the machine tool cost and the tool cost, continuously monitoring the tool for wear, having a fairly accurate estimate of the life of the tool, etc.

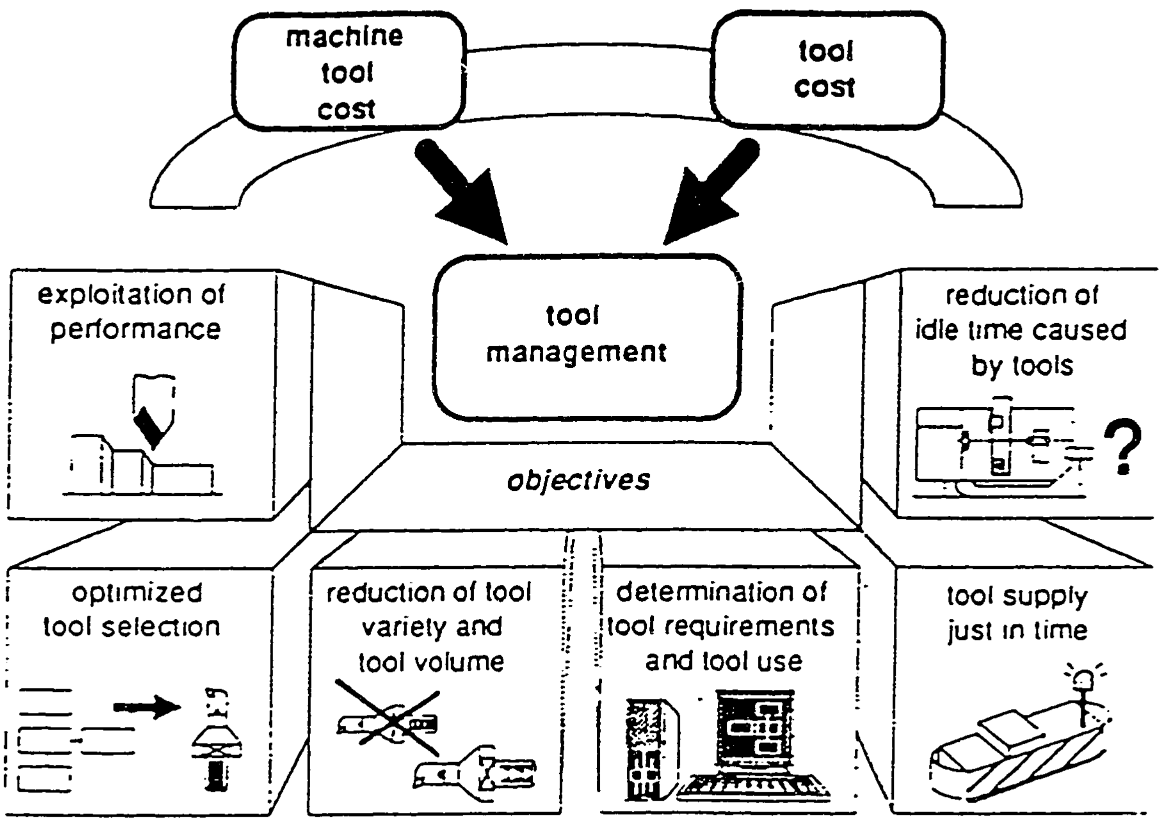


Fig 1.7 Tool Management - Objectives [Eversheim, et al., 1991]

The following is a description of the basic procedures to be followed for an efficient TMS:

To know what parts are to be run, what combinations of parts will flow through a cell during any particular setup or stated interval of manufacture.

To specify the tools for multiple purposes, for example to find common drills that can be used across several jobs.

To anticipate the future, i.e, to look at tool management within a cell with a lot of concern about new parts that will be coming into the system down the road. For example, if it is known that a part is scheduled which requires a 12" long boring cutter the tool becomes a standard at the machine tool, in contrast to stocking several tools of the same diameter but varying lengths. If a tool is a good, all-round performance tool then it should be made a standard tool, if it were to be unique then it should be made special.

The above mentioned examination of workpieces and therefore tooling requirements should be done at the very beginning of cell specification.

Any tool in a manufacturing system undergoes a tool cycle, which in a general sense can be explained as follows (Fig 1.9):

The new or reworked tools are stored in the tool stock, then as per the requirement, they are assembled and adjusted and then transported to the machine tool area and are set in the tool magazines. Then the tool is worked on the workpiece on the machine tool and once the tool is worn or if its function in that manufacturing cycle is

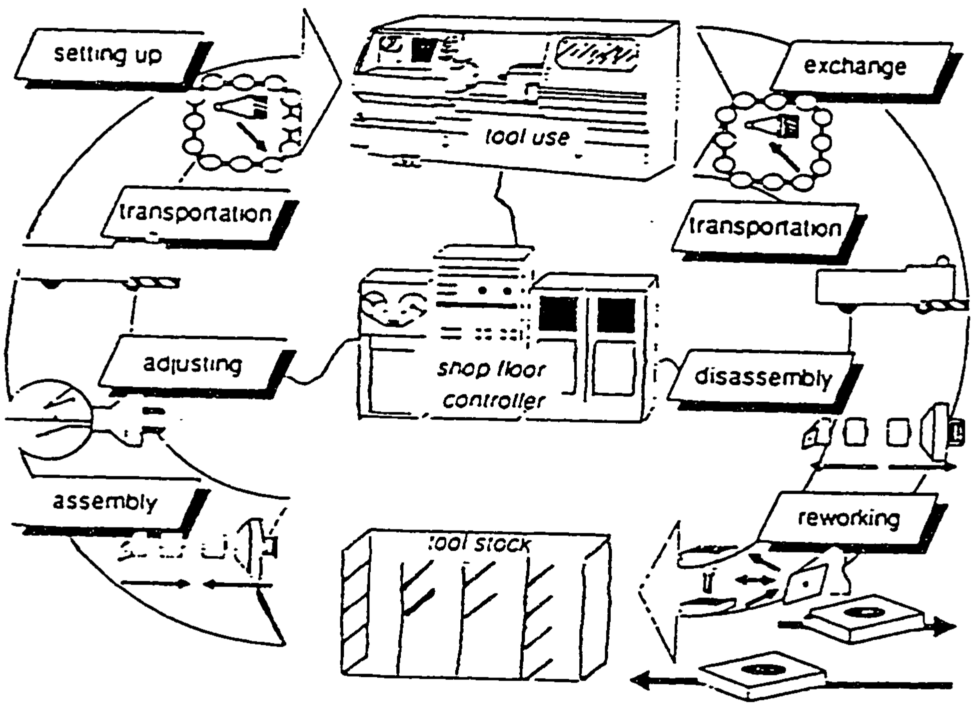


Fig 1.9 Tool cycle [Eversheim, et al., 1991]

over and needs adjusting etc., it is removed from the tool magazine and transported to the disassembly station, disassembled and reworked if required.

The following are the general guidelines for the selection of tool materials:

1. High Speed Steel (HSS) tools are generally used for;

a. High volume and low cutting speed operations (e.g. in screw machines).

b. Low volume operations.

c. Complex tool forms, such as form tools, drills and cutoff tools.

d. Machine tools or setups which lack rigidity.

e. Small diameter end mills and drills.

f. Low powered machine tools.

g. Certain machining operations on problem materials, such as nickel base high temperature alloys.

2. Cast alloy materials are selected as an intermediate choice between high speed steel and carbide tool materials. The high cobalt high speed steels also serve as intermediates, and there appears to be a trend for them to supersede the cast alloy steels.

3. Carbide tools are generally applicable when;

a. The rigidity of the machine tool, tooling and workpiece is high.

b. Machine tool power is adequate for the higher metal removal rates.

c. Configuration of workpiece and machining operation permit higher cutting speeds.

d. High production rates are required.

4. Ceramic tools, high strength carbides, diamond tools, and the cast alloy tools refereed to previously, have rather specific application, in contrast to the wide usage of high speed steel and carbide tools.

Tool engineering decisions on specific operations must balance a number of cost factors to obtain optimum manufacturing costs. Figure 1.10 provides a general guide to the impact that the factors of 1) Cutting speed, 2) tool cost per piece, 3) idle cost, 4) machining cost, 5) tool reconditioning cost and 6) tool cost per piece have upon 1) cost per piece and 2) production rate in pieces per hour.

The general conclusions that can be made from the figure include;

1) Machining cost drops rapidly as cutting speed increases.

2) Tool cost per piece is at its minimum value when the cutting speed is approximately 700 fpm and then it rises sharply.

3) The production rate in pieces per hour is at its maximum when the cutting speed is approximately 950 fpm.

1.4.1.2 Tool life

Tool life can be defined as the time frame within which a tool can machine parts without the necessity for regrinding. There are several factors that affect the life of a tool; they may summarised as follows:

i. Machining speed.

ii. Feed rate.

iii. Material of the work piece as well as the tool.

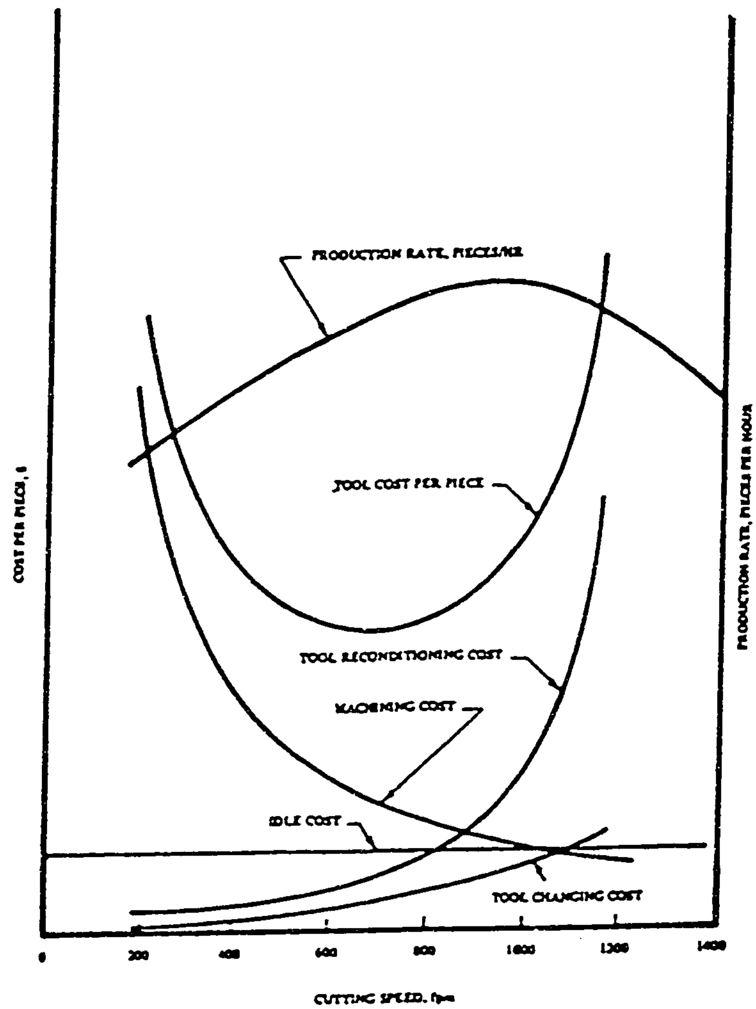


Fig 1.10 Machining cost and production rate vs. cutting speed [Groover and Zimmers, 1984].

iv. Tool being subject to variations in the above mentioned factors.

v. Characteristics of the operation which the tool performs on a part, i.e., angle of machining, depth of cut, etc.,.

vi. Specifications of the tool viz. tool diameter, number of teeth etc.,

The tool life can be expressed as a formula by the expanded Taylor tool life equation which is given as [Rembold, et al., 1994],

$$t = \frac{\lambda C}{V^{\alpha_T} f^{\beta_T} a_p^{\gamma_T}}$$

where,

t = tool life

λ, C = constants for a specific tool/workpiece combination

V = cutting speed

f = feed rate

a_p = depth of cut

α_T = speed exponent

β_T = feed rate exponent

γ_T = depth of cut exponent

The tool life can also be expressed as well as evaluated by using nomograms which are drawn with the values obtained from the extended Taylor's equation or from Table 1.1. Figure 1.11 shows a nomogram for mild steel machined with HSS tools and Fig 1.12 shows a nomogram for mild steel machine with carbide tools. Fig. 1.13 is a nomogram for carbon tool steel, HSS, Cast nonferrous and sintered carbide, used to machine S.A.E low alloy steel to S.A.E X-1112. With the help of these nomograms and equations, the tool life for a particular tool, whose required parameters are known, can

OPERATION	TOOL LIFE t
Turning, boring, facing, parting	$K_T . v^{\alpha_T} . f^{\beta_T} . a_p^{\gamma_T}$
Shaping, planing, drilling, reaming	$K_T . v^{\alpha_T} . f^{\beta_T} . a_p^{\gamma_T} . D_t^{\delta_T}$
Broaching	$K_T . v^{\alpha_T} . a_f^{\beta_T}$

Table 1.1 Equations of tool life[1] foor various cutting operations [Rembold, et al., 1994].

[1] K_T = Tool life equation constant
v = cutting speed (inches/minute)
D_t = diameter of the tool
a_p, a_f = depth of cut
ξ_T, ϵ_T, δ_T = Exponents related to number of teeth in the cutting tool, machined surface width and tool diameter, respectively for tool life equations
z = number of teeth on the cutting tool

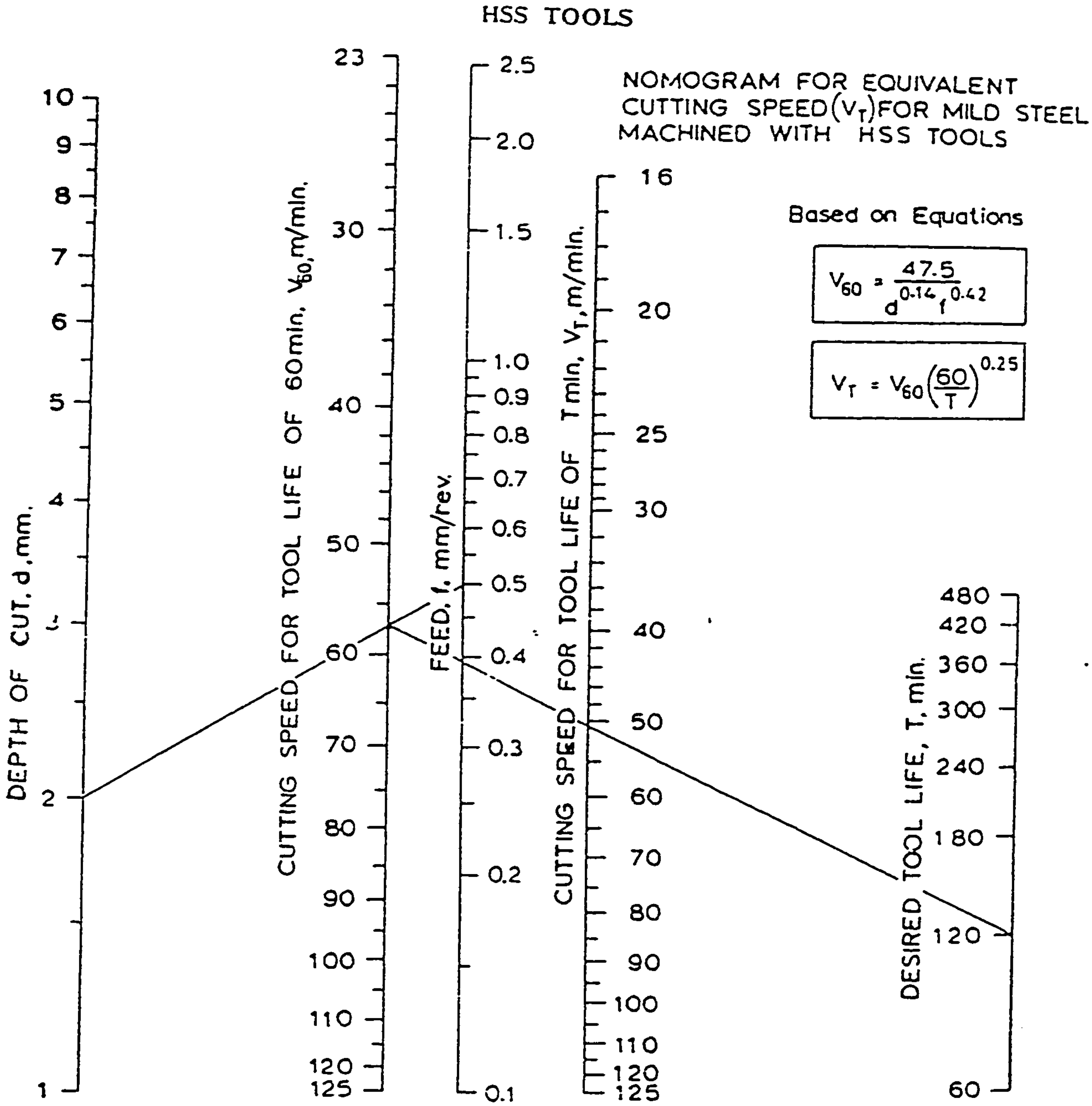


Fig 1.11 Tool life nomogram for mild steel machined with HSS tools [Faculty of Mechanical Engineering (PSG College of Technology), 1989]

TOOL LIFE NOMOGRAM
CARBIDE TIPS

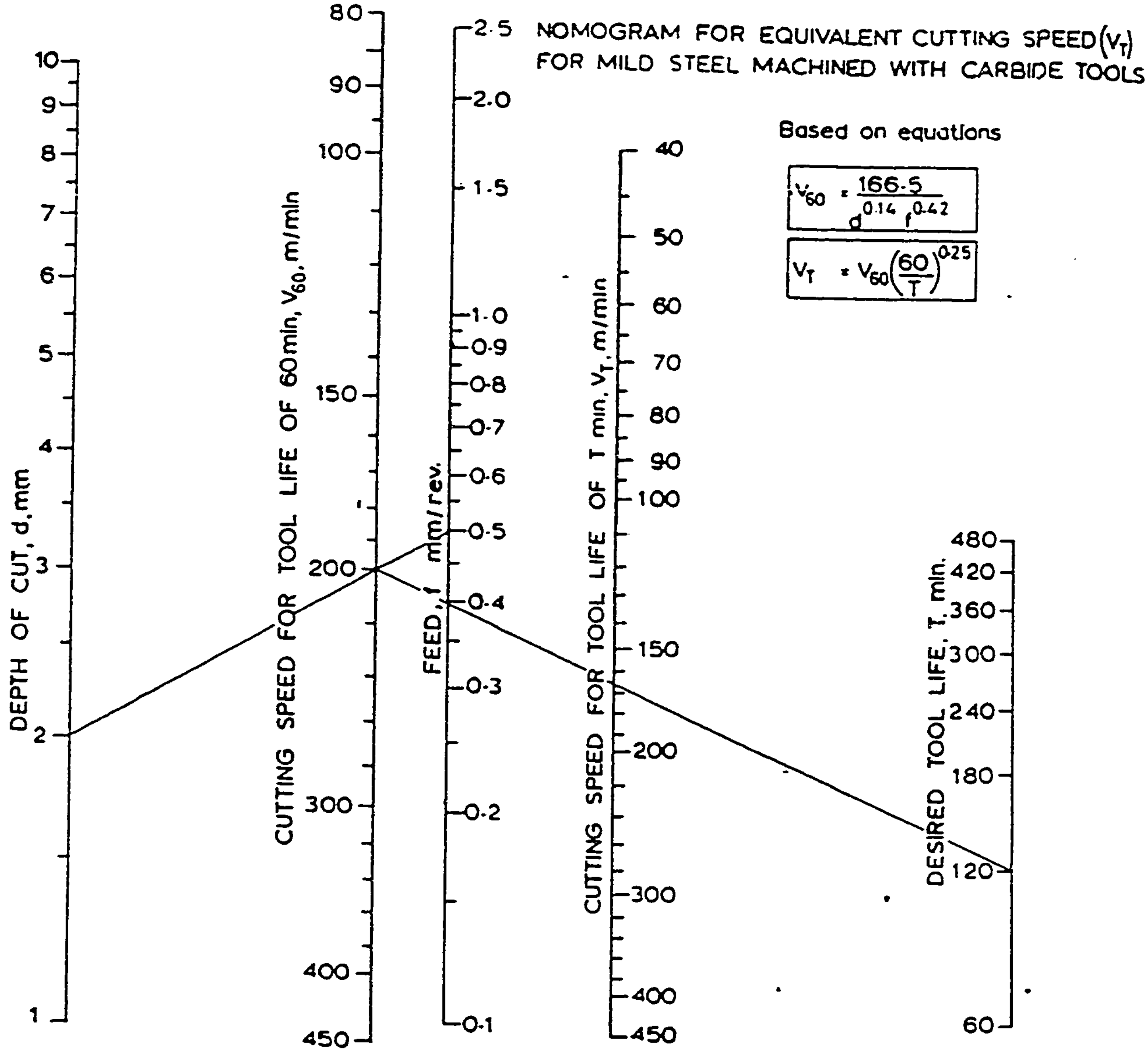


Fig 1.12 Tool life nomogram for mild steel machined with carbide tools [Faculty of Mechanical Engineering (PSG College of Technology), 1989].

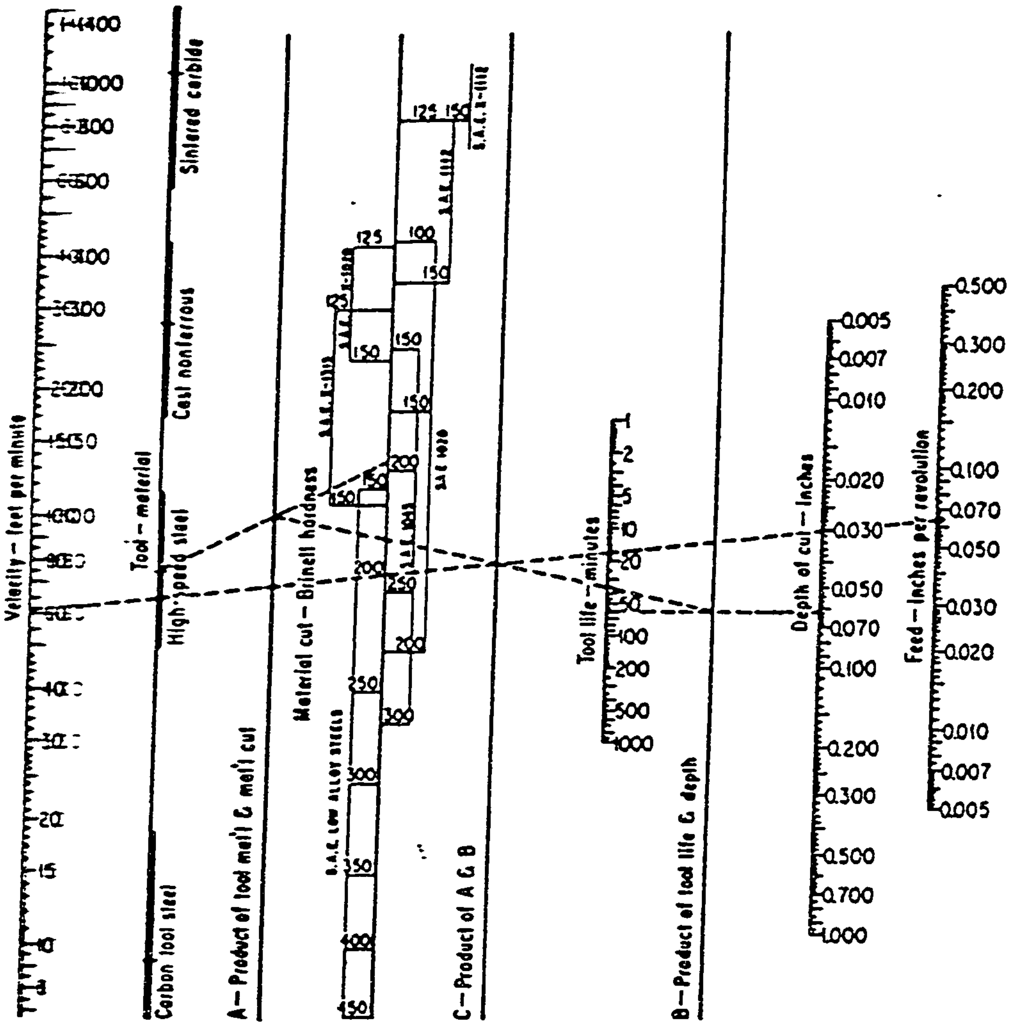


Fig 1.13 Tool life nomogram [Dallas, 1976].

be evaluated.

1.4.2 Fixtures in manufacturing systems

The function of fixtures in manufacturing is to locate and hold parts or workpieces for manufacturing operations. For example, in order to machine a mechanical component on a milling machine, it is necessary to immobilize, support, and locate it in each setup. This is what is refereed to as workholding or, alternatively, fixturing.

Fixtures can be divided into three main categories [Dallas, 1976].

Stationary fixtures

Fixtures that do not index or revolve are considered to be stationary fixtures. The fixture may be mounted on the table of the machine so that it moves to left or right to approach the tools for the operation, or it may be mounted fixed to the base of the machine so that operations are performed by spindles mounted on the slides which approach the fixture. Such fixtures may be of the load and reload type. This means that the part is loaded into one section of the fixture, at which position certain operations are performed and after which the part is reloaded into another section of the fixture for further operations. This can be a useful and economic device for approaching a part in different directions with only one motion of the table or spindle slide, or for performing multiple machining operations involving different directions with only one motion of the table or spindle slide, or for performing multiple machining operations involving different spindles without the need for an indexing mechanism.

Rotating fixtures

Rotating fixtures are fixtures or chucks that are mounted on spindles so that the part itself is rotated about the axis of the spindle. Various surfaces of revolution can thus be generated by tools mounted on the feed slides. The most common is the standard chuck, such as a centralizing jaw or diaphragm type. These are usually power-operated by cylinders at the rear of the spindle, and the chucks are usually of a precision type to achieve the accuracy desired. Many special rotating fixtures and chucks are designed to suit a variety of applications.

Indexing fixtures

Indexing fixtures are fixtures in which it is necessary to move the part, while located and clamped, between two or more located positions on the machine, in order to complete all the operations to be performed. Indexing mechanisms may be part of the fixture itself, or fixtures may be mounted on standard indexing slides or rotary tables.

In addition to the above basic classification, fixtures can also be classified specifically for the type of operations viz. hobbing, precision boring, tapping etc., performed on the part that the fixture holds. Further, fixtures can be classified based on the type of part viz. prismatic parts etc., that they are holding or are intended to hold. Fig 1.14 shows a simple stationary fixture.

1.5 Cellular Manufacturing Systems

Cell formation is an application of the GT philosophy where the manufacturing system,in total or in part, has been converted into cells.

Figure 1.15 shows the difference among the arrangements of machines in flow shop, job shop and CMS type of systems. The cells are designed to allow for efficient flow of parts through the manufacturing system. The aims of cell formation are to reduce setup times (by using part family tooling and family sequencing), to reduce flow

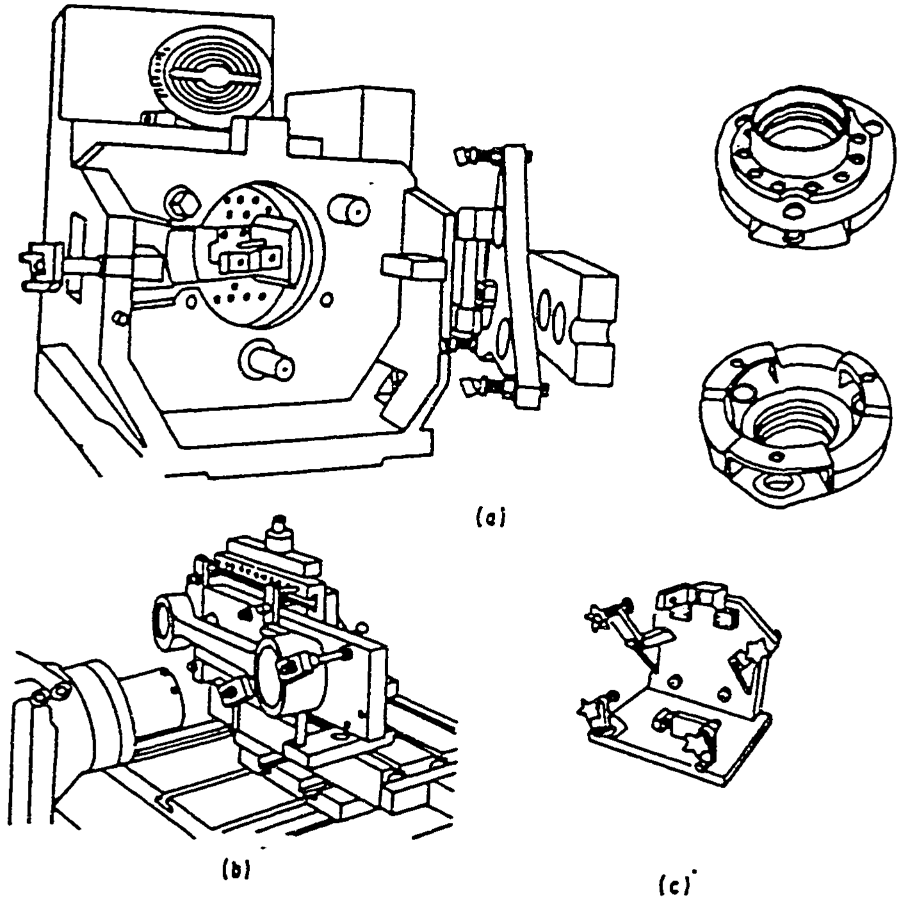


Fig 1.14 Simple stationary fixtures [Dallas, 1976]

a) for planet-pinion carriers, b) for connecting rods, c) has swing clamps

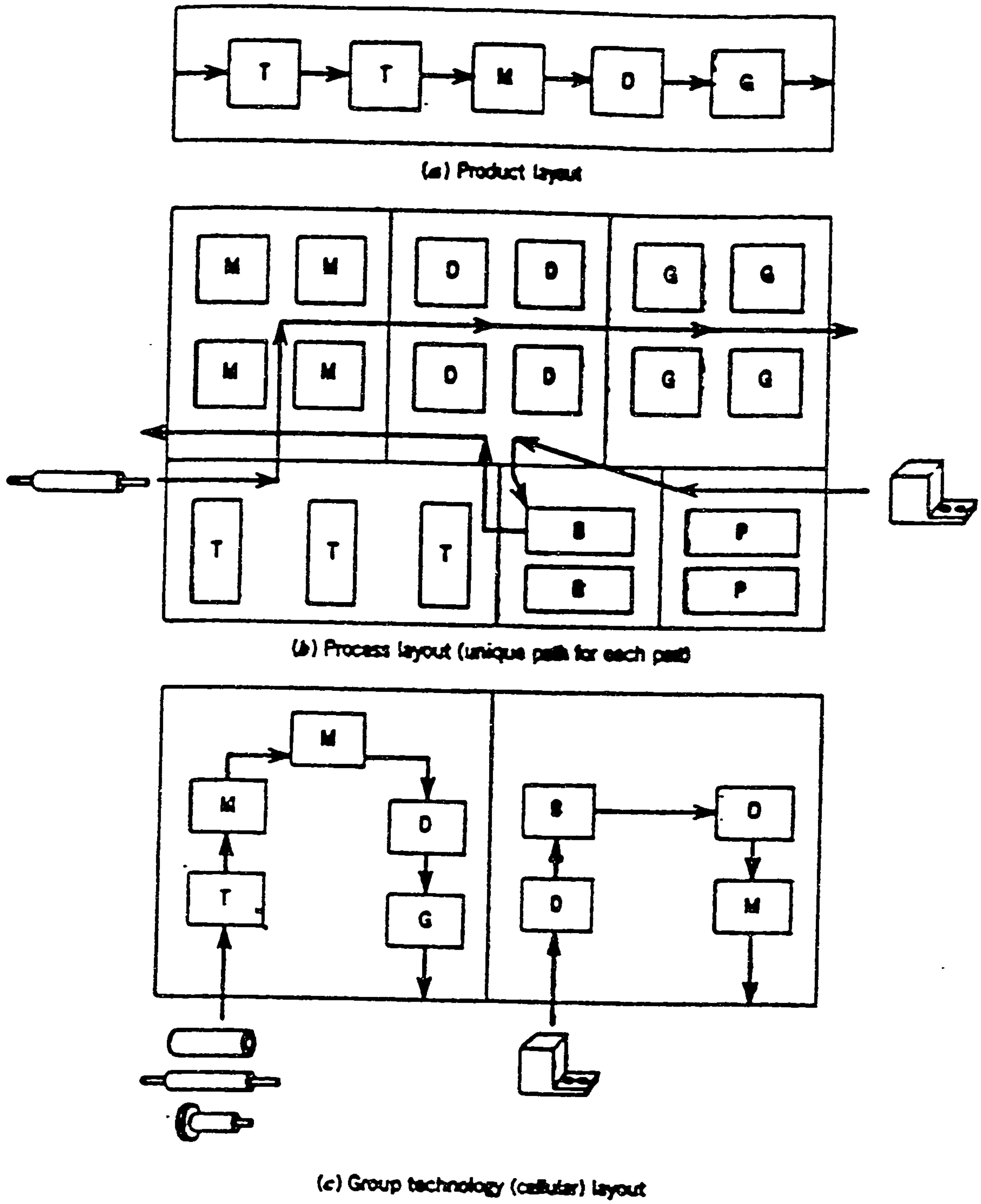


Fig 1.15 Schematic showing the difference between a flow line, job shop and a CMS [Askin and Stanridge, 1993].

times (by reducing setup times, move times, wait times for moves, and the use of small transfer batches) and, therefore, to reduce inventories and market response times.

Basically, manufacturing cells can be divided into four categories [Luggen, 1991],

i) Traditional stand-alone NC machine tool

The stand-alone NC machine tools are characterized as a limited storage, automatic tool changer and are traditionally operated on a one to one machine to operator ratio.

ii) Single NC machine cell or minicell

The single NC machine cells are characterized by an automatic work changer with permanently assigned work pallets or a conveyer-robot arm system mounted to the front of the machine, plus the capability of bulk tool storage. These can be programmed ,loaded, and run unattended for several hours. There can be several single NC machines to operate as a self-contained cell.

iii) Integrated multimachine cell

These are made up of a multiplicity of metal-cutting machine tools, typically all of the same type, which have a queue of parts, either at the entry of the cell or in the front of each machine. Multimachine cells are either serviced by a material-handling robot or parts are palletized in a two- or three-machine, in-line system for progressive movement from one machining station to another. The machines in such a cell can be different and a typical application is high-volume production of a small family of parts.

iv) Flexible Manufacturing Cell (FMC)

FMC is characterized by multi machines, automated random movement of palletized parts to and from processing stations, and central computer control with sophisticated command-driven software. The distinguishing characteristics of this type of cell are the automated flow of raw material to the cell, complete machining of part, part washing, drying, and inspection within the cell, and removal of the finished part.

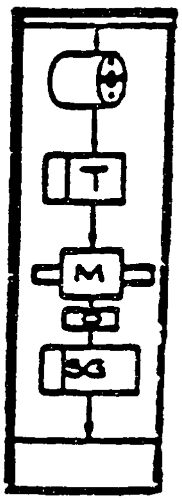
Cells can also be divided into,

a) Formal cells

Formal cells also called actual cells, are manufacturing cells in which the machines are grouped into cells (physically), based on the specific families of parts they manufacture (see Fig. 1.16a).

b) Virtual cell

These cells are not physically constructed grouping of equipments, but are identified paths to selected equipments, through which families of parts will flow. The idea of virtual cells is to reduce the cost of moving the equipment/s that is required in the formal or actual cell concept (see Fig.1.16b).



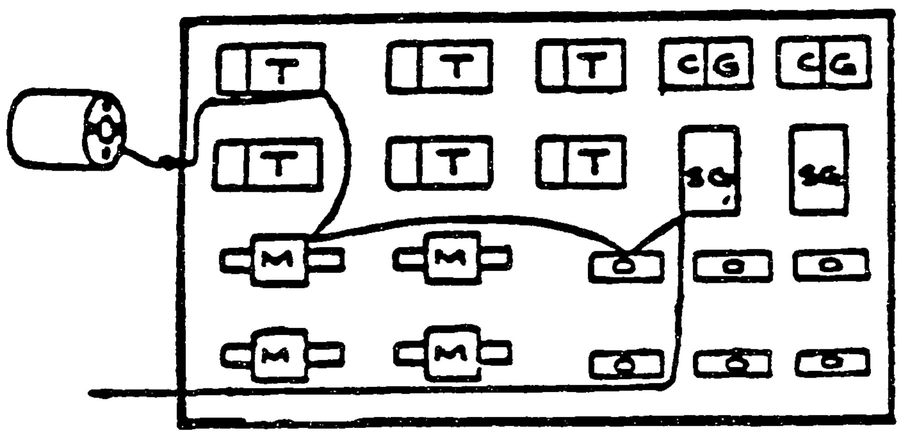


Fig 1.16a Actual cell

Fig 1.16b Virtual cell [Snead, 1989].

CHAPTER 2

LITERATURE REVIEW

In a comprehensive survey of the literature, Offodile et al.(19994), provide a taxonomy of the modelling approaches to the cell formation problem. They state that, in general the objectives of these models are:

* *To minimize intercellular travels*
* *To minimize intracellular travels*
* *To minimize setup time or maximize machine scheduling flexiibility*
* *To maximize similarity (minimize dissimilarity) or compatibility measure*
* *To minimize total production cost*
* *To minimize exceptional elements costs (subcontracting, duplication, or both)*
* *To minimize machine idle time*
* *To maximize machine utilization*

The constraints employed in the models are as follows:

* *Number of groups (cells or part families)*
* *Number of parts per group*
* *Number of machines per group*
* *Machine capacity*
* *Each part, machine, or both belongs to one part family or macchine group*
* *Annual operating budget*

* *Tool or processing requirements of parts*

The other properties of these models are as follows;

Model structure

Matrix formulation: *Similarity coefficient-based, array (sorting) based*

Math programming: *Integer programming, dynamic programming, linear programming*

Graph theory: *Bipartite, other*

Others: *Simulation, expert systems, neural networks, fuzzy sets*

Problem data structure

Binary, weighted and fractional

Clustering problem

Part, machine, concurrent formation of groups

Solution approach

Heuristics

Hierarchial: *Single linkage, average linkage, complete linkage, density seeking, more than two methods*

Non-Hierarchial

Array-based: *Rank ordering, direct clustering, bond energy, cluster identification, occupancy value*

Assignment model

Others: *Linear programming, goal programming, graph partitioning, simulated* *annealing, fuzzy mathematics, (c-mean), expert systems, neural networks*

Decision variables

Number of machines of a given type to be assigned to a given cell

Number of parts or machines assigned to any given cell

Number of operations or tool copies per part per group

Batch size

In this chapter, the relevant literature is broadly classified as i) Approaches employed for the machine-part grouping problem and ii) Literature on tools and tool management in FMS and CMS.

2.1 Approaches employed to solve the machine-part grouping problem

i. Classification and coding approach

ii. Similarity coefficient-based approach

iii. Matrix manipulation approach

iv. Heuristic-based approach

v. Genetic Algorithm-based approach

vi. Network approach

vii. Mathematical programming approach

viii. Expert system-based approach

Due to their relevance to the topic of the thesis mathematical programming approaches will be discussed in detail. However other approaches will be discussed briefly.

i. Classification and coding approach.

The parts classification and coding system groups parts into part families, based on their similarities in design and/or processing (Opitz and Weidahl, 1971; Opitz, 1970). Once the part families are formed the machines are grouped based on their capabilities to process the families; however, this system produces unbalanced loads for finding part families for cellular manufacturing. This is because it groups parts which are similar in design/process but different in batch sizes (Ballakur and Steudel, 1987).

Kusiak (1983) extended the parts classification and coding system for FMS by taking into account the requirements imposed by tools and fixtures for manufacturing a part. He proposed a hierarchical clustering algorithm to form part families. A distance matrix is calculated from the parts code using suitable metrics.

Currie (1992) presented a technique that uses a self-organization neural network model, called the Interactive Activation and Competition (IAC) model. It identifies part families by considering design and manufacturing similarities simultaneously.

ii. Similarity coefficient based approach.

McAuley (1972) defined similarity coefficients as the number of components that visit both pair of machines divided by the number of components which visit at least one of the machines. Using this information the incidence matrix can be transformed to a triangular, machine-by-machine similarity matrix. The similarity coefficients are calculated for every pair of machines based on the production information of parts.

iii. Matrix manipulation Approach

The basic idea of these methods is to arrange the rows and columns of an incidence matrix A in order to bring the non-zero elements around the main diagonal. The matrix A is defined as one in which, each row corresponds to a machine type j. An entry (a_{ij}) will take the value of one if and only if a part type i requires processing by machine type j.

In this technique, the cell formation problem is equivalent to finding a block diagonal form of the matrix A, such that the mutually exclusive families of parts and their corresponding machine groups (cells) are emerged.

Part families and machine groups can be formed either by direct manipulation of the rows and columns of the machine-part matrix successively to form the machine groups and part families, or by indirect manipulation method of working on the (AA^T) matrix to reorder the rows and columns. This method was proposed by King (1980).

Direct manipulation methods

One method developed by King (1980) attempts to determine cells by rank order clustering (ROC) of the machine-component indicator matrix. This clustering technique attempts to create an independent, or near independent, block diagonal structure by repeatedly interchanging columns and rows of a machine-part matrix according to the binary values. The blocks indicate independent groups. The quality of the results of this technique depends strongly on the initial dispersion of the machine-part matrix, and the binary value used for reallocation restricts the size of the problem that the technique can handle.

Indirect manipulation methods

McCormick et al.(1972) developed an algorithm called bond energy algorithm (BEA), which attemps, by means of total bond energy, to identify and exhibit the interrelations within each cell and the associated cell among the clustering groups. A bond is said to exist between each pair of neighbouring rows and columns if the product of their elements is not zero. The BEA begins with an arbitrarily selected column /row, and then places that column/row with the greatest contribution to the total bond energy beside the assigned column/row. The procedure is repeated until all columns and rows are placed. This algorithm can handle problems of any size, because the BEA has nothing to do but calculate the binary values.

iv. Heuristic-based approach.

Purcheck (1985), proposed a method in which part families were formed in terms of the minimum difference between masters and maximum combination of masters (a master is defined as a unique or most complex part that has to be processed in that cell). The heuristic proceeds by computing the master sets and their differences. Then, the corresponding work load is computed and the combination of master sets is revised based on an acceptability criteria.

Ganesh and Srinivasan (1994) developed a heuristic for the cell formation problem. The heuristic considers the p-median cell formation model developed by

Kusiak (1987) to form machine cells. Parts are assigned to the machine cells where they visit maximum number of machines. Finally, an iterative scheme is employed to obtain a solution with high grouping efficacy. The heuristic has been shown to be computationally efficient.

Grznar, et al.(1994) proposed a mixed-integer non-linear programming formulation model for the machine layout problem of CMS. The objectives of the formulation is to minimize a surrogate-weighted cost of intercellular material movement under capacity and part requirement constraints. They also proposed a heuristic solution method to solve the problem.

Lim, et al.(1996) proposed a heuristic-based procedure that uses processing times and demand rates to form production cells. The procedure considers the cell imbalance costs as well as the costs associated with the intercell part movement and intracell processing. The efficiency and effectiveness of the heuristic was compared with other methods and an industrial application was also presented.

v. Genetic Algorithm-based approach.

Ozdemir (1995) proposed mathematical programming models for the design of cellular manufacturing systems. The objective of the models are to minimize the total cost function associated with the design of CMSs, while minimizing exceptional part types and obtaining a balanced machining capacity distribution for single and multi period planning horizons. The mathematical models developed for single period planning horizon considered the economic trade-offs among intercellular movement, machine duplication and subcontracting, whereas the mathematical models developed for multiperiod planning horizon considered the economic trade-offs among intercellular movement, machine duplication, subcontracting and machine cell reconfiguration and recognized the fluctuations in part demand in future periods. To reduce the computational time for large sized problems, a heuristic procedure based on the mathematical models was developed using genetic algorithms.

Joines, et al.(1996) presented an integer program that is solved using Genetic Algorithms to assist in the design of Cellular manufacturing systems. The formulation uses a unique representation scheme for individuals (part/machine partitions) that reduces the size of the cell formation problem and increases the scale of problems that can be solved. This approach offers improved design flexibility by allowing a variety of evaluation functions to be employed and by incorporating design constraints during cell formation.

Su and Hsu (1996) presented a mathematical programming formulation which considers the intercell part flow and the manufacturing cell density for the machine-component grouping problem. They also proposed a two phased Genetic Algorithm to solve the problem. The objective of the algorithm is to minimize intercell part flow subject to capacity constraints. Several important factors like machine duplication, part production volume, machine capacity and operation sequence of parts have been considered in the algorithm. The only assumption to be known in advance is the upper bound of total number of manufacturing cells.

Gupta, et al.(1996) proposed a Genetic Algorithm-based solution approach to address the machine cell-part grouping problem. They considered three different objective functions, i) Minimize total moves (intercell as well as intracell moves), ii) Minimize cell load variation, and iii) Minimize both the above objective functions simultaneously. The total moves were determined as the weighted sum of both intercell and intracell moves.

In the second objective function, cell load variation was minimized to aid the smooth flow of materials inside each cell and was obtained by computing the difference between the workload on the machine and the average load on the cell. The utilization of the workstations in a cell was evaluated and was used in the determination of the best machine cell-part grouping. They also considered the sequence of operations and the impact of the cell layout.

Hwang and Sun (1996) presented a Genetic Algorithm-based heuristic for the group technology cell formation problem. The heuristic incorporated relevant production requirements such as routing sequence, production volume, unit handling size, processing time and cell size. The heuristic consisted of two phases. The first phase was developed based on a genetic algorithm and greedy heuristic to solve the machine grouping problem. Once the machine cells were identified, the second phase was employed to identify the associated part families. The proposed algorithm has flexibility in forming machine cells and part families in the sense that the cell designer can choose the number of cells and the upper limit of the cell size.

vi. Network approach.

Rajagopalan and Batra (1975) proposed a graph theoretic method that uses cliques of the machine-graph as a means of classification. The vertices of this graph are machines, and edges are the similarity coefficients. The clique is the maximum collection of vertices of every pair connected by an edge of the graph.

Malakooti and Yang (1994) developed an unsupervised learning clustering neural network method for designing machine-part cells in CMS. The approach is based on the well known competitive learning algorithm. They used the generalized euclidean distance as similarity measurement and a momentum term in the weight vector updating equations. The cluster structure can be adjusted by changing the coefficients in the generalized euclidean distance. They also developed a neural network clustering system which can be used to cluster the 0-1 matrix into diagonal blocks. The developed neural network clustering system is independent of the initial matrix and gives clear final clustering results which specify the machines and parts in each group. They used the developed neural network clustering system to solve an example, in which the machine-part incidence matrix is to be clustered into diagonal block structure. The computational results were compared with those from the well known rank ordering clustering and direct clustering analysis methods.

Chi and Liu (1995) presented a flexible neural network approach to deal with the generalized machine cell formation problem. The approach considers the information from the part-machine requirement matrix as well as two other extra factors: multiple process plans and sequence of operations. This method is more efficient than the previous artificial neural network approaches, since the previous approaches considered the basic information from the original requirement matrix or involved only one extra practical manufacturing factor. This approach also has the capability of solving large problems quickly, due to the parallel processing capability of neural networks.

vii. Mathematical programming approach.

Kasilingam and Lashkari(1989) presented a methodology to allocate machines to part families on the basis of the tooling requirements of the parts and the tooling available on the machines. These formulations take into account the limitations such as the number of machines in a group and the number of machines of a particular type available, the cost of inter-cell movement and the cost of machine duplication.

Seifoddini (1989) introduced a procedure based on the decomposition of the machine-part matrix to investigate the economic trade-off between machine duplication in cells and inter-cell movement in cell formation. The procedure took into consideration some operational aspects such as production volumes and processing times.

Shtub (1989) introduced an integer programming model to show that the simple cell formation problem is equivalent to the general assignment problem, when each part has a unique process plan. The solution procedure of the model was based on the heuristic sub-gradient algorithm developed by Klastorin(1979).

Lashkari and Kasilingam (1990) proposed a mathematical model for machine allocation to part families in cellular manufacturing systems. Computational refinement of the model based on Lagrangian relaxation approach was introduced to demonstrate the efficiency of the model when it is relaxed. The authors claimed that the Lagrangian relaxation procedure is efficient in terms of CPU time even for large problems.

Rajamani, et al.(1990) developed a mixed integer program for the design of CMS. They assumed that there are alternate process plans for each part and that each operation in these plans can be performed on alternate machines. The objective of the model is to minimize the sum of investment, processing and material handling costs. Processing times, machine capacities and cell size restrictions are considered in the formulation. Part families, machine groups and part plans are identified concurrently. For the efficient solution of the relaxed linear program an efficient column generation scheme is provided. In the problem under consideration columns are generated by solving simple semi-assignment problems. Three different strategies are tested for generating the columns and the best scheme is selected for subsequent use in the branch and bound procedure developed.

Kim and Yano (1992) presented a nonlinear mathematical programming formulation for part type selection, machine grouping and loading problems. An iterative procedure was then introduced to solve the problems sequentially, with one problem using the solution of the previous one as input.

Damodaran et al.(1992) developed a mathematical model for the simultaneous grouping of machines and assignment of operations of parts to the machine groups. The model identified the cost trade-offs among intercell movements, refixturings and the duplication of machines, while taking into consideration the existence of multiple process plans for each part type.

Rajamani et al.(1992) proposed a mathematical model for the formation of cells, where sequence dependent setup times and costs are significant. The model determines the economic number of cells with the objective of minimizing the sum of total discounted cost of machines assigned to the cells and the setup costs incurred due to sequence dependence of parts in each cell. Machine capacity and precedence relationships of the parts under consideration.

Liang and Taboun (1992) presented a model for the simultaneous selection and the assignment of parts in flexible manufacturing systems with existing layouts, while dealing with exceptional parts and intercell movements. The objective of the model was to maximize the total profit while minimizing the intercell movement costs, machining costs and high penalty costs assigned for the unsatisfied due dates of parts.

Riberio and Pradin (1993) proposed a two-phased methodology to organize jobshop production systems into cellular manufacturing systems. The first phase of the methodology selects the machines to be kept on the shop floor and assigns parts to the machines retained by taking into account the machining capacity and the demand for the parts. The second phase establishes a partition of the set of parts and corresponding machine cells and reassigns some of the operations with the objective of eliminating some intercell movements of the parts.

Liang (1994) proposed a two stage approach to jointly solve part selection, machine loading and machine speed selection problems in flexible manufacturing systems. In the first stage, a mathematical model is developed to solve the part selection and machine loading problem with the objective of minimizing the system output (e.g. production quantity, dollar value of the parts produced). Available machining capacity and magazine capacity constraints are considered. In the second stage, a mathematical model is employed to find the optimal cutting speed for all possible jobs, tools and machines combinations. The objective of this model is to minimize the sum of labour, capital, machining overhead and tool costs. Available machining time is the only constraint.

Zhu et al.(1995) presented a zero-one integer linear programming formulation of the cell formation problem. The formulation had a lean structure and aims at maximizing the opportunity costs of the parts that are to be produced. The formulation is computationally efficient and effective for determining the optimal solutions to medium-sized problems. To solve larger problems they suggested the use of problem-size reduction techniques. But the formulation does not consider several of the important factors in cell design, such as material handling costs, refixturing costs etc.,

Atmani et al.(1995) developed a mathematical program for the simultaneous formation of cells and the allocation of operations of part types. The model may be used to reorganize an existing manufacturing system into CMS. It may also be used to design new CMSs altogether. In the case of reorganizing the system, the model takes into consideration the cost of machine availability for the part, costs of refixturing and costs of material handling. In the case of designing a new system machine costs too are considered in addition to the costs of machine availability for the part, costs of refixturing and the costs of material handling. A number of illustrative example problems were solved.

Crama and Oosten (1996) reviewed the existing mathematical programming approaches for the formation of production cells as well as their features were discussed. They proposed an alternative model which allows for the formulation of various constraints and grouping efficiency criteria. Finally, some test problems are used to support the claim that this model may be adequate for the solution to optimality of the cell formation problem.

Cao and McKnew (1996) proposed a new optimization model for the design of CMS, it is based on an integer programming formulation that updates some other models by eliminating redundant machine assignment and cost coefficients dependent on cell configuration. To reduce computational burdens, a simplified integer programming model and a decomposition algorithm are proposed. To evaluate the performance of the new model several computer solutions were performed and are discussed.

vi. Expert system based approach.

Basu, et al.(1995) proposed an expert system approach to CMS. The starting point for the expert system is the initial solution generated by traditional mathematical techniques. The expert system then evaluates the primary solutions for feasibility and quality. The evaluation by the expert system is done based on a flexible set of userdriven quantitative and qualitative factors. If the solutions are not satisfactory (infeasible or of low quality), the system suggests modifications.

2.2 Literature on Tools and Tool Management in FMS and CMS

Eversheim et al.(1991) presented a paper that attempts to describe and evaluate the situation and point out some future trends in tool management. Their work was aimed at determining the goals and areas for future research work in tool management.

Pandey and Adhikari (1994) presented a comprehensive expert system design for all the problem-solving aspects of tool selection for turning operations. The problem of tool selection has been attempted as a two phase problem. All tools that meet the requirements of the operation are listed in the first phase. The selection of the optimal tool for each operation is then decided in the second phase with the overall optimization strategy. The steps in the first stage are realized by a non-algorithmic expert system technique. In the second phase a decision hierarchy is constructed based on different criteria, and the list of feasible tools from the first phase ranked, using the analytical hierarchy process for integrating both quantitative and qualitative factors as discrete elements in systematically finding the best tool. The tool life has been considered in these models as a constant value for each tool.

Kiran and Krason (1988) described the various methods designed for tool transport/changing, tool identification/recognition, tool monitoring, tool storage and tool management in FMS. The focus was on prismatic parts run on milling centres. They have defined the tool life indirectly as the time when the tool is incapable of holding geometric tolerances and finishes and considered to be worn.

Gyampah and Meredith (1996) described three heuristics that can be used to allocate tools to an FMS. The three heuristics are then evaluated through a simulation study, for an FMS. They have assumed the tool life to be exponentially distributed with a typical mean of 30 minutes.

2.3 MOTIVATION FOR THE RESEARCH

In the literature surveyed, the machine grouping and parts allocation for cellular manufacturing systems has been attempted using various approaches. The parts-allocation and machine grouping have been achieved either simultaneously or sequentially. Also, with few exceptions, such important factors as refixturing costs, material handling costs, unutilized machines etc., have been ignored. There is no model that considers tooling during the design, which is a significant cost in the manufacturing systems. Moreover some of the models lack robustness and the capability to solve very large industrial problems. Another factor that has been ignored is the changeover or rearrangement of existing manufacturing facilities into cellular manufacturing systems. The research presented in this thesis, is an attempt in these directions.

2.4 OBJECTIVES OF THE PROPOSED RESEARCH

The main objectives of the proposed research is to develop a model for grouping machines into cells, assign tools to the machines and to allocate operations of parts to the machine-tool combinations.

The following factors have been taken into consideration:

i. Refixturing costs.

ii. Inter and Intra-cell material handling costs.

iii. Operation costs.

iv. Machine capacity and tool life.

v. Batch size of each part type (demand).

CHAPTER 3

MODEL DEVELOPMENT

In this chapter the mathematical models are presented. The notation and the assumptions used are first described, followed by the development of the mathematical models.

3.1 Notations and assumptions

The notation used is as follows.

a. Index set

$j \in (1,2,..., n)$ machine index

$i \in (1,2,..., m)$ part type index

$c \in (1,2,..., C)$ cell index

$p \in (1,2,..., P(i))$ process plans for part type i

$s \in (1,2,..., S(ip))$ operations for part type i under process plan p

$t \in (1,2,..., \tau)$ tool index

(i,p) represents part type i processed under process plan p

(j,t) represents the allocation of tool t to machine j

b. Decision variables

Z(ip)=1 if part type i is processed under process plan p; 0 otherwise.

$\mathbf{X_{sjtc}(ip)}$=1 if operation s of (i, p) is assigned to (j,t) in cell c. ; 0 otherwise.

$\mathbf{Y_{sjtc\hat{j}\hat{t}\hat{c}}(ip)}$, the linearization variable =1 if operation s+1 of (i,p), assigned to $(\hat{j},\hat{t})$ in cell $\hat{c}$, is the successor to operation s of (i, p), assigned to (j, t) in cell c; 0 otherwise.

$\mathbf{M}_{jtc}$ =1 if tool t is assigned to machine j in cell c; 0 otherwise.

c. Parameters

$\mathbf{T}_{sjt}\mathbf{(ip)}$ = time to perform operation s of (i,p), assigned to (j,t).

$\mathbf{C}_{sjt}\mathbf{(ip)}$ = cost (per unit) to perform operation s of (i,p), assigned to (j,t).

$\gamma_{sjt}\mathbf{(ip)}$ = refixturing time for operation s of (i,p), assigned to (j,t).

$\mathbf{R}_{sjt}\mathbf{(ip)}$ = refixturing cost (per unit) for operation s of (i,p), assigned to (j,t).

$\zeta_{ij\hat{j}}$ = material handling cost (per unit) of part type i from machine j to machine $\hat{j}$.

$\mathbf{b}_j$ = available capacity of machine j over the planning period, in time units.

$\mathbf{L}_{st}\mathbf{(ip)}$ = life of tool t when assigned to operation s of (i,p).

$\mathbf{L}_t$ = life of tool t, in time units.

$\mathbf{d}_i$ = demand for part type i during the planning period.

The assumptions used in the development of the models are:

1. There are a set of machines with known capabilities and capacities.
2. There are a given set of part types to be processed, for which the demand is constant and known over the planning period.
3. Each part may have more than one process plan.
4. Each operation of a part type may be done on more than one machine.
5. Tools cannot be shared among machines.
6. Machines and tools are labelled by unit and not by type.
7. The refixturing of the part types is done at work station.

3.2 Mathematical model

The objectives of the model are to select machines, allocate tools to machines, group the machine–tool combinations into cells, and assign operations to the machine–tool combinations, so as to minimize the sum of the operations, material handling, and refixturing costs.

The operation cost is given by,

$$E_1 = \sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S(ip)} \sum_{j=1}^{n} \sum_{t=1}^{\tau} \sum_{c=1}^{C} C_{sjt}(ip) X_{sjtc}(ip)$$

The material handling cost is given by,

$$E_2 = \sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S-1(ip)} \sum_{j=1}^{n} \sum_{\hat{j}=1}^{n} \sum_{t=1}^{\tau} \sum_{\hat{t}=1}^{\tau} \zeta_{i j \hat{j}} X_{sjtc}(ip).X_{(s+1)\hat{j}\hat{t}\tilde{c}}(ip)$$

where The function E'_2 is a nonlinear function, which is linearized, using the technique given in Taha(1992), as follows. The product term $X_{sjtc}(ip).X_{(s+1)\hat{j}\hat{t}\tilde{c}}(ip)$ is replaced by a new 0–1 variable $Y_{sjt\hat{j}\hat{t}\tilde{c}}(ip)$, called the linearization variable, i.e., $Y_{sjt\hat{j}\hat{t}\tilde{c}}(ip) = X_{sjtc}(ip).X_{(s+1)\hat{j}\hat{t}\tilde{c}}(ip)$. In addition, two constraint sets are also added which ensure that the new variable takes on the value of 1 when both $X_{sjtc}(ip)$ and $X_{(s+1)\hat{j}\hat{t}\tilde{c}}(ip)$ are equal to 1, and zero otherwise. Thus equation E'_2 is replaced with,

$$E_2 = \sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S-1(ip)} \sum_{j=1}^{n} \sum_{\hat{j}=1}^{n} \sum_{t=1}^{\tau} \sum_{\hat{t}=1}^{\tau} \zeta_{i j \hat{j}} Y_{sjtc\hat{j}\hat{t}\tilde{c}}(ip)$$

The Refixturing cost is given by,

$$E_3 = \sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S(ip)} \sum_{j=1}^{n} \sum_{t=1}^{\tau} \sum_{c=1}^{C} R_{sjt}(ip) X_{sjtc}(ip)$$

The objective function now is to minimize,

$Z = E_1 + E_2 + E_3$,

i.e., to minimize,

$$Z=\sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S(ip)} \sum_{j=1}^{n} \sum_{t=1}^{\tau} \sum_{c=1}^{C} C_{sjt}(ip) X_{sjtc}(ip)$$

$$+\sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S-1(ip)} \sum_{j=1}^{n} \sum_{\bar{j}=1}^{n} \sum_{t=1}^{\tau} \sum_{\bar{t}=1}^{\tau} \zeta_{ij\bar{j}} Y_{sjtc\bar{j}\bar{t}\bar{c}}(ip)$$

$$+\sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S(ip)} \sum_{j=1}^{n} \sum_{t=1}^{\tau} \sum_{c=1}^{C} R_{sjt}(ip) X_{sjtc}(ip)$$

This can also be written as,

$$Z=\sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S-1(ip)} \sum_{j=1}^{n} \sum_{\bar{j}=1}^{n} \sum_{t=1}^{\tau} \sum_{\bar{t}=1}^{\tau} \zeta_{ij\bar{j}} Y_{sjtc\bar{j}\bar{t}\bar{c}}(ip)$$

$$+\sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S(ip)} \sum_{j=1}^{n} \sum_{t=1}^{\tau} \sum_{c=1}^{C} [C_{sjt}(ip)+R_{sjt}(ip)] X_{sjtc}(ip) \qquad (3.1)$$

The constraints are as follows.

a) The first set of constraints ensures that each part type is processed under a single process plan:

$$\sum_{p=1}^{P(i)} Z(ip)=1, \quad \forall i \qquad (3.2)$$

b) The second constraint set specifies that, once a process plan is selected for a part type, each operation in the plan is assigned to a single machines–tool combination assigned to a particular cell:

$$\sum_{j=1}^{n} \sum_{t=1}^{\tau} \sum_{c=1}^{C} X_{sjtc}(ip)=Z(ip), \quad \forall (i,p,s) \qquad (3.3)$$

c) The next set of constraints ensure that the operations assigned to a machine do not load it beyond its capacity:

$$\sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S(ip)} \sum_{t=1}^{\tau} \sum_{c=1}^{C} X_{sjtc}(ip)[T_{sjt}(ip)+\gamma_{sjt}(ip)] \leq b_j, \quad \forall j \tag{3.4}$$

d) The next set of constraints ensure that each tool is assigned to only one machine in one cell:

$$\sum_{j=1}^{n} \sum_{c=1}^{C} M_{jtc} \leq 1, \quad \forall t \tag{3.5}$$

e) To ensure that the total time of operations assigned to a particular machine–tool combination in a cell does not exceed the tool life, we need the following constraint set:

$$\sum_{i=1}^{m} d_i \sum_{p=1}^{P(i)} \sum_{s=1}^{S(ip)} \sum_{c=1}^{C} X_{sjtc}(ip)[T_{sjt}(ip)+\gamma_{sjt}(ip)] \leq L_t \sum_{c=1}^{C} M_{jtc}, \quad \forall (t,j) \tag{3.6}$$

f) The linearization constraints are represented as:

$$X_{sjtc}(ip) + X_{(s+1)\hat{j}\hat{t}\hat{c}}(ip) - 2Y_{sjtc\hat{j}\hat{t}\hat{c}}(ip) \geq 0 \ , \quad \forall (i,p,s \in [1,2,\ldots,S(ip)-1], j, \hat{j}, c, \hat{c}, t, \hat{t}) \tag{3.7}$$

$$X_{sjtc}(ip) + X_{(s+1)\hat{j}\hat{t}\hat{c}}(ip) - Y_{sjt\hat{j}\hat{t}\hat{c}}(ip) \leq 1 \ , \quad \forall (i,p,s \in [1,2,\ldots,S(ip)-1], j, \hat{j} t, \hat{t}, c, \hat{c}) \tag{3.8}$$

g)The last constraint set indicates the binary nature of the variables:

$$Y_{sjtc\hat{j}\hat{t}\hat{c}}(ip), X_{sjtc}(ip), M_{jtc}, Z(ip) \in [0,1] \quad \forall (i,p,s,j,t,c,\hat{j},\hat{t},\hat{c}) \tag{3.9}$$

CHAPTER 4

COMPUTATIONAL RESULTS

To illustrate the application of the model, a number of examples are presented in this chapter. The solutions are obtained using ILINDO solver.

4.1.1 Example #1

This example concerns the formation of a single cell. In this example we have 13 part types, i = 1,..., 13, to be manufactured, with demands d_i ranging from 10 to 90 units (as shown in Table 4.1.1). Each part type i has a number of different process plans p = 1,2,...,P(i), and each process plan has a number of operations s = 1, 2,..., S(ip), as shown in Table 4.1.1. There are 10 machines denoted by j = 1,..., 10, and 20 tools denoted by t = 1,..., 20. The machine capacities, b_j, range from 250 to 2400 time units. The tool lives denoted by L_t (see Appendix A.2) range from 120 to 800 time units. The capability of the machines and tools to perform the operations of the part types is given as follows: under process plan p=1, part type i=1 has S(ip) = S(11) = 3 operations with indices $s \in \{1,2,3\}$. Operation s = 1 can be completed on machine "1", using any one of the tools $t \in \tau_{ips} = j \in \tau_{111} = \{1,2\}$. Operation s = 2 can be completed on machine "3", using any of the tools $t \in \tau_{ips} = j \in \tau_{112} = \{3,4\}$. Operation s = 3 can be completed on machine "5", using any of the tools $t \in \tau_{ips} = j \in \tau_{113} = \{5,6\}$. The above information as well as the data for all allowable combinations (i,p) are summarized in Table 4.1.1. The Table also contains the values of the operation time $T_{sjt}(ip)$, the operation cost $C_{sjt}(ip)$ and demand of the part types, d_i. The refixturing costs for all combinations of (i,p) is 0$. Table 4.1.2 indicates the intra–cell material handling cost ζ_{ijf}, which is assumed to be the same for all part types. The life of tool 1, when performing operation s = 1, according to processs plan p = 1, of part type

Machines, j	Part types, i									
	1		2			3			4	
	Process plan, p		Process plan, p			Process plan, p			Process plan, p	
	1	2	1	2	3	1	2	3	1	2
1	$10,5^{1}$*					$5,5^{1}$			$5,4^{7}$	
	$5,10^{2}$					$6,5^{2}$			$4,4.5^{13}$	
2		$9,9^{4}$					$10,9^{3}$	$8,9^{13}$		$3,7^{17}$
		$8,10^{3}$					$8,7^{4}$	$9,8^{14}$		$6,5^{14}$
3	$8,4^{3}$	$7,5^{6}$				$10,9^{7}$	$9,10^{9}$	$7,10^{8}$		$10,6^{15}$
	$6,5^{4}$	$8,4^{5}$				$9,10^{9}$	$10,9^{7}$	$11,8^{10}$		$9,7^{16}$
4			$10,5^{9}$	$10,5^{9}$						
			$9,6^{10}$	$9,6^{10}$						
5	$7,6^{5}$	$8,7^{7}$								
	$8,5.5^{6}$	$9,6^{8}$								
6										
7			$9,5^{12}$							
8				$11,5^{6}$	$15,5^{6}$					
				$9,6.5^{8}$	$14,7^{8}$					
9					$13,10^{11}$					
10										$11,4^{15}$
										$8,7^{14}$
Demand, d_i	30		50			60			20	

TABLE 4.1.1 Operation cost, operation times ($C_{ojk}(ip)$, $T_{ojk}(ip)^{l}$) and demand for part types, d_i, for example #1 .

* Operation cost, $C_{ojk}(ip)$ = \$10/unit , Operation time/unit, $T_{ojk}(ip)^{l}$ = 5 time units, l= tool used for the operation

Machines, j	Part types, i: 5 — Process plan, p: 1	5 — 2	6 — 1	6 — 2	6 — 3	7 — 1	7 — 2	8 — 1	8 — 2	9 — 1
1					$8,7^{14}$			$4,3^{1}$		
					$7,8^{15}$			$3,4^{2}$		
2					$9,10^{16}$			$5,4^{3}$		
					$10,9^{17}$			$4,5^{6}$		
3				$4,8^{8}$					$5,5^{3}$	
				$5,9^{10}$					$4,6^{4}$	
4				$5,10^{15}$					$3,3^{15}$	
				$10,5^{16}$					$4,2^{18}$	
5				$3,5^{5}$		$9,8^{7}$				
				$4,6^{6}$		$8,9^{8}$				
6		$15,6^{17}$	$10,5^{17}$				$9,8^{17}$			
			$5,10^{16}$				$8,9^{14}$			
7			$9,4^{12}$							$5,4^{12}$
			$8,5^{13}$							$4,5^{13}$
8	$7,11^{3}$	$8,6^{4}$			$9,10^{20}$		$9,6^{8}$			$3,2^{4}$
	$8,10^{20}$	$9,5^{8}$			$10,9^{19}$		$11,5^{9}$			$2,3^{8}$
9	$10,5^{18}$									
10			$4,9^{16}$			$9,8^{20}$				
			$5,8^{15}$			$8,9^{18}$				
Demand, d_i	30		45			10		90		30

TABLE# 4.1.1(cont.)

Machines, j	Part types, i									bj
	10			11		12		13		
	Process plan, p			Process plan, p		Process plan, p		Process plan, p		
	1	2	3	1	2	1	2	1	2	
1	$5,4^{14}$					$6,5^{9}$		$8,7^{9}$		1000
	$4,5^{15}$					$5,6^{11}$		$7,8^{11}$		
2	$5,5^{17}$	$4,5^{18}$							$6,5^{18}$	430
	$5,6^{20}$	$5,4^{19}$							$5,6^{19}$	
3										2400
4										2000
5		$5,6^{7}$								500
		$6,5^{8}$								
6			$3,2^{10}$							250
			$4,3^{11}$							
7			$5,4^{12}$	$5,4^{12}$	$5,4^{6}$			$6,5^{6}$		830
			$4,5^{13}$	$4,5^{13}$	$3,5^{8}$			$5,6^{8}$		
8									$9,10^{4}$	1000
									$10,9^{8}$	
9										250
10							$10,3^{20}$			500
							$6,5^{18}$			
Demand, d_i	30			20		50		40		

Table 4.1.1 (contd.)

Machines	1	2	3	4	5	6	7	8	9	10
1	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2	0.5	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3	0.5	0.3	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
4	0.5	0.5	0.5	0.0	0.2	0.5	0.5	0.5	0.5	0.5
5	0.5	0.5	0.5	0.2	0.0	0.4	0.5	0.5	0.5	0.5
6	0.5	0.5	0.5	0.5	0.4	0.0	0.3	0.5	0.5	0.5
7	0.5	0.5	0.5	0.5	0.5	0.3	0.0	0.5	0.5	0.5
8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.2	0.5
9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2	0.0	0.3
10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.0

Table 4.1.2 Intra-cell material handling cost for example #1

i = 1, is $L_{st}(ip) = L_{11}(11)$ = 500 time units. The life of tool 1, when performing operation s = 1, according to processs plan p = 1, of part type i = 3, is $L_{st}(ip) = L_{11}(31)$ = 750 time units. The life of tool 1, when performing operation s = 1, according to processs plan p = 1, of part type i = 8, is $L_{st}(ip) = L_{11}(81)$ = 400 time units. Hence the tool life of tool 1, $L_t = L_1$ = minimum value among $L_{11}(11)$, $L_{11}(31)$ and $L_{11}(81)$ = 400 time units. The above information as well the data for all alowable combinations of {i,p,s} are given in Table 4.1.3.

The objective is to assign tools to machines and to allocate operations of part types to the machine–tool combinations.

4.1.2 Analysis of the results for example # 1

Table 4.1.4 displays the results of example #1. It is noted that nine machines will form the cell (machine 10 has been excluded). For example, part type i = 1 will be processed according to process plan p = 1, for which operation s = 1 will be performed on machine 1 using tool 2, operation s = 2 will be perfromed on machine 3 using tool 4, and operation s = 3 will be performed on machine 5 using tool 5. The above information as well as the selection of process plans of the part types, allocation of tools to the machines and the utilization (%) of the machines, for all combinations of (ip) are summarized in Table 4.1.4. The utilization (%) of the tools are summarized in Table 4.1.5.

It may be observed that the utilization of the machines range from 51% to 85%, indicating that the operations of the part types have been allocated in a manner which has utilized the machines to a considerable extent. It can also be noted that no two tools are assigned to the same machine (which was one of the constraints of the model). On observing Table 4.1.5 it can be inferred that the utilization of the tools has been quite high (ranging from 63.1% to

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
1	1	1	1	500	400
	3	1	1	750	
	8	1	1	400	
2	1	1	1	400	375
	3	1	1	375	
	8	1	1	500	
3	1	1	2	670	400
		2	1	400	
	3	2	1	450	
	5	1	1	425	
	8	2	1	700	
4	1	1	2	300	200
		2	1	400	
	3	2	1	200	
	8	2	1	375	
5	1	1	3	600	500
		2	2	500	
	6	2	3	550	
	8	1	2	700	

Table 4.1.3 Table for the evaluation of $L_{st}(ip)$ and L_t for example #1

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
6	1	1	3	800	700
		2	2	750	
	2	2	2	700	
		3	1	775	
	5	2	2	900	
	6	2	3	850	
	7	2	2	700	
	8	1	2	750	
	9	1	2	890	
	11	2	1	1000	
	13	1	2	850	
		2	2	760	
7	1	2	3	600	600
	3	1	2	650	
		2	2	600	
	4	1	1	625	
	7	1	1	700	
	10	2	2	750	

Table 4.1.3 (Contd.,)

Tools t	Part type i	Process plan p	Operation s	$L_{ti}(ip)$	L_t
8	1	2	3	500	500
	2	2	2	550	
		3	1	600	
	3	3	2	650	
	5	2	2	670	
	6	2	1	650	
	7	1	1	500	
		2	2	550	
	9	1	2	560	
	10	2	2	700	
	11	2	1	700	
	13	1	2	700	
		2	2	600	
9	2	1	1	375	350
		2	1	350	
	3	1	2	350	
		2	2	400	
	12	1	1	400	
	13	1	1	435	
10	2	1	1	400	400
		2	2	500	
	3	3	3	600	
	6	2	2	550	
	10	3	3	400	

Table 4.1.3(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
11	2	3	3	150	140
	10	3	3	140	
	12	1	1	170	
	13	1	1	200	
12	2	1	2	300	290
	6	1	2	290	
	9	1	1	290	
	10	3	2	350	
	11	1	1	310	
13	3	3	1	500	500
	4	1	1	550	
	6	1	2	600	
	9	1	1	500	
	10	3	2	670	
	11	1	1	650	
14	3	3	1	160	150
	4	2	1	150	
	6	3	1	200	
	10	1	1	300	

Table 4.1.3(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
15	4	2	2	1000	800
			3	800	
	6	2	2	850	
		1	3	900	
		3	1	900	
	8	2	2	870	
	10	1	1	800	
16	4	2	2	190	170
			3	170	
	6	1	1	200	
			3	250	
		2	1	400	
		3	2	300	
	7	2	2	310	
	8	2	2	175	
17	4	2	1	130	120
	5	2	1	140	
	6	1	1	150	
		3	2	170	
	7	2	1	120	
	10	1	2	120	

Table 4.1.3(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
18	5	1	2	190	160
	7	1	2	200	
	10	2	1	210	
	12	2	1	300	
	13	2	1	160	
19	6	3	3	270	270
	10	2	1	290	
	13	2	1	300	
20	6	3	3	600	500
	7	1	2	650	
	10	1	2	700	
	12	2	1	500	

Table 4.1.3 (cont)

	Part types,i													Machine Utilization (%)
	1	2	3	4	5	6	7	8	9	10	11	12	13	
Process plans →	1	1	1	2	1	2	2	2	1	3	1	1	2	
Machines ↓														
1	*2**		*1*									*9*		*85.0*
2				*14*									*19*	*78.8*
3	*4*		*7*	*16*		*8*		*4*						*72.0*
4		*10*				*15*		*15*						*51.0*
5	*5*					*5*								*81.0*
6							*17*			*11*				*67.2*
7		*12*							*13*	*13*	*13*			*78.3*
8					*3*		*6*		*6*				*6*	*84.0*
9					*18*									*58.8*
10														*00.0*

Table 4.1.4 Results of example #1

* Tool t = 2 is allocated to machine j =1 to perform operation s = 1 of part type i = 1, according to process plan p = 1.

Tools, t	Machine, j	Tool life, Lt Utilized(%)
1*	1	75.0
2	1	80.0
3	8	82.5
4	3	74.8
5	5	80.8
6	8	72.8
7	3	90.0
8	3	72.0
9	1	71.4
10	4	75.0
11	6	63.1
12	7	86.2
13	7	80.0
14	2	66.6
15	4	90.0
16	3	82.3
17	6	66.6
18	9	93.7
19	2	88.8
20	–	00.0

Table 4.1.5 Utilization of the tools for example #1 .

* Tool t =1 is assigned to machine j = 1, and the percentage of it's tool life utilized, L_1 is 75.0 %

93.7%) and there has been only one tool 20 that has not been assigned to any machine.

4.2.1 Example # 2

This example is a variation of example #1, where we again consider thirteen part types to be processed, ten machines and twenty tools. The data for operation costs, operation times, demand for each part type and machine capacities are given in Table 4.2.1, and the data for the tool lives are given in Table 4.2.2. The number of cells to be formed is 1 and the refixturing costs are 0$ for all combinations of (ip). The data for intra-cell material handling costs are assumed to be the same as in example #1.

This example considers a considerably higher level of variations, in the demand for the part types (d_i ranges from 1 to 90 units), as well as in the machine capacities (b_j ranges from 40 to 1300 time units) and in tool lives (L_t ranges from 15 to 800 time units).

4.2.2 Analysis of results for example # 2

The results are summarized in Tables 4.2.3 and 4.2.4. It is observed that nine machines will form a cell (machine 10 has not been assigned to the cell), that the machine utilizations are quite high (ranging from 60.8% to 92.3%), and that each tool has been assigned to one machine only. The high variability in demands for the part types did not cause any difficulty in this case; the demands are satisfied, and the utilization of the machines and tools are within acceptable ranges.

4.3.1 Example #3

In this example we have thirteen part types to be processed, ten machines, and twenty tools, to be allocated to two cells. The data on operation times, operation costs, machine capacity, and demand for the part types, are the same as for example 1, which are summarized in

Machines, j	Part types, i									
	1		2			3			4	
	Process plan, p		Process plan, p			Process plan, p			Process plan, p	
	1	2	1	2	3	1	2	3	1	2
1	$10,5^{1}$					$5,5^{1}$			$5,4^{7}$	
	$5,10^{2}$					$6,5^{2}$			$4,4.5^{13}$	
2		$9,9^{4}$					$10,9^{3}$	$8,9^{13}$		$3,7^{17}$
		$8,10^{3}$					$8,7^{4}$	$9,8^{14}$		$6,5^{14}$
3	$8,4^{3}$	$7,5^{6}$				$10,9^{7}$	$9,10^{9}$	$7,10^{8}$		$10,6^{15}$
	$6,5^{4}$	$8,4^{5}$				$9,10^{9}$	$10,9^{7}$	$11,8^{10}$		$9,7^{16}$
4			$10,5^{9}$	$10,5^{9}$						
			$9,6^{10}$	$9,6^{10}$						
5	$7,6^{5}$	$8,7^{7}$								
	$8,5.5^{6}$	$9,6^{8}$								
6										
7			$9,5^{12}$							
8				$11,5^{6}$	$15,5^{6}$					
				$9,6.5^{8}$	$14,7^{8}$					
9					$13,10^{11}$					
10										$11,4^{15}$
										$8,7^{16}$
Demand, d_i	30		50			60			2	

Table 4.2.1 Operation cost, operation times ($C_{ijk}(ip)$, $T_{ijk}(ip)$) and demand for part types, d_i, for example #2 .

Machines	Part types, i									
	5		6			7		8		9
	Process plan, p		Process plan, p			Process plan, p		Process plan, p		Process plan, p
	1	2	1	2	3	1	2	1	2	1
1					$8,7^{14}$			$4,3^{1}$		
					$7,8^{15}$			$3,4^{2}$		
2					$9,10^{16}$			$5,4^{5}$		
					$10,9^{17}$			$4,5^{6}$		
3				$4,8^{8}$					$5,5^{3}$	
				$5,9^{10}$					$4,6^{4}$	
4				$5,10^{15}$					$3,3^{15}$	
				$10,5^{16}$					$4,2^{16}$	
5				$3,5^{5}$		$9,8^{7}$				
				$4,6^{6}$		$8,9^{8}$				
6		$15,6^{17}$	$10,5^{17}$				$9,8^{17}$			
			$5,10^{16}$				$8,9^{16}$			
7			$9,4^{12}$							$5,4^{12}$
			$8,5^{13}$							$4,5^{13}$
8	$7,11^{3}$	$8,6^{4}$			$9,10^{20}$		$9,6^{8}$			$3,2^{6}$
	$8,10^{20}$	$9,5^{8}$			$10,9^{19}$		$11,5^{6}$			$2,3^{8}$
9	$10,5^{18}$									
10			$4,9^{16}$			$9,8^{20}$				
			$5,8^{15}$			$8,9^{18}$				
Demand, d_i	3		45			1		90		3

Table# 4.2.1(cont.)

Machines, j	Part types, i									bj
	10			11		12		13		
	Process plan, p			Process plan, p		Process plan, p		Process plan, p		
	1	2	3	1	2	1	2	1	2	
1	$5,4^{14}$					$6,5^{9}$		$8,7^{9}$		1000
	$4,5^{15}$					$5,6^{11}$		$7,8^{11}$		
2	$5,5^{17}$	$4,5^{18}$								40
	$5,6^{20}$	$5,4^{19}$							$6,5^{18}$	
									$5,6^{19}$	
3										800
4										230
5		$5,6^{7}$								230
		$6,5^{8}$								
6			$3,2^{10}$							300
			$4,3^{11}$							
7			$5,4^{12}$	$5,4^{12}$	$5,4^{6}$			$6,5^{6}$		300
			$4,5^{13}$	$4,5^{13}$	$3,5^{8}$			$5,6^{8}$		
8									$9,10^{6}$	150
									$10,9^{8}$	
9										450
10							$10,3^{20}$			600
							$6,5^{18}$			
Demand, d_i	3			2		5		4		

Table 4.2.1 (contd.,)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
1	1	1	1	500	400
	3	1	1	450	
	8	1	1	400	
2	1	1	1	400	400
	3	1	1	475	
	8	1	1	500	
3	1	1	2	560	500
		2	1	600	
	3	2	1	550	
	5	1	1	575	
	8	2	1	500	
4	1	1	2	300	300
		2	1	500	
	3	2	1	450	
	8	2	1	375	
5	1	1	3	300	250
		2	2	250	
	6	2	3	450	
	8	1	2	300	

Table 4.2.2 Table for the evaluation of $L_{st}(ip)$ and L_t for example #2

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
6	1	1	3	90	90
		2	2	95	
	2	2	2	100	
		3	1	175	
	5	2	2	200	
	6	2	3	150	
	7	2	2	110	
	8	1	2	150	
	9	1	2	190	
	11	2	1	100	
	13	1	2	120	
		2	2	160	
7	1	2	3	60	10
	3	1	2	15	
		2	2	10	
	4	1	1	25	
	7	1	1	15	
	10	2	2	30	

Table 4.2.2(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
8	1	2	3	50	20
	2	2	2	25	
		3	1	20	
	3	3	2	35	
	5	2	2	40	
	6	2	1	30	
	7	1	1	35	
		2	2	50	
	9	1	2	30	
	10	2	2	20	
	11	2	1	45	
	13	1	2	50	
		2	2	60	
6	2	1	1	875	800
		2	1	850	
	3	1	2	800	
		2	2	900	
	12	1	1	1000	
	13	1	1	935	
10	2	1	1	400	350
		2	2	500	
	3	3	3	350	
	6	2	2	350	
	10	3	3	400	

Table 4.2.2(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
11	2	3	3	15	15
	10	3	3	40	
	12	1	1	25	
	13	1	1	20	
12	2	1	2	300	300
	6	1	2	420	
	9	1	1	310	
	10	3	2	350	
	11	1	1	400	
13	3	3	1	300	300
	4	1	1	450	
	6	1	2	310	
	9	1	1	320	
	10	3	2	370	
	11	1	1	400	
14	3	3	1	260	200
	4	2	1	250	
	6	3	1	200	
	10	1	1	300	

Table 4.2.2(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
15	4	2	2	400	350
			3	500	
	6	2	2	350	
		1	3	370	
		3	1	380	
	8	2	2	470	
	10	1	1	400	
16	4	2	2	490	470
			3	470	
	6	1	1	500	
			3	550	
		2	1	600	
		3	2	480	
	7	2	2	510	
	8	2	2	475	
17	4	2	1	330	305
	5	2	1	305	
	6	1	1	335	
		3	2	325	
	7	2	1	400	
	10	1	2	420	

Table 4.2.2(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
18	5	1	2	90	30
	7	1	2	35	
	10	2	1	40	
	12	2	1	30	
	13	2	1	60	
19	6	3	3	70	35
	10	2	1	40	
	13	2	1	35	
20	6	3	3	400	400
	7	1	2	550	
	10	1	2	450	
	12	2	1	460	

Table 4.2.2(cont)

	Part types													Machine Utilization
	1	2	3	4	5	6	7	8	9	10	11	12	13	
Process plans →	1	1	1	1	2	1	2	2	1	3	1	2	2	
Machines ↓														
1	*2*		*1*	*7*										*60.8*
2													*19*	*60.0*
3	*4*		*9*					*3*						*92.3*
4		*10*						*15*						*71.2*
5	*5*													*78.2*
6					*17*	*17*	*17*			*11*				*86.6*
7		*12*				*13*			*12*	*13*	*13*			*87.2*
8					*6*		*8*		*8*				*6*	*69.0*
9														*00.0*
10				*16*		*16*						*18*		*73.9*
d_i→	30	50	60	2	3	45	1	90	3	3	2	5	4	

Table 4.2.3 Results of example # 2

Tools, t	Machines, j	Percentage of tool life utilized
1	1	75.0
2	1	75.0
3	3	90.0
4	3	50.0
5	5	72.0
6	17	60.0
7	1	76.5
8	8	73.5
9	3	75.0
10	4	85.6
11	6	60.0
12	7	89.0
13	7	83.3
14	–	00.0
15	4	79.9
16	10	89.1
17	6	82.2
18	10	83.1
18	2	68.3
20	–	00.0

Table 4.2.4 Utilization of the tools for example #2 .

in Table 4.1.1. The data on refixturing costs for the various combinations of (i,p) are summarized Table 4.3.1. For example, to perform operation s = 1, of part type i = 1, according to process plan p = 1, on machine j = 1, using tool t = 1, the refixturing cost = $7 and the refixturing time = 4 time units. The data on tool lives are given in Table 4.3.2. The intra–cell material handling cost are the same as in Table 4.1.2, and the inter–cell material handling costs is assumed to be twice the value of the intra–cell cost for the same part type i, machine j, machine $\hat{j}$ combination. The objectives of the model are to assign tools to machines, group the machine–tool combinations into two cells (atmost) and to allocate the operations of the part types to the machine–tool combination.

4.3.2 Analysis of results for example # 3

The results obtained from the solution of this example are summarized in Tables 4.3.3 and 4.3.4. The results indicate that machines 2, 3, 5, 8, 10 will form cell number 1 and machines 1, 4, 6, 7 will form cell 2. Part types, i = 11 and i = 4 are completely processed in cell 2, and part type i = 13 is completely processed in cell 1. All the other part types are partially processed in cell 1 and partially in cell 2.

The inter–cell movement has occurred mainly due to limitations in the capacities of the machines. The utilization of the machines and the tools are quite high (Ranging from 66.0% to 90.0% for machines, and from 60.0 % to 92.3 % for tools).

Machines, j	Part types, i: 1		2			3			4	
	Process plan, p		Process plan, p			Process plan, p			Process plan, p	
	1	2	1	2	3	1	2	3	1	2
1	$7,4^{1}$*					$4,4^{1}$			$3,2^{7}$	
	$4,8^{2}$					$5,3^{2}$			$2,2.5^{13}$	
2		$5,5^{4}$					$5,5^{3}$	$4,5^{13}$		$2,5^{17}$
		$6,5^{3}$					$6,6^{4}$	$7,6^{14}$		$4,4^{14}$
3	$6,3^{3}$	$5,3^{6}$				$7,6^{7}$	$7,5^{9}$	$6,5^{8}$		$6,4^{15}$
	$5,3^{4}$	$5,2^{5}$				$5,4^{9}$	$6,5^{7}$	$6,5^{10}$		$7,4^{16}$
4			$7,4^{9}$	$8,5^{9}$						
			$6,5^{10}$	$7,5^{10}$						
5	$5,4^{5}$	$8,6^{7}$								
	$6,3.5^{6}$	$7,6^{8}$								
6										
7			$6,4^{12}$							
8				$6,2^{6}$	$7,3.5^{6}$					
				$7,3.5^{8}$	$9,6^{8}$					
9					$9.5,6^{11}$					
10										$7.5,5^{15}$
										$6,5^{16}$
Demand, d_i	30		50			60			20	

Table# 4.3.1 Refixturing costs, refixturing times and demand of part types for example #3

* 7 = Refixturing cost in \$, 4 = Refixturing time in time units, 1 = the tool used to perform operation 1 of part type 1, according to process plan 1

Machines, j	Part types, i									
	5		6			7		8		9
	Process plan, p		Process plan, p			Process plan, p		Process plan, p		Process plan, p
	1	2	1	2	3	1	2	1	2	1
1					$5,4^{14}$			$2,1^{1}$		
					$4,3^{15}$			$1,1^{2}$		
2					$5,5^{16}$			$3,2^{5}$		
					$8,5^{17}$			$3,3^{6}$		
3				$3,3^{8}$					$5,5^{3}$	
				$5,4^{10}$					$4,4^{4}$	
4				$5,4^{15}$					$3,3^{15}$	
				$7,4^{16}$					$3,2^{16}$	
5				$3,4^{5}$		$6,5^{7}$				
				$3,2^{6}$		$6,4^{8}$				
6		$8,4^{17}$	$7,5^{17}$				$5,5^{17}$			
			$5,4^{16}$				$5,5^{16}$			
7			$6,4^{12}$							$5,4^{12}$
			$6,5^{13}$							$4,3^{13}$
8	$7,6^{3}$	$8,6^{6}$			$7,6^{20}$		$6,6^{8}$			$3,2^{6}$
	$5,5^{20}$	$6,5^{8}$			$5,4^{19}$		$7,4^{6}$			$2,3^{8}$
9	$6,5^{18}$									
10			$4,3^{16}$			$6,5^{20}$				
			$5,4^{15}$			$5,5^{18}$				
Demand, d_i	30		45			10		90		30

Table# 4.3.1 (cont..)

Machines, j	Part types, i									bj
	10			11		12		13		
	Process plan, p			Process plan, p		Process plan, p		Process plan, p		
	1	2	3	1	2	1	2	1	2	
1	$5,4^{14}$					$4,3^{9}$		$5,4^{9}$		2000
	$4,5^{15}$					$4,2^{11}$		$4,3^{11}$		
2	$4,4^{17}$	$3,2^{18}$							$4,4^{18}$	860
	$3,3^{20}$	$3,3^{19}$							$4,4^{19}$	
3										3000
4										1500
5		$4,3^{7}$								500
		$4,3^{8}$								
6			$3,2^{10}$							1500
			$3,2^{11}$							
7			$4,3^{12}$	$4,3^{12}$	$4,4^{6}$			$5,5^{6}$		1100
			$4,3^{13}$	$4,3^{13}$	$4,4^{8}$			$5,5^{8}$		
8									$6,5^{6}$	2000
									$6,5^{8}$	
9										1000
10							$3,2^{20}$			500
							$3,2^{18}$			
Demand, d_i	30			20		50		40		

Table 4.3.1 (contd.)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
1	1	1	1	900	600
	3	1	1	850	
	8	1	1	600	
2	1	1	1	350	350
	3	1	1	375	
	8	1	1	450	
3	1	1	2	870	1000
		2	1	800	
	3	2	1	950	
	5	1	1	925	
	8	2	1	1000	
4	1	1	2	600	400
		2	1	400	
	3	2	1	500	
	8	2	1	475	
5	1	1	3	600	500
		2	2	550	
	6	2	3	650	
	8	1	2	500	

Table 4.3.2 Table for the evaluation of $L_{st}(ip)$ and L_t for example #3

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
6	1	1	3	1400	1800
		2	2	1750	
	2	2	2	1700	
		3	1	1775	
	5	2	2	1500	
	6	2	3	1450	
	7	2	2	1700	
	8	1	2	1500	
	9	1	2	1400	
	11	2	1	1600	
	13	1	2	1850	
		2	2	1550	
7	1	2	3	1200	1200
	3	1	2	1650	
		2	2	1500	
	4	1	1	1325	
	7	1	1	1200	
	10	2	2	1550	

Table 4.3.2(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
8	1	2	3	500	500
	2	2	2	550	
		3	1	700	
	3	3	2	650	
	5	2	2	710	
	6	2	1	550	
	7	1	1	600	
		2	2	655	
	9	1	2	560	
	10	2	2	700	
	11	2	1	800	
	13	1	2	700	
		2	2	700	
9	2	1	1	700	600
		2	1	850	
	3	1	2	950	
		2	2	700	
	12	1	1	600	
	13	1	1	835	
10	2	1	1	800	800
		2	2	1000	
	3	3	3	1200	
	5	2	2	1050	
	10	3	3	850	

Table 4.3.2(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
11	2	3	3	350	280
	10	3	3	290	
	12	1	1	280	
	13	1	1	300	
12	2	1	2	680	680
	6	1	2	690	
	9	1	1	690	
	10	3	2	780	
	11	1	1	710	
13	3	3	1	650	500
	4	1	1	500	
	6	1	2	500	
	9	1	1	700	
	10	3	2	520	
	11	1	1	650	
14	3	3	1	300	300
	4	2	1	350	
	6	3	1	400	
	10	1	1	300	

Table 4.3.2(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
15	4	2	2	700	600
			3	800	
	6	2	2	850	
		1	3	900	
		3	1	900	
	8	2	2	870	
	10	1	1	600	
16	4	2	2	790	700
			3	840	
	6	1	1	700	
			3	740	
		2	1	700	
		3	2	860	
	7	2	2	870	
	8	2	2	875	
17	4	2	1	1800	1500
	5	2	1	1540	
	6	1	1	1500	
		3	2	1700	
	7	2	1	2300	
	10	1	2	1500	

Table 4.3.2(cont)

Tools t	Part type i	Process plan p	Operation s	$L_{st}(ip)$	L_t
18	5	1	2	320	320
	7	1	2	400	
	10	2	1	370	
	12	2	1	400	
	13	2	1	360	
19	6	3	3	570	540
	10	2	1	540	
	13	2	1	700	
20	6	3	3	600	300
	7	1	2	450	
	10	1	2	300	
	12	2	1	500	

Table 4.3.2(cont)

Cells		Part types													bj# %
		1	2	3	4	5	6	7	8	9	10	11	12	13	
	Process plan	1	2	1	1	2	1	2	2	1	1	1	1	2	
	Machines														
1	2										20*			19	69.7
	3	4		7					3						71.0
	5	5													66.0
	8		6			6		8		8				6	90.0
	10						15						18		81.0
2	1	2		1	13						14		9		77.5
	4		10						16						82.6
	6					17	17	17							92.3
	7						12			12		12			85.0

Table 4.3.3 Results for Example #3

Utilization of machine capaciy (%)

* Operation 1 of part type 10, processed according to process plan 1 is processed using tool 20 is allocated to machine 2, which is assigned to cell 1

Tools, t	Machines, j	Percentage of tool life Utilized (%)
1	1	90.0
2	1	82.0
3	3	90.0
4	3	67.5
5	5	66.0
6	17	84.4
7	3	80.0
8	8	60.0
9	1	75.0
10	4	87.5
11	-	00.0
12	7	86.0
13	7	70.0
14	1	90.0
15	10	67.5
16	4	77.1
17	6	92.3
18	-	00.0
19	2	66.6
20	2	80.0

Table 4.3.4 Utilization of the tools for example #3

5. CONCLUSIONS & DIRECTIONS FOR FUTURE RESEARCH

5.1 Discussions and Conclusions

In this thesis a 0-1 integer programming model has been proposed for the simultaneous grouping of machines into cells, assignment of tool to machines and the allocation of operations of part types to the machine-tool combinations were developed under the following assumptions:

1. There are a set of machines, with known capabilities and capacities.
2. There are a given set of part types to be processed, for which the demand is constant and known over the planning period.
3. Each part type may have more than one process plan.
4. Each operation of a part type may be done on more than one machine.
5. Tools cannot be shared among machines.
6. Machines and tools are labelled by unit and not by type.
7. The refixturing of the part types is done at work station.

The model takes into consideration the important manufacturing aspects which influence cell design, such as material handling cost, operation cost, refixturing cost, processing time, machine capacity, and tool life.

Chapter 1 presented an overview of manufacturing systems, CMS, tools and fixtures in manufacturing, and the design of CMS. Chapter 2 introduces the relevant literature and the methodologies that have been developed in an attempt to solve the cell formation problem, tool management and fixturing in manufacturing systems. It also presents the motivation and the objectives of the proposed research.

The development of the model is presented in Chapter 3. The objectives of the model are to group machines into cells, assign tools to the machines, and allocate operations of part types to these machine-tool combinations while minimizing operation costs, material handling costs (both inter-cell and intra-cell material handling) and refixturing costs. It takes into consideration tooling, tool life, machine capacity, demand for part types, etc.,. To demonstrate the viability of the models, a number of examples have been solved, and the results analyzed and presented in this thesis.

5.2 Directions for future research

The following are the directions/suggestions for future research in this area:

i) The life of the tools can be represented by assigning weightages to the factors that influence tool life, viz., machining speed, brinell hardness of the part type, depth of cut etc.,

ii) Stochastic demands can be accommodated.

iii) Development of a heuristic-based solution procedure to solve the model.

iv) Factors such as the material handling capacity, tool magazine capacity, floor space availability, and budget constraints can be considered.

REFERENCES

1. **Askin G.R and Standridge R.C,** "Modeling and Analysis of Manufacturing Systems", *Wiley, New York, 1993.*
2. **Atmani A., Lashkari R.S., Caron R.J**, "A Mathematical Programming Approach to Joint Cell Formation and Operation Allocation in Cellular Manufacturing", *Int. J. Prod. Res., Vol. 33, No. 1, pp 1-15, 1995.*
3. **Ballakur A. and Steudel H.J.**, "A Within Cell Utilization Based Heuristic For Designing Cellular Manufacturing Systems", *Int. J. Prod. Res. Vol. 25, pp 639-665, 1987.*
4. **Basu A., Hyer N., Shtub A.**, "Expert System Based Approach to Manufacturing Cell Design", *Int. J. Prod. Res., Vol. 33, No. 10, Oct 1995, pp 2739-2755, 1995.*
5. **Cao Q. and McKnew M. A**, "On Modeling the Design of Cellular Manufacturing Systems", *The International Journal of Flexible Manufacturing Systems, Vol. 6, pp 155-172, 1994.*
6. **Chi S. and Liu S.**, "A Flexible Neural Network Approach for Machine Cell Formation", *IEEE Transactions, pp 2064-2069, 1995.*
7. **Chryssolouris G.**, "Manufacturing Systems - Theory and Practice", *Springer-Verlag, 1992.*
8. **Crama Y., Oosten M.**, "Models for Machine-Part Grouping in Cellular Manufacturing", *Int. J. Prod. Res., Vol. 34, No. 6, Jun 1996, pp 1693-1713, 1996.*
9. **Currie K.R.**, "An Intelligent Grouping Algorithm for Cellular

Manufacturing", *Proceedings of the 14th Annual Computers and Industrial Engineering Conference, Orlando, FL, March 9-11, 1992.*

10. **Dallas B.D, Society of Manufacturing Engineers**, " Tool and Manufacturing Engineers Handbook", *Mc Grawhill Book Co., 1976.*

11. **Damodaran V., Lashkari R.S. and Singh N.**, "A Production Planning Model for Cellular Manufacturing Systems with Refixturing Considerations", *Int. J. Prod. Res., Vol. 30, pp 1603-1615, 1992.*

12. **Eversheim W., Kals H. J. J., König W., Luttervelt V. C., Milberg J., Storr A., Tönshoff H. K., Weck M., Weule H., Zbeblick W. J.**, "Tool Management: The Present and the Future", *Annals of the CIRP, Vol. 40, No. 2, 1991.*

13. **Faculty of Mechanical Engineering (PSG College of Technology),** "Design Data", *DPV Printers, Coimbatore, India, 1989.*

14. **Ganesh N. V. and Srinivasan G.**, "Heuristic Algorithm For the Cell Formation Problem", *Comp. and Ind. Engg., Vol. 26, No. 1, Jan. 1994.*

15. **Groover P. M and Zimmers W. E, Jr.**, "CAD/CAM - Computer-Aided Design and Manufacturing", *Prentice Hall, 1984.*

16. **Grznar J., Mehrez A. and Offodile O. F**, "Formulation of Machine Cell Grouping Problem with Capacity and Material Movement Constraints", *Journal of Manufacturing Systems, Vol. 13, No. 4, pp 241-250, 1994.*

17. **Gupta Y., Gupta M., Kumar A. and Sundaram C.**, "A Genetic Algorithm-Based Approach to Cell Composition and Layout Design Problems", *Int. J. Prod.*

Res., Vol. 34, No. 2, pp 447-482, 1996.

18. **Gyampah A. K. and Meredith J. R.**, "A Simulation Study of FMS Tool Allocation Procedures", *Journal of Manufacturing Systems, Vol. 15, No. 6, 1996.*
19. **Hwang H. and Sun J.**, "A Genetic Algorithm-Based Heuristic For the GT Cell Formation Problem", *Computers ind. Engg, Vol. 30, No. 4, pp 941-955, 1996.*
20. **Joines A. J., Thomas C. C and Russell E. K**, "Manufacturing Cell Design: An Integer Programming Model Employing Genetic Algorithms", *IIE Transactions, Vol.28, pp 69-85, 1996.*
21. **Kasilingam R.G. and Lashkari R.S.**, "The Cell Formation in Cellular Manufacturing Systems a Sequential Modelling Approach", *Computers Ind. Engg., Vol. 16, pp 469-476, 1989.*
22. **Kim Y.D. and Yano C.A.**, "An Iterative Approach to system Setup Problems in Flexible Manufacturing Systems", *International Journal of Flexible Manufacturing Systems, Vol. 4, pp 183-209, 1992.*
23. **King J. R.**, "Machine-Component Grouping in Production Flow Analysis: An Approach Using Rank Order Clustering Algorithm", *Int. J. Prod. Res., Vol. 18, pp 213-232, 1980.*
24. **Kiran A. S. and Krason J.R.**, "Automating Tooling In a Flexible Manufacturing System", *Industrial Engineering, pp 52-57, Apr. 1988.*
25. **Klastorin T.D.**, "An Effective Sub-Gradient Algorithm for the Generalized Assignment Problem", *Computers and Operations Research, Vol. 6, pp 155-165,*

1979.

26. **Kusiak A.**, "Part Families Selection Model for Flexible Manufacturing Systems", *Proceedings: Annual Industrial Engineering Conference, Louisville, Kentucky, pp 575-580, 1983.*

27. **Kusiak A.**, "The Generalized GT Concept", *Int. J. Prod. Res., Vol. 25, pp 561-569, 1987.*

28. **Lashkari R.S. and Kasilingam R.G.**, "A Lagrangian Relaxation Approach to Machine Allocation in Cellular Manufacturing Systems", *Computers Ind. Engg., Vol. 19, pp 442-446, 1990.*

29. **Liang M.**, "Integrating Machining Speed , Part Selection and Machine Loading Decisions in Flexible Manufacturing Systems", *Computers Ind. Engg., Vol.26, No. 3, pp 599-608, 1994.*

30. **Liang M. and Taboun S.**, "Part Selection and Part Assignment in Flexible Manufacturing Systems With Cellular Layout", *Computers Ind. Engg., Vol. 23, Nos. 1-4, pp 63-67, 1992.*

31. **Lin T.L., Dessouky M.M., Kumar K.R., Ng Sh N.**, "Heuristic-Based Procedure for the Weighted Production-Cell Formation Problem", *IIE transactions Vol. 28, No. 7, Jul 1996, pp 579-589, 1996.*

32. **Luggen W. W**, "Flexible Manufacturing Cells and Systems", *Prentice Hall, 1991.*

33. **Malakooti B., Yang Z.**, "Unsupervised Neural Network Approach for

Machine-Part Cell Design", *IEEE International Conference On Neural Networks-Conference Proceedings, No. 2, pp 665-670, 1994.*

34. **Martin J. M.**, "Managing Tools Makes the Cell Click", *Manufacturing Engineer, April 1989.*

35. **McAuley J.**, "Machine Grouping For Efficient Production", *The Production Engineer, Vol. 51, pp 53-57, 1972.*

36. **McCormick W.T., Schweitzer P. J. and White W.**, "Problem Decomposition and Data Reorganization by a Clustering Technique", *Operations Research, Vol. 20, pp 992-1009, 1972.*

37. **Offodile O. F., Mehrez A. and Gznar J.**, "Cellular Manufacturing: A Taxonomic Review Framework', *Journal Of Manufacturing Systems, Vol. 13, No. 3, 1994.*

38. **Opitz H.**, "A Classification System to Describe Work Pieces", *Pergamon Press, Oxford, 1970.*

39. **Opitz H. and Weidahl H.P.**, "Group Technology and Manufacturing Systems for Small and Medium Quantity Production", *Int. J. Prod. Res., Vol. 9, pp 181-203, 1971.*

40. **Ozdemir A. A**, "Simultaneous Part Family and Machine Cell Formations in Cellular Manufacturing Systems: An Analytical and Algorithmic Approach", *Masters Thesis, University Of Windsor, 1995.*

41. **Pandey P.C and Adhikari S.**, "Design Of a Knowledge-Based Expert

System For The Selection Of Tools In Turning Operations", *Proc. Fourth Int. FAIM Conf., Virginia Polytechnic Institute and State University, May 1994.*

42. **Purcheck G.**, "Machine-Component Group Formation: A Heuristic Method For Flexible Production Cells and Flexible Manufacturing Systems", *Int. J. Prod. Res., Vol. 23, pp 911-943, 1985.*

43. **Rajagopalan R. and Batra J.L.**, "Design of Cellular Production Systems - A Graph Theoretic Approach", *Int. J. Prod. Res., Vol. 13, pp 567-579, 1975.*

44. **Rajamani D., Singh N. and Aneja Y.P.**, "Integrated Design of Cellular Manufacturing Systems in the Presence of Alternative Process Plans", *Int. J. Prod. Res., Vol. 28, pp 1541-1554, 1990.*

45. **Rajamani D., Singh N. and Aneja Y.P.**, "A Model for Cell Formation in Manufacturing Systems with Sequence Dependence", *Int. J. Prod. Res., Vol. 30, pp 1227-1235, 1992.*

46. **Rembold U., Nnaji B.O. and Storr A.**, "Computer Integrated Manufacturing and Engineering", *Addison-Wesley Publishing Co., 1994.*

47. **Ribeiro F. J. F. and Pradin B.**, "A Methodology for Cellular Manufacturing Design", *Int. J. Prod. Res., Vol. 31, 235-250, 1993.*

48. **Seifoddini H.**, "Duplication Process in Machine Cells Formation in Group Technology", *IIE Transactions, Vol. 21, pp 382-388, 1989.*

49. **Shtub A.**, "Modelling Group Technology Cell Formation as a Generalized Assignment Problem," *Int. J. Prod. Res., Vol. 27, pp 775-782, 1989.*

50. **Snead S. C**, "Group Technology - Foundation for Competitive Manufacturing", *Van Norstrand Reinhold, 1989.*

51. **Su C. and Hsu C.**, "A Two-Phased Genetic Algorithm For the Cell Formation Problem", *Int. J. Ind. Engg., Vol. 3, No.2, pp 114-125, 1996.*

52. **Taha H. A.**, "Introduction to Operations Research (1992)", *MacMillan Publishers, NewYork.*

53. **Talavage J. and Hannam R.G.**, "Flexible Manufacturing Systems in Practice: Applications, Design & Simulation", *Marcel Dekker Inc., 1988.*

54. **Zhu Z., Heady R. B and Reiners S.**, "An Efficient Zero-One Formulation of the Cell Formation Problem", *Computers ind. Engg. Vol.28, No. 4, pp 911-916, 1995.*

APPENDICES

A.1 Linearizing nonlinear terms in the 0-1 integer programming model

To linearize the nonlinear terms in the 0-1 integer programming model, the linearization method by Taha(1992) is adopted, this method is explained below.

Consider the product term $X_{sjtc}(ip).X_{(s+1)\hat{j}\hat{t}\hat{c}}(ip)$, where $X_{sjtc}(ip)$ and $X_{(s+1)\hat{j}\hat{t}\hat{c}}(ip)$ are binary variables. Each product term is replaced by a continuous linearization variable $Y_{sjt\hat{j}\hat{t}\hat{c}}(ip)$; i.e., $Y_{sjt\hat{j}\hat{t}\hat{c}}(ip) = X_{sjtc}(ip).X_{(s+1)\hat{j}\hat{t}\hat{c}}(ip)$, then the term $Y_{sjt\hat{j}\hat{t}\hat{c}}(ip)$ is also a binary variable. However, to ensure that $Y_{sjt\hat{j}\hat{t}\hat{c}}(ip) = 1$ when both $X_{sjtc}(ip)$ and $X_{(s+1)\hat{j}\hat{t}\hat{c}}(ip)$ equal one, and zero otherwise, the following constraints are introduced:

$$X_{sjtc}(ip)+X_{(s+1)\hat{j}\hat{t}\hat{c}}(ip)-2Y_{sjtc\hat{j}\hat{t}\hat{c}}(ip)\geq 0,\ \forall i,p,s\in[1,2,....,S(ip)-1],j\in J_{ips},\hat{j}\in J_{ip(s+1)},t\in\tau_{ips},\hat{t}\in\tau_{ip(s+1)},c,\hat{c}$$

$$X_{sjtc}(ip)+X_{(s+1)\hat{j}\hat{t}\hat{c}}(ip)-Y_{sjtc\hat{j}\hat{t}\hat{c}}(ip)\leq 1,\ \forall i,p,s\in[1,2,....,S(ip)-1],j\in J_{ips},\hat{j}\in J_{ip(s+1)},t\in\tau_{ips},\hat{t}\in\tau_{ip(s+1)},c,\hat{c}$$

$$Y_{sjtc\hat{j}\hat{t}\hat{c}}(ip),X_{sjtc}(ip)\in 0,1,\ \forall i,p,s,j,t,\hat{j},\hat{t},c,\hat{c}$$

The above constraints force the variable $Y_{sjt\hat{j}\hat{t}\hat{c}}(ip)$ to assume 0-1 values. Therefore, linearization of each term results in an additional binary variable and two additional constraints.

A.2 Evaluation of tool life L_t from $L_{st}(ip)$

In the model presented in this thesis, the tool life is expressed as $L_{st}(ip)$, which is defined as tool life of a tool for a particular operation s done on part type i according to process plan p. Then from these values of $L_{st}(ip)$ for a particular tool t, the minimum value is selected and is denoted as L_t. For example, consider example # 1, the life of tool t = 1, when performing operation s = 1 on part type i = 1, according to process plan p = 1, is $L_{11}(11)$ = 500 time units. Likewise, for that tool, $L_{11}(31)$ = 750, $L_{11}(81)$ = 400. Then for that tool, the minimum of the values of $L_{st}(ip)$ is selected, which is L_1 = 400.

A.3 LINDO CODES

A.4.1 Example # 1 .

```
MIN   300 X1AAA1 + 150 X1ABA1 + 300 X1AAC1 + 360 X1ABC1 + 100 X1AGD1 + 80 X1AMD1 + 360 X1ANF3 + 315 X1AOF3
+ 360 X1AAH1 + 270 X1ABH1 + 150 X1ANJ1 + 120 X1AOJ1 + 300 X1AIL1 + 350 X1AKL1 + 320 X1AIM1 + 280 X1AKM1 + 270
X1BDA2 + 240 X1BCA2 + 600 X1BCC2 + 480 X1BDC2 + 480 X1BMC3 + 40 X1BMD2 + 540 X1BNC3 + 120 X1BND2 + 405 X2BPF3
+ 450 X2BQF3 + 450 X2BEH1 + 360 X2BFH1 + 150 X2BQJ1 + 150 X2BTJ1 + 120 X1BRJ2 + 150 X1BSJ2 + 240 X1BRM2 + 200
X1BSM2 + 240 X2CCA1 + 180 X2CDA1 + 210 X2CFA2 + 240 X2CEA2 + 600 X2CGC1 + 540 X2CIC1 + 540 X2CIC2 + 600 X2CGC2
+ 420 X2CHC3 + 660 X2CJC3 + 200 X2COD2
    + 180 X2CPD2 + 180 X1CHF2 + 225 X1CJF2 + 450 X1CCH2 + 360 X1CDH2
    + 500 X1DIB1 + 450 X1DJB1 + 500 X1DIB2 + 450 X1DJB2 + 180 X2DOF2
    + 225 X2DPF2 + 270 X2DOH2 + 360 X2DPH2 + 210 X3EEA1 + 260 X3EFA1
    + 240 X3EGA2 + 270 X3EHA2 + 135 X3EEF2 + 180 X3EFF2 +  90 X1EGG1
    + 80 X1EHG1  + 150 X2EGJ2 + 180 X2EHJ2 + 450 X1FQE2 + 450 X1FQF1
    + 225 X1FPF1 +  90 X1FQG2  + 80 X1FPG2 +  90 X1FJJ3 +  12 X1FKJ3
    + 450 X2GLB1 + 405 X2GLF1 + 360 X2GMF1 + 150 X1GLI1 + 120 X1GMI1
    + 150 X2GLJ3 + 120 XGMJ3  + 100 X1GLK1 + 80 X1GMK1  + 100 X1GFK2
    + 60 X1GHK2  + 240 X2GFM1 + 240 X2GHM1 + 540 X2HFB2 + 450 X2HHB2
    + 750 X1HFB3 + 700 X1HHB3 + 210 X1HCE1 + 240 X1HTE1 + 240 X2HFE2
    + 270 X2HHE2 + 405 X3HTF3 + 450 X3HSF3 + 110 X2HFG2 +  90 X2HHG2
    + 90 X2HFI1  +  60 X2HHI1 + 360 X2HFM2 + 400 X2HHM2 + 650 X2IKB3
    + 300 X2IRE1 + 220 X2JOD1 + 160 X2JPD1 + 180 X3JPF1 + 225 X3JOF1
    + 90 X2JTG1  + 80 X2JRG1  + 500 X1JTL2 + 300 X1JRL2 + 15 Y1AACCA1
    + 15 Y1AACDA1 + 15 Y1ABCCA1 + 15 Y1ABCDA1 + 15 Y2CCEEA1 + 15 Y2CCEFA1
    + 15 Y2CDEFA1 +    Y2CDEEA1 + 9  Y1BDCFA2 + 9  Y1BDCEA2 +  9 Y1BCCEA2
    + 9 Y1BCCFA2  + 15 Y2CFEGA2 + 15 Y2CFEHA2 + 15 Y2CEEGA2 + 15 Y2CEEHA2
    + 25 Y1DIGLB1 + 25 Y1DJGLB1 + 25 Y1DIHFB2 + 25 Y1DIHHB2 + 25 Y1DJHFB2
    + 25 Y1DJHHB2 + 25 Y1HFIKB3 + 25 Y1HHIKB3 + 30 Y1AACGC1 + 30 Y1AACIC1
    + 30 Y1ABCGC1 + 30 Y1ABCIC1 + 18 Y1BCCIC2 + 18 Y1BCCGC2 + 18 Y1BDCIC2
    + 18 Y1BDCGC2 + 18 Y1BMCHC3 + 18 Y1BMCJC3 + 18 Y1BNCHC3 + 10 Y1AGJOD1
    + 10 Y1AGJPD1 + 10 Y1AMJOD1 + 10 Y1AMJPD1 +  6 Y1BMCOD2 +  6 Y1BMCPD2
    +  6 Y1BNCOD2 +  6 Y1BNCPD2  + 6 Y1HCIRE1  +  6 Y1HTIRE1 + 15 Y1FQHFE2
    + 15 Y1FQHHE2 +13.5 Y1FQGLF1 + 13.5 Y1FQGMF1 + 13.5 Y1FPGLF1
    + 13.5 Y1FPGMF1 + 22.5 Y2GLJOF1 + 22.5 Y2GLJPF1 + 22.5 Y2GMJOF1
    + 22.5 Y2GMJPF1 + 22.5 Y1CHDOF2 + 22.5 Y1CHDPF2 + 22.5 Y1CJDOF2
    + 22.5 Y1CJDPF2 + 9 Y2DOEEF2 + 9 Y2DOEFF2 + 9 Y2DPEEF2 + 9 Y2DPEFF2
    + 22.5 Y1ANBQF3 + 22.5 Y1ANBPF3 + 22.5 Y1AOBQF3 + 22.5 Y1AOBPF3
    + 15 Y1EGJTG1 + 5 Y1EGJRG1 + 5 Y1EHJTG1 + 5 Y1EHJRG1 + 5 Y1FQHFG2
    + 5 Y1FQHHG2 + 5 Y1FPHFG2 + 5 Y1FPHHG2 + 45 Y1AABEH1 + 45 Y1AABFH1
    + 45 Y1ABBEH1 + 45 Y1ABBFH1 + 45 Y1CCDOH2 + 45 Y1CCDPH2 + 90 Y1CDDOH2
    + 15 Y1GLHFI1 + 15 Y1GLHHI1 + 15 Y1GMHFI1 + 15 Y1GMHHI1 + 15 Y1ANBQJ1
    + 15 Y1ANBTJ1 + 15 Y1AOBQJ1 + 15 Y1AOBTJ1 + 15 Y1BREGJ2 + 15 Y1BREHJ2
    + 15 Y1BSEGJ2 + 15 Y1BSEHJ2 + 9 Y1FJGLJ3 + 9 Y1FJGMJ3 + 9 Y1FKGLJ3
    + 9 Y1FKGMJ3 + 20 Y1AIGFM1 + 20 Y1AIGHM1 + 20 Y1AKGFM1 + 20 Y1AKGHM1
    + 20 Y1BRHFM2 + 20 Y1BRHHM2 + 20 Y1BSHFM2 + 20 Y1BSHHM2

SUBJECT TO THE FOLLOWING SET OF CONSTRAINTS:
```

CONSTRAINT TO ENSURE THAT ONLY ONE PROCESS PLAN IS SELECTED:

```
   2)  ZA1 + ZA2 =   1
   3)  ZB1 + ZB2 + ZB3 =   1
   4)  ZC1 + ZC2 + ZC3 =   1
   5)  ZD1 + ZD2 =   1
   6)  ZE1 + ZE2 =   1
   7)  ZF1 + ZF2 + ZF3 =   1
   8)  ZG1 + ZG2 =   1
   9)  ZH1 + ZH2 =   1
  10)  ZI1 =   1
  11)  ZJ1 + ZJ2 + ZJ3 =   1
```

12) ZK1 + ZK2 = 1
13) ZL1 + ZL2 = 1
14) ZM1 + ZM2 = 1

CONSTRAINT TO ENSURE THAT ONCE A PROCESS PLAN IS SELECTED, EACH OPERATION IN THE PLAN CAN BE DONE ON ONLY ONE OF THE AVAILABLE MACHINE-TOOL COMBINATIONS:

15) X1AAA1 + X1ABA1 - ZA1 = 0
16) X2CCA1 + X2CDA1 - ZA1 = 0
17) X3EEA1 + X3EFA1 - ZA1 = 0
18) X1BDA2 + X1BCA2 - ZA2 = 0
19) X2CFA2 + X2CEA2 - ZA2 = 0
20) X1DIB1 + X1DJB1 - ZB1 = 0
21) X3EGA2 + X3EHA2 - ZA2 = 0
22) X2GLB1 - ZB1 = 0
23) X1DIB2 + X1DJB2 - ZB2 = 0
24) X1HFB3 + X1HHB3 - ZB3 = 0
25) X2HFB2 + X2HHB2 - ZB2 = 0
26) X2IKB3 - ZB3 = 0
27) X1AAC1 + X1ABC1 - ZC1 = 0
28) X1BCC2 + X1BDC2 - ZC2 = 0
29) X2CGC1 + X2CIC1 - ZC1 = 0
30) X2CIC2 + X2CGC2 - ZC2 = 0
31) X1BMC3 + X1BNC3 - ZC3 = 0
32) X1AGD1 + X1AMD1 - ZD1 = 0
33) X2CHC3 + X2CJC3 - ZC3 = 0
34) X2JOD1 + X2JPD1 - ZD1 = 0
35) X1BMD2 + X1BND2 - ZD2 = 0
36) X1HCE1 + X1HTE1 - ZE1 = 0
37) X2COD2 + X2CPD2 - ZD2 = 0
38) X2IRE1 - ZE1 = 0
39) X1FQE2 - ZE2 = 0
40) X1FQF1 + X1FPF1 - ZF1 = 0
41) X2HFE2 + X2HHE2 - ZE2 = 0
42) X2GLF1 + X2GMF1 - ZF1 = 0
43) X3JPF1 + X3JOF1 - ZF1 = 0
44) X1CHF2 + X1CJF2 - ZF2 = 0
45) X2DOF2 + X2DPF2 - ZF2 = 0
46) X3EEF2 + X3EFF2 - ZF2 = 0
47) X1ANF3 + X1AOF3 - ZF3 = 0
48) X1EGG1 + X1EHG1 - ZG1 = 0
49) X2BPF3 + X2BQF3 - ZF3 = 0
50) X2JTG1 + X2JRG1 - ZG1 = 0
51) X3HTF3 + X3HSF3 - ZF3 = 0
52) X1FQG2 + X1FPG2 - ZG2 = 0
53) X1AAH1 + X1ABH1 - ZH1 = 0
54) X2HFG2 + X2HHG2 - ZG2 = 0
55) X2BEH1 + X2BFH1 - ZH1 = 0
56) X1CCH2 + X1CDH2 - ZH2 = 0
57) X1GLI1 + X1GMI1 - ZI1 = 0
58) X2DOH2 + X2DPH2 - ZH2 = 0
59) X2HFI1 + X2HHI1 - ZI1 = 0
60) X1ANJ1 + X1AOJ1 - ZJ1 = 0
61) X1BRJ2 + X1BSJ2 - ZJ2 = 0
62) X2BQJ1 + X2BTJ1 - ZJ1 = 0
63) X2EGJ2 + X2EHJ2 - ZJ2 = 0
64) X1FJJ3 + X1FKJ3 - ZJ3 = 0
65) X1GLK1 + X1GMK1 - ZK1 = 0
66) X2GLJ3 - ZJ3 + X2GMJ3 = 0
67) X1GFK2 + X1GHK2 - ZK2 = 0
68) X1AIL1 + X1AKL1 - ZL1 = 0
69) X1AIM1 + X1AKM1 - ZM1 = 0

70) X1JTL2 + X1JRL2 - ZL2 = 0
71) X2GFM1 + X2GHM1 - ZM1 = 0
72) X1BRM2 + X1BSM2 - ZM2 = 0
73) X2HFM2 + X2HHM2 - ZM2 = 0

CONSTRAINT ON THE CAPACITY OF MACHINES:

74) 150 X1AAA1 + 300 X1ABA1 + 300 X1AAC1 + 300 X1ABC1 + 80 X1AGD1 + 90 X1AMD1 + 315 X1ANF3 + 360 X1AOF3 + 270 X1AAH1 + 360 X1ABH1 + 120 X1ANJ1 + 150 X1AOJ1 + 250 X1AIL1 + 300 X1AKL1 + 350 X1AIM1 + 400 X1AKM1 <= 1000
75) 270 X1BDA2 + 300 X1BCA2 + 540 X1BCC2 + 420 X1BDC2 + 540 X1BMC3 + 140 X1BMD2 + 480 X1BNC3 + 100 X1BND2 + 450 X2BPF3 + 405 X2BQF3 + 360 X2BEH1 + 450 X2BFH1 + 150 X2BQJ1 + 180 X2BTJ1 + 150 X1BRJ2 + 120 X1BSJ2 + 200 X1BRM2 + 240 X1BSM2 <= 430
76) 120 X2CCA1 + 150 X2CDA1 + 150 X2CFA2 + 120 X2CEA2 + 540 X2CGC1 + 600 X2CIC1 + 600 X2CIC2 + 540 X2CGC2 + 600 X2CHC3 + 480 X2CJC3 + 120 X2COD2 + 140 X2CPD2 + 360 X1CHF2 + 405 X1CJF2 + 450 X1CCH2 + 540 X1CDH2 <= 2400
77) 250 X1DIB1 + 300 X1DJB1 + 250 X1DIB2 + 300 X1DJB2 + 450 X2DOF2 + 225 X2DPF2 + 270 X2DOH2 + 180 X2DPH2 <= 2000
78) 180 X3EEA1 + 165 X3EFA1 + 210 X3EGA2 + 180 X3EHA2 + 225 X3EEF2 + 270 X3EFF2 + 80 X1EGG1 + 90 X1EHG1 + 180 X2EGJ2 + 150 X2EHJ2 <= 500
79) 180 X1FQE2 + 225 X1FQF1 + 450 X1FPF1 + 80 X1FQG2 + 90 X1FPG2 + 60 X1FJJ3 + 90 X1FKJ3 <= 250
80) 250 X2GLB1 + 180 X2GLF1 + 225 X2GMF1 + 120 X1GLI1 + 150 X1GMI1 + 120 X2GLJ3 + 150 XGMJ3 + 80 X1GLK1 + 100 X1GMK1 + 80 X1GFK2 + 100 X1GHK2 + 100 X2GFM1 + 120 X2GHM1 <= 830
81) 250 X2HFB2 + 325 X2HHB2 + 250 X1HFB3 + 350 X1HHB3 + 330 X1HCE1 + 300 X1HTE1 + 180 X2HFE2 + 150 X2HHE2 + 450 X3HTF3 + 405 X3HSF3 + 50 X2HFG2 + 90 X2HHG2 + 60 X2HFI1 + 90 X2HHI1 + 400 X2HFM2 + 360 X2HHM2 <= 1000
82) 500 X2IKB3 + 150 X2IRE1 <= 250
83) 200 X2JOD1 + 350 X2JPD1 + 405 X3JPF1 + 360 X3JOF1 + 80 X2JTG1 + 90 X2JRG1 + 150 X1JTL2 + 250 X1JRL2 <= 500

CONSTRAINT TO ENSURE THAT EACH TOOL IS ASSIGNED TO ONE MACHINE ONLY:

84) MAA <= 1
85) MAB <= 1
86) MBC + MCC + MHC <= 1
87) MBD + MCD <= 1
88) MBF + MCF + MEF + MHF + MGF <= 1
89) MAG + MCG + MEG <= 1
90) MCH + MEH + MGH + MHH <= 1
91) MAI + MCI + MDI <= 1
92) MCJ + MDJ + MFJ <= 1
93) MAK + MFK + MIK <= 1
94) MGL <= 1
95) MAM + MBM + MGM <= 1
96) MAN + MBN <= 1
97) MAO + MCO + MDO + MJO <= 1
98) MBP + MCP + MDP + MFP + MJP <= 1
99) MBQ + MFQ <= 1
100) MBR + MIR + MJR <= 1
101) MBS + MHS <= 1
102) MBT + MHT + MJT <= 1
103) MBE + MCE + MEE <= 1

CONSTRAINT ON THE LIFE OF TOOLS:

104) 150 X1AAA1 + 300 X1AAC1 + 270 X1AAH1 - 400 MAA <= 0
105) 300 X1ABA1 + 300 X1ABC1 + 360 X1ABH1 - 375 MAB <= 0
106) 300 X1BCA2 + 540 X1BCC2 - 400 MBC <= 0
107) 120 X2CCA1 + 450 X1CCH2 - 400 MCC <= 0
108) 150 X2CDA1 + 540 X1CDH2 - 200 MCD <= 0
109) 360 X2BEH1 - 500 MBE <= 0
110) 120 X2CEA2 - 500 MCE <= 0
111) 180 X3EEA1 + 225 X3EEF2 - 500 MEE <= 0
112) 450 X2BFH1 - 700 MBF <= 0
113) 150 X2CFA2 - 700 MCF <= 0
114) 165 X3EFA1 + 270 X3EFF2 - 700 MEF <= 0
115) 250 X2HFB2 + 250 X1HFB3 + 180 X2HFE2 + 50 X2HFG2 + 60 X2HFI1
+ 400 X2HFM2 - 700 MHF <= 0
116) 80 X1GFK2 + 200 X2GFM1 - 700 MGF <= 0
117) 160 X1AGD1 - 600 MAG <= 0
118) 540 X2CGC1 + 540 X2CGC2 - 600 MCG <= 0
119) 210 X3EGA2 + 80 X1EGG1 + 180 X2EGJ2 - 600 MEG <= 0
120) 600 X2CHC3 + 360 X1CHF2 - 500 MCH <= 0
121) 180 X3EHA2 + 90 X1EHG1 + 150 X2EHJ2 - 500 MEH <= 0
122) 100 X1GHK2 + 240 X2GHM1 - 500 MGH <= 0
123) 325 X2HHB2 + 350 X1HHB3 + 150 X2HHE2 + 90 X2HHG2 + 90 X2HHI1
+ 360 X2HHM2 - 500 MHH <= 0
124) 250 X1AIL1 + 280 X1AIM1 - 350 MAI <= 0
125) 600 X2CIC1 + 600 X2CIC2 - 350 MCI <= 0
126) 250 X1DIB1 + 250 X1DIB2 - 350 MDI <= 0
127) 540 X2CJC3 + 405 X1CJF2 - 400 MCJ <= 0
128) 400 X1DJB1 + 400 X1DJB2 - 400 MDJ <= 0
129) 60 X1FJJ3 - 400 MFJ <= 0
130) 300 X1AKL1 + 280 X1AKM1 - 140 MAK <= 0
131) 90 X1FKJ3 - 140 MFK <= 0
132) 500 X2IKB3 - 140 MIK <= 0
133) 250 X2GLB1 + 180 X2GLF1 + 120 X1GLI1 + 120 X2GLJ3 + 80 X1GLK1
- 290 MGL <= 0
134) 95 X1AMD1 - 500 MAM <= 0
135) 540 X1BMC3 + 140 X1BMD2 - 500 MBM <= 0
136) 225 X2GMF1 + 150 X1GMI1 + 100 X1GMK1 + 150 X2GMJ3 - 500 MGM
<= 0
137) 315 X1ANF3 + 120 X1ANJ1 - 150 MAN <= 0
138) 480 X1BNC3 + 100 X1BND2 - 150 MBN <= 0
139) 360 X1AOF3 + 150 X1AOJ1 - 800 MAO <= 0
140) 270 X2DOF2 + 270 X2DOH2 - 800 MDO <= 0
141) 80 X2JOD1 - 800 MJO <= 0
142) 450 X2BPF3 - 170 MBP <= 0
143) 140 X2CPD2 - 170 MCP <= 0
144) 225 X2DPF2 + 180 X2DPH2 - 170 MDP <= 0
145) 450 X1FPF1 + 90 X1FPG2 - 170 MFP <= 0
146) 140 X2JPD1 + 405 X3JPF1 - 170 MJP <= 0
147) 405 X2BQF3 + 150 X2BQJ1 - 120 MBQ <= 0
148) 180 X1FQE2 + 225 X1FQF1 + 90 X1FQG2 - 120 MFQ <= 0
149) 150 X1BRJ2 + 200 X1BRM2 - 160 MBR <= 0
150) 150 X2IRE1 - 160 MIR <= 0
151) 90 X2JRG1 + 250 X1JRL2 - 160 MJR <= 0
152) 120 X1BSJ2 + 240 X1BSM2 - 270 MBS <= 0
153) 405 X3HSF3 - 270 MHS + 330 X1HSE2 <= 0
154) 180 X2BTJ1 - 500 MBT <= 0
155) 300 X1HTE1 + 450 X3HTF3 - 500 MHT <= 0
156) 80 X2JTG1 + 150 X1JTL2 - 500 MJT <= 0
157) 330 X1HCE1 - 400 MHC <= 0

LINEARIZATION CONSTRAINTS:

157) X1AAA1 + X2CCA1 - 2 Y1AACCA1 >= 0

158) X1AAA1 + X2CDA1 - 2 Y1AACDA1 >= 0
159) X1ABA1 + X2CCA1 - 2 Y1ABCCA1 >= 0
160) X1ABA1 + X2CDA1 - 2 Y1ABCDA1 >= 0
161) X2CCA1 + X3EEA1 - 2 Y2CCEEA1 >= 0
162) X2CCA1 + X3EFA1 - 2 Y2CCEFA1 >= 0
163) X2CDA1 + X3EFA1 - 2 Y2CDEFA1 >= 0
164) X2CDA1 + X3EEA1 - 2 Y2CDEEA1 >= 0
165) X1BDA2 + X2CFA2 - 2 Y1BDCFA2 >= 0
166) X1BDA2 + X2CEA2 - 2 Y1BDCEA2 >= 0
167) X1BCA2 + X2CEA2 - 2 Y1BCCEA2 >= 0
168) X1BCA2 + X2CFA2 - 2 Y1BCCFA2 >= 0
169) X2CFA2 + X3EGA2 - 2 Y2CFEGA2 >= 0
170) X2CFA2 + X3EHA2 - 2 Y2CFEHA2 >= 0
171) X2CEA2 + X3EGA2 - 2 Y2CEEGA2 >= 0
172) X2CEA2 + X3EHA2 - 2 Y2CEEHA2 >= 0
173) X1DIB1 + X2GLB1 - 2 Y1DIGLB1 >= 0
174) X1DJB1 + X2GLB1 - 2 Y1DJGLB1 >= 0
175) X1DIB2 + X2HFB2 - 2 Y1DIHFB2 >= 0
176) X1DIB2 + X2HHB2 - 2 Y1DIHHB2 >= 0
177) X1DJB2 + X2HFB2 - 2 Y1DJHFB2 >= 0
178) X1DJB2 + X2HHB2 - 2 Y1DJHHB2 >= 0
179) X1HFB3 + X2IKB3 - 2 Y1HFIKB3 >= 0
180) X1HHB3 + X2IKB3 - 2 Y1HHIKB3 >= 0
181) X1AAC1 + X2CGC1 - 2 Y1AACGC1 >= 0
182) X1AAC1 + X2CIC1 - 2 Y1AACIC1 >= 0
183) X1ABC1 + X2CGC1 - 2 Y1ABCGC1 >= 0
184) X1ABC1 + X2CIC1 - 2 Y1ABCIC1 >= 0
185) X1BCC2 + X2CIC2 - 2 Y1BCCIC2 >= 0
186) X1BCC2 + X2CGC2 - 2 Y1BCCGC2 >= 0
187) X1BDC2 + X2CIC2 - 2 Y1BDCIC2 >= 0
188) X1BDC2 + X2CGC2 - 2 Y1BDCGC2 >= 0
189) X1BMC3 + X2CHC3 - 2 Y1BMCHC3 >= 0
190) X1BMC3 + X2CJC3 - 2 Y1BMCJC3 >= 0
191) X1BNC3 + X2CHC3 - 2 Y1BNCHC3 >= 0
192) X1BNC3 + X2CJC3 - 2 Y1BNCJC3 >= 0
193) X1AGD1 + X2JOD1 - 2 Y1AGJOD1 >= 0
194) X1AGD1 + X2JPD1 - 2 Y1AGJPD1 >= 0
195) X1AMD1 + X2JOD1 - 2 Y1AMJOD1 >= 0
196) X1AMD1 + X2JPD1 - 2 Y1AMJPD1 >= 0
197) X1BMD2 + X2COD2 - 2 Y1BMCOD2 >= 0
198) X1BMD2 + X2CPD2 - 2 Y1BMCPD2 >= 0
199) X1BND2 + X2COD2 - 2 Y1BNCOD2 >= 0
200) X1BND2 + X2CPD2 - 2 Y1BNCPD2 >= 0
201) X1HCE1 + X2IRE1 - 2 Y1HCIRE1 >= 0
202) X1HTE1 + X2IRE1 - 2 Y1HTIRE1 >= 0
203) X1FQE2 + X2HFE2 - 2 Y1FQHFE2 >= 0
204) X1FQE2 + X2HHE2 - 2 Y1FQHHE2 >= 0
205) X1FQF1 + X2GLF1 - 2 Y1FQGLF1 >= 0
206) X1FQF1 + X2GMF1 - 2 Y1FQGMF1 >= 0
207) X1FPF1 + X2GLF1 - 2 Y1FPGLF1 >= 0
208) X1FPF1 + X2GMF1 - 2 Y1FPGMF1 >= 0
209) X2GLF1 + X3JOF1 - 2 Y2GLJOF1 >= 0
210) X2GLF1 + X3JPF1 - 2 Y2GLJPF1 >= 0
211) X2GMF1 + X3JOF1 - 2 Y2GMJOF1 >= 0
212) X2GMF1 + X3JPF1 - 2 Y2GMJPF1 >= 0
213) X1CHF2 + X2DOF2 - 2 Y1CHDOF2 >= 0
214) X1CHF2 + X2DPF2 - 2 Y1CHDPF2 >= 0
215) X1CJF2 + X2DOF2 - 2 Y1CJDOF2 >= 0
216) X1CJF2 + X2DPF2 - 2 Y1CJDPF2 >= 0
217) X2DOF2 + X3EEF2 - 2 Y2DOEEF2 >= 0
218) X2DOF2 + X3EFF2 - 2 Y2DOEFF2 >= 0
219) X2DPF2 + X3EEF2 - 2 Y2DPEEF2 >= 0

220) X2DPF2 + X3EFF2 - 2 Y2DPEFF2 >= 0
221) X1ANF3 + X2BQF3 - 2 Y1ANBQF3 >= 0
222) X1ANF3 + X2BPF3 - 2 Y1ANBPF3 >= 0
223) X1AOF3 + X2BQF3 - 2 Y1AOBQF3 >= 0
224) X1AOF3 + X2BPF3 - 2 Y1AOBPF3 >= 0
225) X1EGG1 + X2JTG1 - 2 Y1EGJTG1 >= 0
226) X1EGG1 + X2JRG1 - 2 Y1EGJRG1 >= 0
227) X1EHG1 + X2JTG1 - 2 Y1EHJTG1 >= 0
228) X1EHG1 + X2JRG1 - 2 Y1EHJRG1 >= 0
229) X1FQG2 + X2HFG2 - 2 Y1FQHFG2 >= 0
230) X1FQG2 + X2HHG2 - 2 Y1FQHHG2 >= 0
231) X1FPG2 + X2HFG2 - 2 Y1FPHFG2 >= 0
232) X1FPG2 + X2HHG2 - 2 Y1FPHHG2 >= 0
233) X1AAH1 + X2BEH1 - 2 Y1AABEH1 >= 0
234) X1AAH1 + X2BFH1 - 2 Y1AABFH1 >= 0
235) X1ABH1 + X2BEH1 - 2 Y1ABBEH1 >= 0
236) X1ABH1 + X2BFH1 - 2 Y1ABBFH1 >= 0
237) X1CCH2 + X2DOH2 - 2 Y1CCDOH2 >= 0
238) X1CCH2 + X2DPH2 - 2 Y1CCDPH2 >= 0
239) X1CDH2 + X2DOH2 - 2 Y1CDDOH2 >= 0
240) X1CDH2 + X2DOH2 - 2 Y1CDDOH2 >= 0
241) X1GLI1 + X2HFI1 - 2 Y1GLHFI1 >= 0
242) X1GLI1 + X2HHI1 - 2 Y1GLHHI1 >= 0
243) X1GMI1 + X2HFI1 - 2 Y1GMHFI1 >= 0
244) X1GMI1 + X2HHI1 - 2 Y1GMHHI1 >= 0
245) X1ANJ1 + X2BQJ1 - 2 Y1ANBQJ1 >= 0
246) X1ANJ1 + X2BTJ1 - 2 Y1ANBTJ1 >= 0
247) X1AOJ1 + X2BQJ1 - 2 Y1AOBQJ1 >= 0
248) X1AOJ1 + X2BTJ1 - 2 Y1AOBTJ1 >= 0
249) X1BRJ2 + X2EGJ2 - 2 Y1BREGJ2 >= 0
250) X1BRJ2 + X2EHJ2 - 2 Y1BREHJ2 >= 0
251) X1BSJ2 + X2EGJ2 - 2 Y1BSEGJ2 >= 0
252) X1BSJ2 + X2EHJ2 - 2 Y1BSEHJ2 >= 0
253) X1FJJ3 + X2GLJ3 - 2 Y1FJGLJ3 >= 0
254) X1FJJ3 - 2 Y1FJGMJ3 + X2GMJ3 >= 0
255) X1FKJ3 + X2GLJ3 - 2 Y1FKGLJ3 >= 0
256) X1FKJ3 - 2 Y1FKGMJ3 + X2GMJ3 >= 0
257) X1AIM1 + X2GFM1 - 2 Y1AIGFM1 >= 0
258) X1AIM1 + X2GHM1 - 2 Y1AIGHM1 >= 0
259) X1AKM1 + X2GFM1 - 2 Y1AKGFM1 >= 0
260) X1AKM1 + X2GHM1 - 2 Y1AKGHM1 >= 0
261) X1BRM2 + X2HFM2 - 2 Y1BRHFM2 >= 0
262) X1BRM2 + X2HHM2 - 2 Y1BRHHM2 >= 0
263) X1BSM2 + X2HFM2 - 2 Y1BSHFM2 >= 0
264) X1BSM2 + X2HHM2 - 2 Y1BSHHM2 >= 0
265) X1AAA1 + X2CCA1 - Y1AACCA1 <= 1
266) X1AAA1 + X2CDA1 - Y1AACDA1 <= 1
267) X1ABA1 + X2CCA1 - Y1ABCCA1 <= 1
268) X1ABA1 + X2CDA1 - Y1ABCDA1 <= 1
269) X2CCA1 + X3EEA1 - Y2CCEEA1 <= 1
270) X2CCA1 + X3EFA1 - Y2CCEFA1 <= 1
271) X2CDA1 + X3EFA1 - Y2CDEFA1 <= 1
272) X2CDA1 + X3EEA1 - Y2CDEEA1 <= 1
273) X1BDA2 + X2CFA2 - Y1BDCFA2 <= 1
274) X1BDA2 + X2CEA2 - Y1BDCEA2 <= 1
275) X1BCA2 + X2CEA2 - Y1BCCEA2 <= 1
276) X1BCA2 + X2CFA2 - Y1BCCFA2 <= 1
277) X2CFA2 + X3EGA2 - Y2CFEGA2 <= 1
278) X2CFA2 + X3EHA2 - Y2CFEHA2 <= 1
279) X2CEA2 + X3EGA2 - Y2CEEGA2 <= 1
280) X2CEA2 + X3EHA2 - Y2CEEHA2 <= 1
281) X1DIB1 + X2GLB1 - Y1DIGLB1 <= 1

282) X1DJB1 + X2GLB1 - Y1DJGLB1 <= 1
283) X1DIB2 + X2HFB2 - Y1DIHFB2 <= 1
284) X1DIB2 + X2HHB2 - Y1DIHHB2 <= 1
285) X1DJB2 + X2HFB2 - Y1DJHFB2 <= 1
286) X1DJB2 + X2HHB2 - Y1DJHHB2 <= 1
287) X1HFB3 + X2IKB3 - Y1HFIKB3 <= 1
288) X1HHB3 + X2IKB3 - Y1HHIKB3 <= 1
289) X1AAC1 + X2CGC1 - Y1AACGC1 <= 1
290) X1AAC1 + X2CIC1 - Y1AACIC1 <= 1
291) X1ABC1 + X2CGC1 - Y1ABCGC1 <= 1
292) X1ABC1 + X2CIC1 - Y1ABCIC1 <= 1
293) X1BCC2 + X2CIC2 - Y1BCCIC2 <= 1
294) X1BCC2 + X2CGC2 - Y1BCCGC2 <= 1
295) X1BDC2 + X2CIC2 - Y1BDCIC2 <= 1
296) X1BDC2 + X2CGC2 - Y1BDCGC2 <= 1
297) X1BMC3 + X2CHC3 - Y1BMCHC3 <= 1
298) X1BMC3 + X2CJC3 - Y1BMCJC3 <= 1
299) X1BNC3 + X2CHC3 - Y1BNCHC3 <= 1
300) X1BNC3 + X2CJC3 - Y1BNCJC3 <= 1
301) X1AGD1 + X2JOD1 - Y1AGJOD1 <= 1
302) X1AGD1 + X2JPD1 - Y1AGJPD1 <= 1
303) X1AMD1 + X2JOD1 - Y1AMJOD1 <= 1
304) X1AMD1 + X2JPD1 - Y1AMJPD1 <= 1
305) X1BMD2 + X2COD2 - Y1BMCOD2 <= 1
306) X1BMD2 + X2CPD2 - Y1BMCPD2 <= 1
307) X1BND2 + X2COD2 - Y1BNCOD2 <= 1
308) X1BND2 + X2CPD2 - Y1BNCPD2 <= 1
309) X1HCE1 + X2IRE1 - Y1HSIRE1 <= 1
310) X1HTE1 + X2IRE1 - Y1HTIRE1 <= 1
311) X1FQE2 + X2HFE2 - Y1FQHFE2 <= 1
312) X1FQE2 + X2HHE2 - Y1FQHHE2 <= 1
313) X1FQF1 + X2GLF1 - Y1FQGLF1 <= 1
314) X1FQF1 + X2GMF1 - Y1FQGMF1 <= 1
315) X1FPF1 + X2GLF1 - Y1FPGLF1 <= 1
316) X1FPF1 + X2GMF1 - Y1FPGMF1 <= 1
317) X2GLF1 + X3JOF1 - Y2GLJOF1 <= 1
318) X2GLF1 + X3JPF1 - Y2GLJPF1 <= 1
319) X2GMF1 + X3JOF1 - Y2GMJOF1 <= 1
320) X2GMF1 + X3JPF1 - Y2GMJPF1 <= 1
321) X1CHF2 + X2DOF2 - Y1CHDOF2 <= 1
322) X1CHF2 + X2DPF2 - Y1CHDPF2 <= 1
323) X1CJF2 + X2DOF2 - Y1CJDOF2 <= 1
324) X1CJF2 + X2DPF2 - Y1CJDPF2 <= 1
325) X2DOF2 + X3EEF2 - Y2DOEEF2 <= 1
326) X2DOF2 + X3EFF2 - Y2DOEFF2 <= 1
327) X2DPF2 + X3EEF2 - Y2DPEEF2 <= 1
328) X2DPF2 + X3EFF2 - Y2DPEFF2 <= 1
329) X1ANF3 + X2BQF3 - Y1ANBQF3 <= 1
330) X1ANF3 + X2BPF3 - Y1ANBPF3 <= 1
331) X1AOF3 + X2BQF3 - Y1AOBQF3 <= 1
332) X1AOF3 + X2BPF3 - Y1AOBPF3 <= 1
333) X1EGG1 + X2JTG1 - Y1EGJTG1 <= 1
334) X1EGG1 + X2JRG1 - Y1EGJRG1 <= 1
335) X1EHG1 + X2JTG1 - Y1EHJTG1 <= 1
336) X1EHG1 + X2JRG1 - Y1EHJRG1 <= 1
337) X1FQG2 + X2HFG2 - Y1FQHFG2 <= 1
338) X1FQG2 + X2HHG2 - Y1FQHHG2 <= 1
339) X1FPG2 + X2HFG2 - Y1FPHFG2 <= 1
340) X1FPG2 + X2HHG2 - Y1FPHHG2 <= 1
341) X1AAH1 + X2BEH1 - Y1AABEH1 <= 1
342) X1AAH1 + X2BFH1 - Y1AABFH1 <= 1
343) X1ABH1 + X2BEH1 - Y1ABBEH1 <= 1

344) X1ABH1 + X2BFH1 - Y1ABBFH1 <= 1
345) X1CCH2 + X2DOH2 - Y1CCDOH2 <= 1
346) X1CCH2 + X2DPH2 - Y1CCDPH2 <= 1
347) X1CDH2 + X2DOH2 - Y1CDDOH2 <= 1
348) X1CDH2 + X2DOH2 - Y1CDDOH2 <= 1
349) X1GLI1 + X2HFI1 - Y1GLHFI1 <= 1
350) X1GLI1 + X2HHI1 - Y1GLHHI1 <= 1
351) X1GMI1 + X2HFI1 - Y1GMHFI1 <= 1
352) X1GMI1 + X2HHI1 - Y1GMHHI1 <= 1
353) X1ANJ1 + X2BQJ1 - Y1ANBQJ1 <= 1
354) X1ANJ1 + X2BTJ1 - Y1ANBTJ1 <= 1
355) X1AOJ1 + X2BQJ1 - Y1AOBQJ1 <= 1
356) X1AOJ1 + X2BTJ1 - Y1AOBTJ1 <= 1
357) X1BRJ2 + X2EGJ2 - Y1BREGJ2 <= 1
358) X1BRJ2 + X2EHJ2 - Y1BREHJ2 <= 1
359) X1BSJ2 + X2EGJ2 - Y1BSEGJ2 <= 1
360) X1BSJ2 + X2EHJ2 - Y1BSEHJ2 <= 1
362) X1FJJ3 + X2GLJ3 - Y1FJGLJ3 <= 1
363) X1FJJ3 - Y1FJGMJ3 + X2GMJ3 <= 1
364) X1FKJ3 + X2GLJ3 - Y1FKGLJ3 <= 1
365) X1FKJ3 - Y1FKGMJ3 + X2GMJ3 <= 1
366) X1AIM1 + X2GFM1 - Y1AIGFM1 <= 1
367) X1AIM1 + X2GHM1 - Y1AIGHM1 <= 1
368) X1AKM1 + X2GFM1 - Y1AKGFM1 <= 1
369) X1AKM1 + X2GHM1 - Y1AKGHM1 <= 1
370) X1BRM2 + X2HFM2 - Y1BRHFM2 <= 1
371) X1BRM2 + X2HHM2 - Y1BRHHM2 <= 1
372) X1BSM2 + X2HFM2 - Y1BSHFM2 <= 1
373) X1BSM2 + X2HHM2 - Y1BSHHM2 <= 1

A.4.2 Example # 2

MIN 300 X1AAA1 + 150 X1ABA1 + 300 X1AAC1 + 360 X1ABC1 + 10 X1AGD1
+ 8 X1AMD1 + 360 X1ANF3 + 315 X1AOF3 + 360 X1AAH1 + 270 X1ABH1
+ 15 X1ANJ1 + 12 X1AOJ1 + 30 X1AIL1 + 35 X1AKL1 + 32 X1AIM1
+ 28 X1AKM1 + 270 X1BDA2 + 240 X1BCA2 + 600 X1BCC2 + 480 X1BDC2
+ 480 X1BMC3 + 4 X1BMD2 + 540 X1BNC3 + 12 X1BND2 + 405 X2BPF3
+ 450 X2BQF3 + 450 X2BEH1 + 360 X2BFH1 + 15 X2BQJ1 + 15 X2BTJ1
+ 12 X1BRJ2 + 15 X1BSJ2 + 24 X1BRM2 + 20 X1BSM2 + 240 X2CCA1
+ 180 X2CDA1 + 210 X2CFA2 + 240 X2CEA2 + 600 X2CGC1 + 540 X2CIC1
+ 540 X2CIC2 + 600 X2CGC2 + 420 X2CHC3 + 660 X2CJC3 + 20 X2COD2
+ 18 X2CPD2 + 180 X1CHF2 + 225 X1CJF2 + 450 X1CCH2 + 360 X1CDH2
+ 500 X1DIB1 + 450 X1DJB1 + 500 X1DIB2 + 450 X1DJB2 + 180 X2DOF2
+ 225 X2DPF2 + 270 X2DOH2 + 360 X2DPH2 + 210 X3EEA1 + 260 X3EFA1
+ 240 X3EGA2 + 270 X3EHA2 + 135 X3EEF2 + 180 X3EFF2 + 9 X1EGG1
+ 8 X1EHG1 + 15 X2EGJ2 + 18 X2EHJ2 + 45 X1FQE2 + 450 X1FQF1
+ 225 X1FPF1 + 9 X1FQG2 + 8 X1FPG2 + 9 X1FJJ3 + 12 X1FKJ3
+ 450 X2GLB1 + 405 X2GLF1 + 360 X2GMF1 + 15 X1GLI1 + 12 X1GMI1
+ 15 X2GLJ3 + 12 XGMJ3 + 10 X1GLK1 + 8 X1GMK1 + 10 X1GFK2
+ 6 X1GHK2 + 24 X2GFM1 + 24 X2GHM1 + 540 X2HFB2 + 450 X2HHB2
+ 750 X1HFB3 + 700 X1HHB3 + 21 X1HCE1 + 24 X1HTE1 + 24 X2HFE2
+ 27 X2HHE2 + 405 X3HTF3 + 450 X3HSF3 + 11 X2HFG2 + 9 X2HHG2
+ 9 X2HFI1 + 6 X2HHI1 + 36 X2HFM2 + 40 X2HHM2 + 650 X2IKB3
+ 30 X2IRE1 + 22 X2JOD1 + 16 X2JPD1 + 180 X3JPF1 + 225 X3JOF1
+ 9 X2JTG1 + 8 X2JRG1 + 50 X1JTL2 + 30 X1JRL2 + 15 Y1AACCA1
+ 15 Y1AACDA1 + 15 Y1ABCCA1 + 15 Y1ABCDA1 + 15 Y2CCEEA1 + 15 Y2CCEFA1
+ 15 Y2CDEFA1 + Y2CDEEA1 + 9 Y1BDCFA2 + 9 Y1BDCEA2 + 9 Y1BCCEA2
+ 9 Y1BCCFA2 + 15 Y2CFEGA2 + 15 Y2CFEHA2 + 15 Y2CEEGA2 + 15 Y2CEEHA2
+ 25 Y1DIGLB1 + 25 Y1DJGLB1 + 25 Y1DIHFB2 + 25 Y1DIHHB2 + 25 Y1DJHFB2
+ 25 Y1DJHHB2 + 25 Y1HFIKB3 + 25 Y1HHIKB3 + 30 Y1AACGC1 + 30 Y1AACIC1
+ 30 Y1ABCGC1 + 30 Y1ABCIC1 + 18 Y1BCCIC2 + 18 Y1BCCGC2 + 18 Y1BDCIC2
+ 18 Y1BDCGC2 + 18 Y1BMCHC3 + 18 Y1BMCJC3 + 18 Y1BNCHC3
+ 1 Y1AGJOD1 + 1 Y1AGJPD1 + 1 Y1AMJOD1 + 1 Y1AMJPD1 + 0.6 Y1BMCOD2 + .6 Y1BMCPD2 + .6 Y1BNCOD2 +
.6 Y1BNCPD2 + .6 Y1HCIRE1 + .6 Y1HTIRE1 + 1.5 Y1FQHFE2
+ 1.5 Y1FQHHE2 + 13.5 Y1FQGLF1 + 13.5 Y1FQGMF1 + 13.5 Y1FPGLF1
+ 13.5 Y1FPGMF1 + 22.5 Y2GLJOF1 + 22.5 Y2GLJPF1 + 22.5 Y2GMJOF1
+ 22.5 Y2GMJPF1 + 22.5 Y1CHDOF2 + 22.5 Y1CHDPF2 + 22.5 Y1CJDOF2
+ 22.5 Y1CJDPF2 + 9 Y2DOEEF2 + 9 Y2DOEFF2 + 9 Y2DPEEF2 + 9 Y2DPEFF2
+ 22.5 Y1ANBQF3 + 22.5 Y1ANBPF3 + 22.5 Y1AOBQF3 + 22.5 Y1AOBPF3
+ 1.5 Y1EGJTG1 + .5 Y1EGJRG1 + .5 Y1EHJTG1 + .5 Y1EHJRG1 + .5 Y1FQHFG2
+ .5 Y1FQHHG2 + .5 Y1FPHFG2 + .5 Y1FPHHG2 + 45 Y1AABEH1 + 45 Y1AABFH1
+ 45 Y1ABBEH1 + 45 Y1ABBFH1 + 45 Y1CCDOH2 + 45 Y1CCDPH2 + 90 Y1CDDOH2
+ 1.5 Y1GLHFI1 + 1.5 Y1GLHHI1 + 1.5 Y1GMHFI1 + 1.5 Y1GMHHI1 + 15 Y1ANBQJ1
+ 15 Y1ANBTJ1 + 15 Y1AOBQJ1 + 15 Y1AOBTJ1 + 15 Y1BREGJ2 + 15 Y1BREHJ2
+ 15 Y1BSEGJ2 + 15 Y1BSEHJ2 + 9 Y1FJGLJ3 + 9 Y1FJGMJ3 + 9 Y1FKGLJ3
+ 9 Y1FKGMJ3 + 2 Y1AIGFM1 + 2 Y1AIGHM1 + 2 Y1AKGFM1 + 2 Y1AKGHM1
+ 2 Y1BRHFM2 + 2 Y1BRHHM2 + 2 Y1BSHFM2 + 2 Y1BSHHM2

SUBJECT TO THE FOLLOWING SET OF CONSTRAINTS:

CONSTRAINT TO ENSURE THAT ONLY ONE PROCESS PLAN IS SELECTED:

2) ZA1 + ZA2 = 1
3) ZB1 + ZB2 + ZB3 = 1
4) ZC1 + ZC2 + ZC3 = 1
5) ZD1 + ZD2 = 1
6) ZE1 + ZE2 = 1
7) ZF1 + ZF2 + ZF3 = 1
8) ZG1 + ZG2 = 1
9) ZH1 + ZH2 = 1
10) ZI1 = 1
11) ZJ1 + ZJ2 + ZJ3 = 1
12) ZK1 + ZK2 = 1

13) ZL1 + ZL2 = 1
14) ZM1 + ZM2 = 1

CONSTRAINT TO ENSURE THAT ONCE A PROCESS PLAN IS SELECTED. EACH OPERATION IN THE PLAN CAN BE DONE ON ONLY ONE OF THE AVAILABLE MACHINE-TOOL COMBINATIONS:

15) X1AAA1 + X1ABA1 - ZA1 = 0
16) X2CCA1 + X2CDA1 - ZA1 = 0
17) X3EEA1 + X3EFA1 - ZA1 = 0
18) X1BDA2 + X1BCA2 - ZA2 = 0
19) X2CFA2 + X2CEA2 - ZA2 = 0
20) X1DIB1 + X1DJB1 - ZB1 = 0
21) X3EGA2 + X3EHA2 - ZA2 = 0
22) X2GLB1 - ZB1 = 0
23) X1DIB2 + X1DJB2 - ZB2 = 0
24) X1HFB3 + X1HHB3 - ZB3 = 0
25) X2HFB2 + X2HHB2 - ZB2 = 0
26) X2IKB3 - ZB3 = 0
27) X1AAC1 + X1ABC1 - ZC1 = 0
28) X1BCC2 + X1BDC2 - ZC2 = 0
29) X2CGC1 + X2CIC1 - ZC1 = 0
30) X2CIC2 + X2CGC2 - ZC2 = 0
31) X1BMC3 + X1BNC3 - ZC3 = 0
32) X1AGD1 + X1AMD1 - ZD1 = 0
33) X2CHC3 + X2CJC3 - ZC3 = 0
34) X2JOD1 + X2JPD1 - ZD1 = 0
35) X1BMD2 + X1BND2 - ZD2 = 0
36) X1HCE1 + X1HTE1 - ZE1 = 0
37) X2COD2 + X2CPD2 - ZD2 = 0
38) X2IRE1 - ZE1 = 0
39) X1FQE2 - ZE2 = 0
40) X1FQF1 + X1FPF1 - ZF1 = 0
41) X2HFE2 + X2HHE2 - ZE2 = 0
42) X2GLF1 + X2GMF1 - ZF1 = 0
43) X3JPF1 + X3JOF1 - ZF1 = 0
44) X1CHF2 + X1CJF2 - ZF2 = 0
45) X2DOF2 + X2DPF2 - ZF2 = 0
46) X3EEF2 + X3EFF2 - ZF2 = 0
47) X1ANF3 + X1AOF3 - ZF3 = 0
48) X1EGG1 + X1EHG1 - ZG1 = 0
49) X2BPF3 + X2BQF3 - ZF3 = 0
50) X2JTG1 + X2JRG1 - ZG1 = 0
51) X3HTF3 + X3HSF3 - ZF3 = 0
52) X1FQG2 + X1FPG2 - ZG2 = 0
53) X1AAH1 + X1ABH1 - ZH1 = 0
54) X2HFG2 + X2HHG2 - ZG2 = 0
55) X2BEH1 + X2BFH1 - ZH1 = 0
56) X1CCH2 + X1CDH2 - ZH2 = 0
57) X1GLI1 + X1GMI1 - ZI1 = 0
58) X2DOH2 + X2DPH2 - ZH2 = 0
59) X2HFI1 + X2HHI1 - ZI1 = 0
60) X1ANJ1 + X1AOJ1 - ZJ1 = 0
61) X1BRJ2 + X1BSJ2 - ZJ2 = 0
62) X2BQJ1 + X2BTJ1 - ZJ1 = 0
63) X2EGJ2 + X2EHJ2 - ZJ2 = 0
64) X1FJJ3 + X1FKJ3 - ZJ3 = 0
65) X1GLK1 + X1GMK1 - ZK1 = 0
66) X2GLJ3 - ZJ3 + X2GMJ3 = 0
67) X1GFK2 + X1GHK2 - ZK2 = 0
68) X1AIL1 + X1AKL1 - ZL1 = 0
69) X1AIM1 + X1AKM1 - ZM1 = 0
70) X1JTL2 + X1JRL2 - ZL2 = 0

71) X2GFM1 + X2GHM1 - ZM1 = 0
72) X1BRM2 + X1BSM2 - ZM2 = 0
73) X2HFM2 + X2HHM2 - ZM2 = 0

CONSTRAINT ON THE CAPACITY OF MACHINES:

74) 150 X1AAA1 + 300 X1ABA1 + 300 X1AAC1 + 300 X1ABC1 + 8 X1AGD1
+ 9 X1AMD1 + 315 X1ANF3 + 360 X1AOF3 + 270 X1AAH1 + 360 X1ABH1
+ 120 X1ANJ1 + 150 X1AOJ1 + 25 X1AIL1 + 30 X1AKL1 + 35 X1AIM1
+ 40 X1AKM1 <= 1000
75) 270 X1BDA2 + 300 X1BCA2 + 540 X1BCC2 + 420 X1BDC2 + 540 X1BMC3
+ 14 X1BMD2 + 480 X1BNC3 + 10 X1BND2 + 450 X2BPF3 + 405 X2BQF3
+ 360 X2BEH1 + 450 X2BFH1 + 15 X2BQJ1 + 18 X2BTJ1 + 15 X1BRJ2
+ 12 X1BSJ2 + 20 X1BRM2 + 24 X1BSM2 <= 40
76) 120 X2CCA1 + 150 X2CDA1 + 150 X2CFA2 + 120 X2CEA2 + 540 X2CGC1
+ 600 X2CIC1 + 600 X2CIC2 + 540 X2CGC2 + 600 X2CHC3 + 480 X2CJC3
+ 12 X2COD2 + 14 X2CPD2 + 360 X1CHF2 + 405 X1CJF2 + 450 X1CCH2
+ 540 X1CDH2 <= 1300
77) 250 X1DIB1 + 300 X1DJB1 + 250 X1DIB2 + 300 X1DJB2 + 450 X2DOF2
+ 225 X2DPF2 + 270 X2DOH2 + 180 X2DPH2 <= 800
78) 180 X3EEA1 + 165 X3EFA1 + 210 X3EGA2 + 180 X3EHA2 + 225 X3EEF2
+ 270 X3EFF2 + 8 X1EGG1 + 9 X1EHG1 + 18 X2EGJ2 + 15 X2EHJ2
<= 230
79) 18 X1FQE2 + 225 X1FQF1 + 450 X1FPF1 + 8 X1FQG2 + 9 X1FPG2
+ 6 X1FJJ3 + 9 X1FKJ3 <= 300
80) 250 X2GLB1 + 180 X2GLF1 + 225 X2GMF1 + 12 X1GLI1 + 15 X1GMI1
+ 12 X2GLJ3 + 15 XGMJ3 + 8 X1GLK1 + 10 X1GMK1 + 8 X1GFK2
+ 10 X1GHK2 + 10 X2GFM1 + 12 X2GHM1 <= 300
81) 250 X2HFB2 + 325 X2HHB2 + 250 X1HFB3 + 350 X1HHB3 + 33 X1HCE1
+ 30 X1HTE1 + 18 X2HFE2 + 15 X2HHE2 + 450 X3HTF3 + 405 X3HSF3
+ 5 X2HFG2 + 9 X2HHG2 + 6 X2HFI1 + 9 X2HHI1 + 40 X2HFM2
+ 36 X2HHM2 <= 150
82) 500 X2IKB3 + 15 X2IRE1 <= 450
83) 20 X2JOD1 + 35 X2JPD1 + 405 X3JPF1 + 360 X3JOF1 + 8 X2JTG1
+ 9 X2JRG1 + 15 X1JTL2 + 25 X1JRL2 <= 600

CONSTRAINT TO ENSURE THAT EACH TOOL IS ASSIGNED TO ONE MACHINE ONLY:

84) MAA <= 1
85) MAB <= 1
86) MBC + MCC + MHC <= 1
87) MBD + MCD <= 1
88) MBF + MCF + MEF + MHF + MGF <= 1
89) MAG + MCG + MEG <= 1
90) MCH + MEH + MGH + MHH <= 1
91) MAI + MCI + MDI <= 1
92) MCJ + MDJ + MFJ <= 1
93) MAK + MFK + MIK <= 1
94) MGL <= 1
95) MAM + MBM + MGM <= 1
96) MAN + MBN <= 1
97) MAO + MCO + MDO + MJO <= 1
98) MBP + MCP + MDP + MFP + MJP <= 1
99) MBQ + MFQ <= 1
100) MBR + MIR + MJR <= 1
101) MBS + MHS <= 1
102) MBT + MHT + MJT <= 1
103) MBE + MCE + MEE <= 1

CONSTRAINT ON THE LIFE OF TOOLS:

104) 150 X1AAA1 + 300 X1AAC1 + 270 X1AAH1 - 400 MAA <= 0

105) 300 X1ABA1 + 300 X1ABC1 + 360 X1ABH1 - 400 MAB <= 0
106) 300 X1BCA2 + 540 X1BCC2 - 500 MBC <= 0
107) 120 X2CCA1 + 450 X1CCH2 - 500 MCC <= 0
108) 150 X2CDA1 + 540 X1CDH2 - 300 MCD <= 0
109) 360 X2BEH1 - 250 MBE <= 0
110) 120 X2CEA2 - 250 MCE <= 0
111) 180 X3EEA1 + 22.5 X3EEF2 - 250 MEE <= 0
112) 450 X2BFH1 - 90 MBF <= 0
113) 150 X2CFA2 - 90 MCF <= 0
114) 165 X3EFA1 + 270 X3EFF2 - 90 MEF <= 0
115) 250 X2HFB2 + 250 X1HFB3 + 18 X2HFE2 + 5 X2HFG2 + 6 X2HFI1
+ 40 X2HFM2 - 90 MHF <= 0
116) 8 X1GFK2 + 20 X2GFM1 - 90 MGF <= 0
117) 16 X1AGD1 - 10 MAG <= 0
118) 540 X2CGC1 + 540 X2CGC2 - 10 MCG <= 0
119) 210 X3EGA2 + 8 X1EGG1 + 18 X2EGJ2 - 10 MEG <= 0
120) 600 X2CHC3 + 360 X1CHF2 - 20 MCH <= 0
121) 180 X3EHA2 + 9 X1EHG1 + 15 X2EHJ2 - 20 MEH <= 0
122) 10 X1GHK2 + 24 X2GHM1 - 20 MGH <= 0
123) 325 X2HHB2 + 350 X1HHB3 + 15 X2HHE2 + 9 X2HHG2 + 90 X2HHI1
+ 36 X2HHM2 - 20 MHH <= 0
124) 25 X1AIL1 + 28 X1AIM1 - 800 MAI <= 0
125) 600 X2CIC1 + 600 X2CIC2 - 800 MCI <= 0
126) 250 X1DIB1 + 250 X1DIB2 - 800 MDI <= 0
127) 540 X2CJC3 + 405 X1CJF2 - 350 MCJ <= 0
128) 400 X1DJB1 + 400 X1DJB2 - 350 MDJ <= 0
129) 6 X1FJJ3 - 350 MFJ <= 0
130) 30 X1AKL1 + 28 X1AKM1 - 15 MAK <= 0
131) 90 X1FKJ3 - 15 MFK <= 0
132) 500 X2IKB3 - 15 MIK <= 0
133) 250 X2GLB1 + 180 X2GLF1 + 12 X1GLI1 + 12 X2GLJ3 + 8 X1GLK1
- 300 MGL <= 0
134) 9.5 X1AMD1 - 300 MAM <= 0
135) 540 X1BMC3 + 14 X1BMD2 - 300 MBM <= 0
136) 225 X2GMF1 + 15 X1GMI1 + 10 X1GMK1 + 15 X2GMJ3 - 300 MGM
<= 0
137) 315 X1ANF3 + 12 X1ANJ1 - 200 MAN <= 0
138) 480 X1BNC3 + 10 X1BND2 - 200 MBN <= 0
139) 360 X1AOF3 + 15 X1AOJ1 - 350 MAO <= 0
140) 270 X2DOF2 + 270 X2DOH2 - 350 MDO <= 0
141) 8 X2JOD1 - 350 MJO <= 0
142) 450 X2BPF3 - 470 MBP <= 0
143) 14 X2CPD2 - 470 MCP <= 0
144) 225 X2DPF2 + 180 X2DPH2 - 470 MDP <= 0
145) 450 X1FPF1 + 9 X1FPG2 - 470 MFP <= 0
146) 14 X2JPD1 + 405 X3JPF1 - 470 MJP <= 0
147) 405 X2BQF3 + 15 X2BQJ1 - 305 MBQ <= 0
148) 18 X1FQE2 + 225 X1FQF1 + 9 X1FQG2 - 305 MFQ <= 0
149) 15 X1BRJ2 + 20 X1BRM2 - 30 MBR <= 0
150) 15 X2IRE1 - 30 MIR <= 0
151) 9 X2JRG1 + 25 X1JRL2 - 30 MJR <= 0
152) 12 X1BSJ2 + 24 X1BSM2 - 35 MBS <= 0
153) 405 X3HSF3 - 35 MHS + 33 X1HSE2 <= 0
154) 18 X2BTJ1 - 400 MBT <= 0
155) 30 X1HTE1 + 450 X3HTF3 - 400 MHT <= 0
156) 8 X2JTG1 + 15 X1JTL2 - 400 MJT <= 0
157) 33 X1HCE1 - 500 MHC <= 0

LINEARIZATION CONSTRAINTS:

157) X1AAA1 + X2CCA1 - 2 Y1AACCA1 >= 0
158) X1AAA1 + X2CDA1 - 2 Y1AACDA1 >= 0

159) X1ABA1 + X2CCA1 - 2 Y1ABCCA1 >= 0
160) X1ABA1 + X2CDA1 - 2 Y1ABCDA1 >= 0
161) X2CCA1 + X3EEA1 - 2 Y2CCEEA1 >= 0
162) X2CCA1 + X3EFA1 - 2 Y2CCEFA1 >= 0
163) X2CDA1 + X3EFA1 - 2 Y2CDEFA1 >= 0
164) X2CDA1 + X3EEA1 - 2 Y2CDEEA1 >= 0
165) X1BDA2 + X2CFA2 - 2 Y1BDCFA2 >= 0
166) X1BDA2 + X2CEA2 - 2 Y1BDCEA2 >= 0
167) X1BCA2 + X2CEA2 - 2 Y1BCCEA2 >= 0
168) X1BCA2 + X2CFA2 - 2 Y1BCCFA2 >= 0
169) X2CFA2 + X3EGA2 - 2 Y2CFEGA2 >= 0
170) X2CFA2 + X3EHA2 - 2 Y2CFEHA2 >= 0
171) X2CEA2 + X3EGA2 - 2 Y2CEEGA2 >= 0
172) X2CEA2 + X3EHA2 - 2 Y2CEEHA2 >= 0
173) X1DIB1 + X2GLB1 - 2 Y1DIGLB1 >= 0
174) X1DJB1 + X2GLB1 - 2 Y1DJGLB1 >= 0
175) X1DIB2 + X2HFB2 - 2 Y1DIHFB2 >= 0
176) X1DIB2 + X2HHB2 - 2 Y1DIHHB2 >= 0
177) X1DJB2 + X2HFB2 - 2 Y1DJHFB2 >= 0
178) X1DJB2 + X2HHB2 - 2 Y1DJHHB2 >= 0
179) X1HFB3 + X2IKB3 - 2 Y1HFIKB3 >= 0
180) X1HHB3 + X2IKB3 - 2 Y1HHIKB3 >= 0
181) X1AAC1 + X2CGC1 - 2 Y1AACGC1 >= 0
182) X1AAC1 + X2CIC1 - 2 Y1AACIC1 >= 0
183) X1ABC1 + X2CGC1 - 2 Y1ABCGC1 >= 0
184) X1ABC1 + X2CIC1 - 2 Y1ABCIC1 >= 0
185) X1BCC2 + X2CIC2 - 2 Y1BCCIC2 >= 0
186) X1BCC2 + X2CGC2 - 2 Y1BCCGC2 >= 0
187) X1BDC2 + X2CIC2 - 2 Y1BDCIC2 >= 0
188) X1BDC2 + X2CGC2 - 2 Y1BDCGC2 >= 0
189) X1BMC3 + X2CHC3 - 2 Y1BMCHC3 >= 0
190) X1BMC3 + X2CJC3 - 2 Y1BMCJC3 >= 0
191) X1BNC3 + X2CHC3 - 2 Y1BNCHC3 >= 0
192) X1BNC3 + X2CJC3 - 2 Y1BNCJC3 >= 0
193) X1AGD1 + X2JOD1 - 2 Y1AGJOD1 >= 0
194) X1AGD1 + X2JPD1 - 2 Y1AGJPD1 >= 0
195) X1AMD1 + X2JOD1 - 2 Y1AMJOD1 >= 0
196) X1AMD1 + X2JPD1 - 2 Y1AMJPD1 >= 0
197) X1BMD2 + X2COD2 - 2 Y1BMCOD2 >= 0
198) X1BMD2 + X2CPD2 - 2 Y1BMCPD2 >= 0
199) X1BND2 + X2COD2 - 2 Y1BNCOD2 >= 0
200) X1BND2 + X2CPD2 - 2 Y1BNCPD2 >= 0
201) X1HCE1 + X2IRE1 - 2 Y1HCIRE1 >= 0
202) X1HTE1 + X2IRE1 - 2 Y1HTIRE1 >= 0
203) X1FQE2 + X2HFE2 - 2 Y1FQHFE2 >= 0
204) X1FQE2 + X2HHE2 - 2 Y1FQHHE2 >= 0
205) X1FQF1 + X2GLF1 - 2 Y1FQGLF1 >= 0
206) X1FQF1 + X2GMF1 - 2 Y1FQGMF1 >= 0
207) X1FPF1 + X2GLF1 - 2 Y1FPGLF1 >= 0
208) X1FPF1 + X2GMF1 - 2 Y1FPGMF1 >= 0
209) X2GLF1 + X3JOF1 - 2 Y2GLJOF1 >= 0
210) X2GLF1 + X3JPF1 - 2 Y2GLJPF1 >= 0
211) X2GMF1 + X3JOF1 - 2 Y2GMJOF1 >= 0
212) X2GMF1 + X3JPF1 - 2 Y2GMJPF1 >= 0
213) X1CHF2 + X2DOF2 - 2 Y1CHDOF2 >= 0
214) X1CHF2 + X2DPF2 - 2 Y1CHDPF2 >= 0
215) X1CJF2 + X2DOF2 - 2 Y1CJDOF2 >= 0
216) X1CJF2 + X2DPF2 - 2 Y1CJDPF2 >= 0
217) X2DOF2 + X3EEF2 - 2 Y2DOEEF2 >= 0
218) X2DOF2 + X3EFF2 - 2 Y2DOEFF2 >= 0
219) X2DPF2 + X3EEF2 - 2 Y2DPEEF2 >= 0
220) X2DPF2 + X3EFF2 - 2 Y2DPEFF2 >= 0

221) X1ANF3 + X2BQF3 - 2 Y1ANBQF3 >= 0
222) X1ANF3 + X2BPF3 - 2 Y1ANBPF3 >= 0
223) X1AOF3 + X2BQF3 - 2 Y1AOBQF3 >= 0
224) X1AOF3 + X2BPF3 - 2 Y1AOBPF3 >= 0
225) X1EGG1 + X2JTG1 - 2 Y1EGJTG1 >= 0
226) X1EGG1 + X2JRG1 - 2 Y1EGJRG1 >= 0
227) X1EHG1 + X2JTG1 - 2 Y1EHJTG1 >= 0
228) X1EHG1 + X2JRG1 - 2 Y1EHJRG1 >= 0
229) X1FQG2 + X2HFG2 - 2 Y1FQHFG2 >= 0
230) X1FQG2 + X2HHG2 - 2 Y1FQHHG2 >= 0
231) X1FPG2 + X2HFG2 - 2 Y1FPHFG2 >= 0
232) X1FPG2 + X2HHG2 - 2 Y1FPHHG2 >= 0
233) X1AAH1 + X2BEH1 - 2 Y1AABEH1 >= 0
234) X1AAH1 + X2BFH1 - 2 Y1AABFH1 >= 0
235) X1ABH1 + X2BEH1 - 2 Y1ABBEH1 >= 0
236) X1ABH1 + X2BFH1 - 2 Y1ABBFH1 >= 0
237) X1CCH2 + X2DOH2 - 2 Y1CCDOH2 >= 0
238) X1CCH2 + X2DPH2 - 2 Y1CCDPH2 >= 0
239) X1CDH2 + X2DOH2 - 2 Y1CDDOH2 >= 0
240) X1CDH2 + X2DOH2 - 2 Y1CDDOH2 >= 0
241) X1GLI1 + X2HFI1 - 2 Y1GLHFI1 >= 0
242) X1GLI1 + X2HHI1 - 2 Y1GLHHI1 >= 0
243) X1GMI1 + X2HFI1 - 2 Y1GMHFI1 >= 0
244) X1GMI1 + X2HHI1 - 2 Y1GMHHI1 >= 0
245) X1ANJ1 + X2BQJ1 - 2 Y1ANBQJ1 >= 0
246) X1ANJ1 + X2BTJ1 - 2 Y1ANBTJ1 >= 0
247) X1AOJ1 + X2BQJ1 - 2 Y1AOBQJ1 >= 0
248) X1AOJ1 + X2BTJ1 - 2 Y1AOBTJ1 >= 0
249) X1BRJ2 + X2EGJ2 - 2 Y1BREGJ2 >= 0
250) X1BRJ2 + X2EHJ2 - 2 Y1BREHJ2 >= 0
251) X1BSJ2 + X2EGJ2 - 2 Y1BSEGJ2 >= 0
252) X1BSJ2 + X2EHJ2 - 2 Y1BSEHJ2 >= 0
253) X1FJJ3 + X2GLJ3 - 2 Y1FJGLJ3 >= 0
254) X1FJJ3 - 2 Y1FJGMJ3 + X2GMJ3 >= 0
255) X1FKJ3 + X2GLJ3 - 2 Y1FKGLJ3 >= 0
256) X1FKJ3 - 2 Y1FKGMJ3 + X2GMJ3 >= 0
257) X1AIM1 + X2GFM1 - 2 Y1AIGFM1 >= 0
258) X1AIM1 + X2GHM1 - 2 Y1AIGHM1 >= 0
259) X1AKM1 + X2GFM1 - 2 Y1AKGFM1 >= 0
260) X1AKM1 + X2GHM1 - 2 Y1AKGHM1 >= 0
261) X1BRM2 + X2HFM2 - 2 Y1BRHFM2 >= 0
262) X1BRM2 + X2HHM2 - 2 Y1BRHHM2 >= 0
263) X1BSM2 + X2HFM2 - 2 Y1BSHFM2 >= 0
264) X1BSM2 + X2HHM2 - 2 Y1BSHHM2 >= 0
265) X1AAA1 + X2CCA1 - Y1AACCA1 <= 1
266) X1AAA1 + X2CDA1 - Y1AACDA1 <= 1
267) X1ABA1 + X2CCA1 - Y1ABCCA1 <= 1
268) X1ABA1 + X2CDA1 - Y1ABCDA1 <= 1
269) X2CCA1 + X3EEA1 - Y2CCEEA1 <= 1
270) X2CCA1 + X3EFA1 - Y2CCEFA1 <= 1
271) X2CDA1 + X3EFA1 - Y2CDEFA1 <= 1
272) X2CDA1 + X3EEA1 - Y2CDEEA1 <= 1
273) X1BDA2 + X2CFA2 - Y1BDCFA2 <= 1
274) X1BDA2 + X2CEA2 - Y1BDCEA2 <= 1
275) X1BCA2 + X2CEA2 - Y1BCCEA2 <= 1
276) X1BCA2 + X2CFA2 - Y1BCCFA2 <= 1
277) X2CFA2 + X3EGA2 - Y2CFEGA2 <= 1
278) X2CFA2 + X3EHA2 - Y2CFEHA2 <= 1
279) X2CEA2 + X3EGA2 - Y2CEEGA2 <= 1
280) X2CEA2 + X3EHA2 - Y2CEEHA2 <= 1
281) X1DIB1 + X2GLB1 - Y1DIGLB1 <= 1
282) X1DJB1 + X2GLB1 - Y1DJGLB1 <= 1

283) X1DIB2 + X2HFB2 - Y1DIHFB2 <= 1
284) X1DIB2 + X2HHB2 - Y1DIHHB2 <= 1
285) X1DJB2 + X2HFB2 - Y1DJHFB2 <= 1
286) X1DJB2 + X2HHB2 - Y1DJHHB2 <= 1
287) X1HFB3 + X2IKB3 - Y1HFIKB3 <= 1
288) X1HHB3 + X2IKB3 - Y1HHIKB3 <= 1
289) X1AAC1 + X2CGC1 - Y1AACGC1 <= 1
290) X1AAC1 + X2CIC1 - Y1AACIC1 <= 1
291) X1ABC1 + X2CGC1 - Y1ABCGC1 <= 1
292) X1ABC1 + X2CIC1 - Y1ABCIC1 <= 1
293) X1BCC2 + X2CIC2 - Y1BCCIC2 <= 1
294) X1BCC2 + X2CGC2 - Y1BCCGC2 <= 1
295) X1BDC2 + X2CIC2 - Y1BDCIC2 <= 1
296) X1BDC2 + X2CGC2 - Y1BDCGC2 <= 1
297) X1BMC3 + X2CHC3 - Y1BMCHC3 <= 1
298) X1BMC3 + X2CJC3 - Y1BMCJC3 <= 1
299) X1BNC3 + X2CHC3 - Y1BNCHC3 <= 1
300) X1BNC3 + X2CJC3 - Y1BNCJC3 <= 1
301) X1AGD1 + X2JOD1 - Y1AGJOD1 <= 1
302) X1AGD1 + X2JPD1 - Y1AGJPD1 <= 1
303) X1AMD1 + X2JOD1 - Y1AMJOD1 <= 1
304) X1AMD1 + X2JPD1 - Y1AMJPD1 <= 1
305) X1BMD2 + X2COD2 - Y1BMCOD2 <= 1
306) X1BMD2 + X2CPD2 - Y1BMCPD2 <= 1
307) X1BND2 + X2COD2 - Y1BNCOD2 <= 1
308) X1BND2 + X2CPD2 - Y1BNCPD2 <= 1
309) X1HCE1 + X2IRE1 - Y1HSIRE1 <= 1
310) X1HTE1 + X2IRE1 - Y1HTIRE1 <= 1
311) X1FQE2 + X2HFE2 - Y1FQHFE2 <= 1
312) X1FQE2 + X2HHE2 - Y1FQHHE2 <= 1
313) X1FQF1 + X2GLF1 - Y1FQGLF1 <= 1
314) X1FQF1 + X2GMF1 - Y1FQGMF1 <= 1
315) X1FPF1 + X2GLF1 - Y1FPGLF1 <= 1
316) X1FPF1 + X2GMF1 - Y1FPGMF1 <= 1
317) X2GLF1 + X3JOF1 - Y2GLJOF1 <= 1
318) X2GLF1 + X3JPF1 - Y2GLJPF1 <= 1
319) X2GMF1 + X3JOF1 - Y2GMJOF1 <= 1
320) X2GMF1 + X3JPF1 - Y2GMJPF1 <= 1
321) X1CHF2 + X2DOF2 - Y1CHDOF2 <= 1
322) X1CHF2 + X2DPF2 - Y1CHDPF2 <= 1
323) X1CJF2 + X2DOF2 - Y1CJDOF2 <= 1
324) X1CJF2 + X2DPF2 - Y1CJDPF2 <= 1
325) X2DOF2 + X3EEF2 - Y2DOEEF2 <= 1
326) X2DOF2 + X3EFF2 - Y2DOEFF2 <= 1
327) X2DPF2 + X3EEF2 - Y2DPEEF2 <= 1
328) X2DPF2 + X3EFF2 - Y2DPEFF2 <= 1
329) X1ANF3 + X2BQF3 - Y1ANBQF3 <= 1
330) X1ANF3 + X2BPF3 - Y1ANBPF3 <= 1
331) X1AOF3 + X2BQF3 - Y1AOBQF3 <= 1
332) X1AOF3 + X2BPF3 - Y1AOBPF3 <= 1
333) X1EGG1 + X2JTG1 - Y1EGJTG1 <= 1
334) X1EGG1 + X2JRG1 - Y1EGJRG1 <= 1
335) X1EHG1 + X2JTG1 - Y1EHJTG1 <= 1
336) X1EHG1 + X2JRG1 - Y1EHJRG1 <= 1
337) X1FQG2 + X2HFG2 - Y1FQHFG2 <= 1
338) X1FQG2 + X2HHG2 - Y1FQHHG2 <= 1
339) X1FPG2 + X2HFG2 - Y1FPHFG2 <= 1
340) X1FPG2 + X2HHG2 - Y1FPHHG2 <= 1
341) X1AAH1 + X2BEH1 - Y1AABEH1 <= 1
342) X1AAH1 + X2BFH1 - Y1AABFH1 <= 1
343) X1ABH1 + X2BEH1 - Y1ABBEH1 <= 1
344) X1ABH1 + X2BFH1 - Y1ABBFH1 <= 1

345) X1CCH2 + X2DOH2 - Y1CCDOH2 <= 1
346) X1CCH2 + X2DPH2 - Y1CCDPH2 <= 1
347) X1CDH2 + X2DOH2 - Y1CDDOH2 <= 1
348) X1CDH2 + X2DOH2 - Y1CDDOH2 <= 1
349) X1GLI1 + X2HFI1 - Y1GLHFI1 <= 1
350) X1GLI1 + X2HHI1 - Y1GLHHI1 <= 1
351) X1GMI1 + X2HFI1 - Y1GMHFI1 <= 1
352) X1GMI1 + X2HHI1 - Y1GMHHI1 <= 1
353) X1ANJ1 + X2BQJ1 - Y1ANBQJ1 <= 1
354) X1ANJ1 + X2BTJ1 - Y1ANBTJ1 <= 1
355) X1AOJ1 + X2BQJ1 - Y1AOBQJ1 <= 1
356) X1AOJ1 + X2BTJ1 - Y1AOBTJ1 <= 1
357) X1BRJ2 + X2EGJ2 - Y1BREGJ2 <= 1
358) X1BRJ2 + X2EHJ2 - Y1BREHJ2 <= 1
359) X1BSJ2 + X2EGJ2 - Y1BSEGJ2 <= 1
360) X1BSJ2 + X2EHJ2 - Y1BSEHJ2 <= 1
362) X1FJJ3 + X2GLJ3 - Y1FJGLJ3 <= 1
363) X1FJJ3 - Y1FJGMJ3 + X2GMJ3 <= 1
364) X1FKJ3 + X2GLJ3 - Y1FKGLJ3 <= 1
365) X1FKJ3 - Y1FKGMJ3 + X2GMJ3 <= 1
366) X1AIM1 + X2GFM1 - Y1AIGFM1 <= 1
367) X1AIM1 + X2GHM1 - Y1AIGHM1 <= 1
368) X1AKM1 + X2GFM1 - Y1AKGFM1 <= 1
369) X1AKM1 + X2GHM1 - Y1AKGHM1 <= 1
370) X1BRM2 + X2HFM2 - Y1BRHFM2 <= 1
371) X1BRM2 + X2HHM2 - Y1BRHHM2 <= 1
372) X1BSM2 + X2HFM2 - Y1BSHFM2 <= 1
373) X1BSM2 + X2HHM2 - Y1BSHHM2 <= 1

A.4.3 Example #1 for Model #2

MIN 510 X1AA1A1 + 270 X1AB1A1 + 540 X1AA1C1 + 660 X1AB1C1
+ 160 X1AG1D1 + 120 X1AM1D1 + 585 X1AN1F3 + 495 X1AO1F3 + 540 X1AA1H1
+ 360 X1AB1H1 + 300 X1AN1J1 + 240 X1AO1J1 + 500 X1AI1L1 + 550 X1AK1L1
+ 520 X1AI1M1 + 440 X1AK1M1 + 420 X1BD1A2 + 420 X1BC1A2 + 900 X1BC1C2
+ 840 X1BD1C2 + 720 X1BM1C3 + 80 X1BQ1D2 + 960 X1BN1C3 + 200 X1BN1D2
+ 630 X2BP1F3 + 810 X2BQ1F3 + 720 X2BE1H1 + 630 X2BF1H1 + 270 X2BQ1J1
+ 240 X2BT1J1 + 210 X1BR1J2 + 240 X1BS1J2 + 400 X1BR1M2 + 360 X1BS1M2
+ 420 X2CC1A1 + 330 X2CD1A1 + 360 X2CF1A2 + 390 X2CE1A2 + 1020 X2CG1C1
+ 840 X2CI1C1 + 960 X2CI1C2 + 960 X2CG1C2 + 780 X2CH1C3 + 1020 X2CJ1C3
+ 320 X2CO1D2 + 320 X2CP1D2 + 315 X1CH1F2 + 550 X1CJ1F2 + 900 X1CC1H2
+ 720 X1CD1H2 + 850 X1DI1B1 + 750 X1DJ1B1 + 900 X1DI1B2 + 900 X1DJ1B2
+ 405 X2DO1F2 + 540 X2DP1F2 + 540 X2DO1H2 + 630 X2DP1H2 + 360 X3EE1A1
+ 440 X3EF1A1 + 480 X3EG1A2 + 480 X3EH1A2 + 270 X3EE1F2 + 315 X3EF1F2
+ 150 X1EG1G1 + 140 X1EH1G1 + 270 X2EG1J2 + 300 X2EH1J2 + 690 X1FQ1E2
+ 765 X1FQ1F1 + 550 X1FP1F1 + 140 X1FQ1G2 + 130 X1FP1G2 + 180 X1FJ1J3
+ 210 X1FK1J3 + 750 X2GL1B1 + 675 X2GL1F1 + 630 X2GM1F1 + 300 X1GL1I1
+ 240 X1GM1I1 + 270 X2GL1J3 + 240 XGM1J3 + 180 X1GL1K1 + 160 X1GM1K1
+ 180 X1GF1K2 + 140 X1GH1K2 + 440 X2GF1M1 + 440 X2GH1M1 + 840 X2HF1B2
+ 800 X2HH1B2 + 1100 X1HF1B3 + 1150 X1HH1B3 + 420 X1HC1E1
+ 390 X1HT1E1 + 480 X2HF1E2 + 450 X2HH1E2 + 720 X3HT1F3 + 675 X3HS1F3
+ 170 X2HF1G2 + 160 X2HH1G2 + 180 X2HF1I1 + 120 X2HH1I1 + 600 X2HF1M2
+ 640 X2HH1M2 + 1145 X2IK1B3 + 480 X2IR1E1 + 370 X2JO1D2 + 160 X2JP1D2
+ 320 X3JP1F1 + 550 X3JO1F1 + 150 X2JT1G1 + 130 X2JR1G1 + 650 X1JT1L2
+ 450 X1JR1L2 + 510 X1AA2A1 + 270 X1AB2A1 + 540 X1AA2C1 + 660 X1AB2C1
+ 160 X1AG2D1 + 120 X1AM2D1 + 585 X1AN2F3 + 495 X1AO2F3 + 540 X1AA2H1
+ 360 X1AB2H1 + 300 X1AN2J1 + 240 X1AO2J1 + 500 X1AI2L1 + 550 X1AK2L1
+ 520 X1AI2M1 + 440 X1AK2M1 + 420 X1BD2A2 + 420 X1BC2A2 + 900 X1BC2C2
+ 840 X1BD2C2 + 720 X1BM2C3 + 80 X1BQ2D2 + 960 X1BN2C3 + 200 X1BN2D2

+ 630 X2BP2F3 + 810 X2BQ2F3 + 720 X2BE2H1 + 630 X2BF2H1 + 270 X2BQ2J1
+ 240 X2BT2J1 + 210 X1BR2J2 + 240 X1BS2J2 + 400 X1BR2M2 + 360 X1BS2M2
+ 420 X2CC2A1 + 330 X2CD2A1 + 360 X2CF2A2 + 390 X2CE2A2 + 1020 X2CG2C1
+ 840 X2CI2C1 + 960 X2CI2C2 + 960 X2CG2C2 + 780 X2CH2C3 + 1020 X2CJ2C3
+ 320 X2CO2D2 + 320 X2CP2D2 + 315 X1CH2F2 + 550 X1CJ2F2 + 900 X1CC2H2
+ 720 X1CD2H2 + 850 X1DI2B1 + 750 X1DJ2B1 + 900 X1DI2B2 + 900 X1DJ2B2
+ 405 X2DO2F2 + 540 X2DP2F2 + 540 X2DO2H2 + 630 X2DP2H2 + 360 X3EE2A1
+ 440 X3EF2A1 + 480 X3EG2A2 + 480 X3EH2A2 + 270 X3EE2F2 + 315 X3EF2F2
+ 150 X1EG2G1 + 140 X1EH2G1 + 270 X2EG2J2 + 300 X2EH2J2 + 690 X1FQ2E2
+ 765 X1FQ2F1 + 550 X1FP2F1 + 140 X1FQ2G2 + 130 X1FP2G2 + 180 X1FJ2J3
+ 210 X1FK2J3 + 750 X2GL2B1 + 675 X2GL2F1 + 630 X2GM2F1 + 300 X1GL2I1
+ 240 X1GM2I1 + 270 X2GL2J3 + 240 XGM2J3 + 180 X1GL2K1 + 160 X1GM2K1
+ 180 X1GF2K2 + 140 X1GH2K2 + 440 X2GF2M1 + 440 X2GH2M1 + 840 X2HF2B2
+ 800 X2HH2B2 + 1100 X1HF2B3 + 1150 X1HH2B3 + 420 X1HC2E1
+ 390 X1HT2E1 + 480 X2HF2E2 + 450 X2HH2E2 + 720 X3HT2F3 + 675 X3HS2F3
+ 170 X2HF2G2 + 160 X2HH2G2 + 180 X2HF2I1 + 120 X2HH2I1 + 600 X2HF2M2
+ 640 X2HH2M2 + 1145 X2IK2B3 + 480 X2IR2E1 + 370 X2JO2D2 + 160 X2JP2D2
+ 320 X3JP2F1 + 550 X3JO2F1 + 150 X2JT2G1 + 130 X2JR2G1 + 650 X1JT2L2
+ 450 X1JR2L2 + 15 F1 + 15 F2 + 15 F3 + 15 F4 + 15 F5 + 15 F6 + 15 F7
+ 15 F8 + 9 F9 + 9 F10 + 9 F11 + 9 F12 + 15 F13 + 15 F14 + 15 F15
+ 15 F16 + 25 F17 + 25 F18 + 25 F19 + 25 F20 + 25 F21 + 25 F22
+ 25 F23 + 25 F24 + 30 F25 + 30 F26 + 30 F27 + 30 F28 + 18 F29
+ 18 F30 + 18 F31 + 18 F32 + 18 F33 + 18 F34 + 18 F35 + 10 F36
+ 10 F37 + 10 F38 + 10 F39 + 6 F40 + 6 F41 + 6 F42 + 6 F43 + 6 F44
+ 6 F45 + 15 F46 + 15 F47 + 13.5 F48 + 13.5 F49 + 13.5 F50 + 13.5 F51
+ 22.5 F52 + 22.5 F53 + 22.5 F54 + 22.5 F55 + 22.5 F56 + 22.5 F57
+ 22.5 F58 + 22.5 F59 + 9 F60 + 9 F61 + 9 F62 + 9 F63 + 22.5 F64
+ 22.5 F65 + 22.5 F66 + 22.5 F67 + 15 F68 + 5 F69 + 5 F70 + 5 F71
+ 5 F72 + 5 F73 + 5 F74 + 5 F75 + 45 F76 + 45 F77 + 45 F78 + 45 F79
+ 45 F80 + 45 F81 + 90 F82 + 15 F83 + 15 F84 + 15 F85 + 15 F86
+ 15 F87 + 15 F88 + 15 F89 + 15 F90 + 15 F91 + 15 F92 + 15 F93
+ 15 F94 + 9 F95 + 9 F96 + 9 F97 + 9 F98 + 20 F99 + 20 F100 + 20 F101
+ 20 F102 + 20 F103 + 20 F104 + 20 F105 + 20 F106 + 20 F107 + 20 F108
+ 30 F1B + 30 F2B + 30 F3B + 30 F4B + 30 F5B + 30 F6B + 30 F7B
+ 30 F8B + 18 F9B + 18 F10B + 18 F11B + 18 F12B + 30 F13B + 30 F14B
+ 30 F15B + 30 F16B + 50 F17B + 50 F18B + 50 F19B + 50 F20B + 50 F21B
+ 50 F22B + 50 F23B + 50 F24B + 60 F25B + 60 F26B + 60 F27B + 60 F28B
+ 36 F29B + 36 F30B + 36 F31B + 36 F32B + 36 F33B + 36 F34B + 36 F35B
+ 20 F36B + 20 F37B + 20 F38B + 20 F39B + 12 F40B + 12 F41B + 12 F42B
+ 12 F43B + 12 F44B + 12 F45B + 30 F46B + 30 F47B + 27 F48B + 27 F49B
+ 27 F50B + 27 F51B + 45 F52B + 45 F53B + 45 F54B + 45 F55B + 45 F56B
+ 45 F57B + 45 F58B + 45 F59B + 18 F60B + 18 F61B + 18 F62B + 18 F63B
+ 45 F64B + 45 F65B + 45 F66B + 45 F67B + 30 F68B + 10 F69B + 10 F70B
+ 10 F71B + 10 F72B + 10 F73B + 10 F74B + 10 F75B + 90 F76B + 90 F77B
+ 90 F78B + 90 F79B + 90 F80B + 90 F81B + 180 F82B + 30 F83B + 30 F84B
+ 30 F85B + 30 F86B + 30 F87B + 30 F88B + 30 F89B + 30 F90B + 30 F91B
+ 30 F92B + 30 F93B + 30 F94B + 18 F95B + 18 F96B + 18 F97B + 18 F98B
+ 40 F99B + 40 F100B + 40 F101B + 40 F102B + 40 F103B + 40 F104B
+ 40 F105B + 40 F106B + 40 F107B + 40 F108B + 30 F1C + 30 F2C + 30 F3C
+ 30 F4C + 30 F5C + 30 F6C + 30 F7C + 30 F8C + 18 F9C + 18 F10C
+ 18 F11C + 18 F12C + 30 F13C + 30 F14C + 30 F15C + 30 F16C + 50 F17C
+ 50 F18C + 50 F19C + 50 F20C + 50 F21C + 50 F22C + 50 F23C + 50 F24C
+ 60 F25C + 60 F26C + 60 F27C + 60 F28C + 36 F29C + 36 F30C + 36 F31C
+ 36 F32C + 36 F33C + 36 F34C + 36 F35C + 20 F36C + 20 F37C + 20 F38C
+ 20 F39C + 12 F40C + 12 F41C + 12 F42C + 12 F43C + 12 F44C + 12 F45C
+ 30 F46C + 30 F47C + 27 F48C + 27 F49C + 27 F50C + 27 F51C + 45 F52C
+ 45 F53C + 45 F54C + 45 F55C + 45 F56C + 45 F57C + 45 F58C + 45 F59C
+ 18 F60C + 18 F61C + 18 F62C + 18 F63C + 45 F64C + 45 F65C + 45 F66C
+ 45 F67C + 30 F68C + 10 F69C + 10 F70C + 10 F71C + 10 F72C + 10 F73C
+ 10 F74C + 10 F75C + 90 F76C + 90 F77C + 90 F78C + 90 F79C + 90 F80C
+ 90 F81C + 180 F82C + 30 F83C + 30 F84C + 30 F85C + 30 F86C + 30 F87C
+ 30 F88C + 30 F89C + 30 F90C + 30 F91C + 30 F92C + 30 F93C + 30 F94C

+ 18 F95C + 18 F96C + 18 F97C + 18 F98C + 40 F99C + 40 F100C
+ 40 F101C + 40 F102C + 40 F103C + 40 F104C + 40 F105C + 40 F106C
+ 40 F107C + 40 F108C + 15 F1D + 15 F2D + 15 F3D + 15 F4D + 15 F5D
+ 15 F6D + 15 F7D + 15 F8D + 9 F9D + 9 F10D + 9 F11D + 9 F12D
+ 15 F13D + 15 F14D + 15 F15D + 15 F16D + 25 F17D + 25 F18D + 25 F19D
+ 25 F20D + 25 F21D + 25 F22D + 25 F23D + 25 F24D + 30 F25D + 30 F26D
+ 30 F27D + 30 F28D + 18 F29D + 18 F30D + 18 F31D + 18 F32D + 18 F33D
+ 18 F34D + 18 F35D + 10 F36D + 10 F37D + 10 F38D + 10 F39D + 6 F40D
+ 6 F41D + 6 F42D + 6 F43D + 6 F44D + 6 F45D + 15 F46D + 15 F47D
+ 13.5 F48D + 13.5 F49D + 13.5 F50D + 13.5 F51D + 22.5 F52D
+ 22.5 F53D + 22.5 F54D + 22.5 F55D + 22.5 F56D + 22.5 F57D
+ 22.5 F58D + 22.5 F59D + 9 F60D + 9 F61D + 9 F62D + 9 F63D
+ 22.5 F64D + 22.5 F65D + 22.5 F66D + 22.5 F67D + 15 F68D + 5 F69D
+ 5 F70D + 5 F71D + 5 F72D + 5 F73D + 5 F74D + 5 F75D + 45 F76D
+ 45 F77D + 45 F78D + 45 F79D + 45 F80D + 45 F81D + 90 F82D + 15 F83D
+ 15 F84D + 15 F85D + 15 F86D + 15 F87D + 15 F88D + 15 F89D + 15 F90D
+ 15 F91D + 15 F92D + 15 F93D + 15 F94D + 9 F95D + 9 F96D + 9 F97D
+ 9 F98D + 20 F99D + 20 F100D + 20 F101D + 20 F102D + 20 F103D
+ 20 F104D + 20 F105D + 20 F106D + 20 F107D + 20 F108D

SUBJECT TO THE FOLLOWING SET OF CONSTRAINTS:

CONSTRAINT TO ENSURE THAT ONLY ONE PROCESS PLAN IS SELECTED:

2) ZA1 + ZA2 = 1
3) ZB1 + ZB2 + ZB3 = 1
4) ZC1 + ZC2 + ZC3 = 1
5) ZD1 + ZD2 = 1
6) ZE1 + ZE2 = 1
7) ZF1 + ZF2 + ZF3 = 1
8) ZG1 + ZG2 = 1
9) ZH1 + ZH2 = 1
10) ZI1 = 1
11) ZJ1 + ZJ2 + ZJ3 = 1
12) ZK1 + ZK2 = 1
13) ZL1 + ZL2 = 1
14) ZM1 + ZM2 = 1

CONSTRAINT TO ENSURE THAT ONCE A PROCESS PLAN IS SELECTED, EACH OPERATION IN THAT PLAN IS DONE ON ONLY ONE OF THE AVAILABLE MACHINES USING THE REQUIRED TOOL, ASSIGNED TO A PARTICULAR CELL:

15) X1AA1A1 + X1AB1A1 + X1AA2A1 + X1AB2A1 - ZA1 = 0
16) X2CC1A1 + X2CD1A1 + X2CC2A1 + X2CD2A1 - ZA1 = 0
17) X3EE1A1 + X3EF1A1 + X3EE2A1 + X3EF2A1 - ZA1 = 0
18) X1BD1A2 + X1BC1A2 + X1BD2A2 + X1BC2A2 - ZA2 = 0
19) X2CF1A2 + X2CE1A2 + X2CF2A2 + X2CE2A2 - ZA2 = 0
20) X1DI1B1 + X1DJ1B1 + X1DI2B1 + X1DJ2B1 - ZB1 = 0
21) X3EG1A2 + X3EH1A2 + X3EG2A2 + X3EH2A2 - ZA2 = 0
22) X2GL1B1 + X2GL2B1 - ZB1 = 0
23) X1DI1B2 + X1DJ1B2 + X1DI2B2 + X1DJ2B2 - ZB2 = 0
24) X1HF1B3 + X1HH1B3 + X1HF2B3 + X1HH2B3 - ZB3 = 0
25) X2HF1B2 + X2HH1B2 + X2HF2B2 + X2HH2B2 - ZB2 = 0
26) X2IK1B3 + X2IK2B3 - ZB3 = 0
27) X1AA1C1 + X1AB1C1 + X1AA2C1 + X1AB2C1 - ZC1 = 0
28) X1BC1C2 + X1BD1C2 + X1BC2C2 + X1BD2C2 - ZC2 = 0
29) X2CG1C1 + X2CI1C1 + X2CG2C1 + X2CI2C1 - ZC1 = 0
30) X2CI1C2 + X2CG1C2 + X2CI2C2 + X2CG2C2 - ZC2 = 0
31) X1BM1C3 + X1BN1C3 + X1BM2C3 + X1BN2C3 - ZC3 = 0
32) X1AG1D1 + X1AM1D1 + X1AG2D1 + X1AM2D1 - ZD1 = 0
33) X2CH1C3 + X2CJ1C3 + X2CH2C3 + X2CJ2C3 - ZC3 = 0
34) - ZD1 + X2JO1D1 + X2JP1D1 + X2JO2D1 + X2JP2D1 = 0
35) X1BN1D2 + X1BN2D2 - ZD2 + X1BM1D2 + X1BM2D2 = 0

36) X1HC1E1 + X1HT1E1 + X1HC2E1 + X1HT2E1 - ZE1 = 0
37) X2CO1D2 + X2CP1D2 + X2CO2D2 + X2CP2D2 - ZD2 = 0
38) X2IR1E1 + X2IR2E1 - ZE1 = 0
39) X1FQ1E2 + X1FQ2E2 - ZE2 = 0
40) X1FQ1F1 + X1FP1F1 + X1FQ2F1 + X1FP2F1 - ZF1 = 0
41) X2HF1E2 + X2HH1E2 + X2HF2E2 + X2HH2E2 - ZE2 = 0
42) X2GL1F1 + X2GM1F1 + X2GL2F1 + X2GM2F1 - ZF1 = 0
43) X3JP1F1 + X3JO1F1 + X3JP2F1 + X3JO2F1 - ZF1 = 0
44) X1CH1F2 + X1CJ1F2 + X1CH2F2 + X1CJ2F2 - ZF2 = 0
45) X2DO1F2 + X2DP1F2 + X2DO2F2 + X2DP2F2 - ZF2 = 0
46) X3EE1F2 + X3EF1F2 + X3EE2F2 + X3EF2F2 - ZF2 = 0
47) X1AN1F3 + X1AO1F3 + X1AN2F3 + X1AO2F3 - ZF3 = 0
48) X1EG1G1 + X1EH1G1 + X1EG2G1 + X1EH2G1 - ZG1 = 0
49) X2BP1F3 + X2BQ1F3 + X2BP2F3 + X2BQ2F3 - ZF3 = 0
50) X2JT1G1 + X2JR1G1 + X2JT2G1 + X2JR2G1 - ZG1 = 0
51) X3HT1F3 + X3HS1F3 + X3HT2F3 + X3HS2F3 - ZF3 = 0
52) X1FQ1G2 + X1FP1G2 + X1FQ2G2 + X1FP2G2 - ZG2 = 0
53) X1AA1H1 + X1AB1H1 + X1AA2H1 + X1AB2H1 - ZH1 = 0
54) X2HF1G2 + X2HH1G2 + X2HF2G2 + X2HH2G2 - ZG2 = 0
55) X2BE1H1 + X2BF1H1 + X2BE2H1 + X2BF2H1 - ZH1 = 0
56) X1CC1H2 + X1CD1H2 + X1CC2H2 + X1CD2H2 - ZH2 = 0
57) X1GL1I1 + X1GM1I1 + X1GL2I1 + X1GM2I1 - ZI1 = 0
58) X2DO1H2 + X2DP1H2 + X2DO2H2 + X2DP2H2 - ZH2 = 0
59) X2HF1I1 + X2HH1I1 + X2HF2I1 + X2HH2I1 - ZI1 = 0
60) X1AN1J1 + X1AO1J1 + X1AN2J1 + X1AO2J1 - ZJ1 = 0
61) X1BR1J2 + X1BS1J2 + X1BR2J2 + X1BS2J2 - ZJ2 = 0
62) X2BQ1J1 + X2BT1J1 + X2BQ2J1 + X2BT2J1 - ZJ1 = 0
63) X2EG1J2 + X2EH1J2 + X2EG2J2 + X2EH2J2 - ZJ2 = 0
64) X1FJ1J3 + X1FK1J3 + X1FJ2J3 + X1FK2J3 - ZJ3 = 0
65) X1GL1K1 + X1GM1K1 + X1GL2K1 + X1GM2K1 - ZK1 = 0
66) X2GL1J3 + X2GL2J3 - ZJ3 + X2GM1J3 + X2GM2J3 = 0
67) X1GF1K2 + X1GH1K2 + X1GF2K2 + X1GH2K2 - ZK2 = 0
68) X1AI1L1 + X1AK1L1 + X1AI2L1 + X1AK2L1 - ZL1 = 0
69) X1AI1M1 + X1AK1M1 + X1AI2M1 + X1AK2M1 - ZM1 = 0
70) X1JT1L2 + X1JR1L2 + X1JT2L2 + X1JR2L2 - ZL2 = 0
71) X2GF1M1 + X2GH1M1 + X2GF2M1 + X2GH2M1 - ZM1 = 0
72) X1BR1M2 + X1BS1M2 + X1BR2M2 + X1BS2M2 - ZM2 = 0
73) X2HF1M2 + X2HH1M2 + X2HF2M2 + X2HH2M2 - ZM2 = 0

CONSTRAINT ON THE CAPACITY OF MACHINES:

74) 270 X1AA1A1 + 540 X1AB1A1 + 540 X1AA1C1 + 480 X1AB1C1
+ 120 X1AG1D1 + 140 X1AM1D1 + 495 X1AN1F3 + 495 X1AO1F3 + 360 X1AA1H1
+ 450 X1AB1H1 + 240 X1AN1J1 + 300 X1AO1J1 + 400 X1AI1L1 + 400 X1AK1L1
+ 510 X1AI1M1 + 520 X1AK1M1 + 270 X1AA2A1 + 540 X1AB2A1 + 540 X1AA2C1
+ 480 X1AB2C1 + 120 X1AG2D1 + 140 X1AM2D1 + 495 X1AN2F3 + 495 X1AO2F3
+ 360 X1AA2H1 + 450 X1AB2H1 + 240 X1AN2J1 + 300 X1AO2J1 + 400 X1AI2L1
+ 400 X1AK2L1 + 510 X1AI2M1 + 520 X1AK2M1 <= 2000
75) 420 X1BD1A2 + 450 X1BC1A2 + 840 X1BC1C2 + 780 X1BD1C2
+ 840 X1BM1C3 + 240 X1BQ1D2 + 840 X1BN1C3 + 180 X1BN1D2 + 675 X2BP1F3
+ 630 X2BQ1F3 + 585 X2BE1H1 + 700 X2BF1H1 + 270 X2BQ1J1 + 270 X2BT1J1
+ 210 X1BR1J2 + 210 X1BS1J2 + 360 X1BR1M2 + 400 X1BS1M2 + 420 X1BD2A2
+ 450 X1BC2A2 + 840 X1BC2C2 + 780 X1BD2C2 + 840 X1BM2C3 + 240 X1BQ2D2
+ 840 X1BN2C3 + 180 X1BN2D2 + 675 X2BP2F3 + 630 X2BQ2F3 + 585 X2BE2H1
+ 700 X2BF2H1 + 270 X2BQ2J1 + 270 X2BT2J1 + 210 X1BR2J2 + 210 X1BS2J2
+ 360 X1BR2M2 + 400 X1BS2M2 <= 860
76) 210 X2CC1A1 + 240 X2CD1A1 + 240 X2CF1A2 + 180 X2CE1A2
+ 900 X2CG1C1 + 840 X2CI1C1 + 900 X2CI1C2 + 840 X2CG1C2 + 900 X2CH1C3
+ 780 X2CJ1C3 + 200 X2CO1D2 + 220 X2CP1D2 + 495 X1CH1F2 + 485 X1CJ1F2
+ 900 X1CC1H2 + 900 X1CD1H2 + 210 X2CC2A1 + 240 X2CD2A1 + 240 X2CF2A2
+ 180 X2CE2A2 + 900 X2CG2C1 + 840 X2CI2C1 + 900 X2CI2C2 + 840 X2CG2C2
+ 900 X2CH2C3 + 780 X2CJ2C3 + 200 X2CO2D2 + 220 X2CP2D2 + 495 X1CH2F2

+ 485 X1CJ2F2 + 900 X1CC2H2 + 900 X1CD2H2 <= 3000
77) 450 X1DI1B1 + 550 X1DJ1B1 + 500 X1DI1B2 + 550 X1DJ1B2
+ 630 X2DO1F2 + 405 X2DP1F2 + 540 X2DO1H2 + 360 X2DP1H2 + 450 X1DI2B1
+ 550 X1DJ2B1 + 500 X1DI2B2 + 550 X1DJ2B2 + 630 X2DO2F2 + 405 X2DP2F2
+ 540 X2DO2H2 + 360 X2DP2H2 <= 1500
78) 300 X3EE1A1 + 270 X3EF1A1 + 390 X3EG1A2 + 360 X3EH1A2
+ 405 X3EE1F2 + 360 X3EF1F2 + 130 X1EG1G1 + 130 X1EH1G1 + 270 X2EG1J2
+ 240 X2EH1J2 + 300 X3EE2A1 + 270 X3EF2A1 + 390 X3EG2A2 + 360 X3EH2A2
+ 405 X3EE2F2 + 360 X3EF2F2 + 130 X1EG2G1 + 130 X1EH2G1 + 270 X2EG2J2
+ 240 X2EH2J2 <= 500
79) 300 X1FQ1E2 + 550 X1FQ1F1 + 630 X1FP1F1 + 130 X1FQ1G2
+ 140 X1FP1G2 + 120 X1FJ1J3 + 180 X1FK1J3 + 300 X1FQ2E2 + 550 X1FQ2F1
+ 630 X1FP2F1 + 130 X1FQ2G2 + 140 X1FP2G2 + 120 X1FJ2J3 + 180 X1FK2J3
<= 1500
80) 450 X2GL1B1 + 505 X2GL1F1 + 550 X2GM1F1 + 240 X1GL1I1
+ 240 X1GM1I1 + 210 X2GL1J3 + 240 XGM1J3 + 140 X1GL1K1 + 160 X1GM1K1
+ 160 X1GF1K2 + 180 X1GH1K2 + 300 X2GF1M1 + 320 X2GH1M1 + 450 X2GL2B1
+ 505 X2GL2F1 + 550 X2GM2F1 + 240 X1GL2I1 + 240 X1GM2I1 + 210 X2GL2J3
+ 240 XGM2J3 + 140 X1GL2K1 + 160 X1GM2K1 + 160 X1GF2K2 + 180 X1GH2K2
+ 300 X2GF2M1 + 320 X2GH2M1 <= 1100
81) 350 X2HF1B2 + 500 X2HH1B2 + 425 X1HF1B3 + 650 X1HH1B3
+ 510 X1HC1E1 + 450 X1HT1E1 + 360 X2HF1E2 + 300 X2HH1E2 + 720 X3HT1F3
+ 585 X3HS1F3 + 90 X2HF1G2 + 150 X2HH1G2 + 120 X2HF1I1 + 180 X2HH1I1
+ 600 X2HF1M2 + 560 X2HH1M2 + 350 X2HF2B2 + 500 X2HH2B2 + 425 X1HF2B3
+ 650 X1HH2B3 + 510 X1HC2E1 + 450 X1HT2E1 + 360 X2HF2E2 + 300 X2HH2E2
+ 720 X3HT2F3 + 585 X3HS2F3 + 90 X2HF2G2 + 150 X2HH2G2 + 120 X2HF2I1
+ 180 X2HH2I1 + 600 X2HF2M2 + 560 X2HH2M2 <= 2000
82) 800 X2IK1B3 + 300 X2IR1E1 + 800 X2IK2B3 + 300 X2IR2E1 <= 1000
83) 540 X3JP1F1 + 540 X3JO1F1 + 130 X2JT1G1 + 140 X2JR1G1
+ 250 X1JT1L2 + 350 X1JR1L2 + 540 X3JP2F1 + 540 X3JO2F1 + 130 X2JT2G1
+ 140 X2JR2G1 + 250 X1JT2L2 + 350 X1JR2L2 + 300 X2JO1D1 + 450 X2JP1D1
+ 300 X2JO2D1 + 450 X2JP2D1 <= 500
84) 540 X3JP1F1 + 540 X3JO1F1 + 130 X2JT1G1 + 140 X2JR1G1
+ 250 X1JT1L2 + 350 X1JR1L2 + 540 X3JP2F1 + 540 X3JO2F1 + 130 X2JT2G1
+ 140 X2JR2G1 + 250 X1JT2L2 + 350 X1JR2L2 + 300 X2JO1D1 + 450 X2JP1D1
+ 300 X2JO2D1 + 450 X2JP2D1 <= 500

CONSTRAINT TO ENSURE THAT EACH TOOL IS ASSIGNED TO ONE MACHINE ONLY, AND THE MACHINE-TOOL COMBINATION TO ONE CELL ONLY:

85) MAA1 + MAA2 <= 1
86) MAB1 + MAB2 <= 1
87) MBC1 + MCC1 + MHC1 + MBC2 + MCC2 + MHC2 <= 1
88) MBD1 + MCD1 + MBD2 + MCD2 <= 1
89) MBF1 + MCF1 + MEF1 + MHF1 + MGF1 + MBF2 + MCF2 + MEF2 + MHF2
+ MGF2 <= 1
90) MAG1 + MCG1 + MEG1 + MAG2 + MCG2 + MEG2 <= 1
91) MCH1 + MEH1 + MGH1 + MHH1 + MCH2 + MEH2 + MGH2 + MHH2 <= 1
92) MAI1 + MCI1 + MDI1 + MAI2 + MCI2 + MDI2 <= 1
93) MCJ1 + MDJ1 + MFJ1 + MCJ2 + MDJ2 + MFJ2 <= 1
94) MAK1 + MFK1 + MIK1 + MAK2 + MFK2 + MIK2 <= 1
95) MGL1 + MGL2 <= 1
96) MAM1 + MBM1 + MGM1 + MAM2 + MBM2 + MGM2 <= 1
97) MAN1 + MBN1 + MAN2 + MBN2 <= 1
98) MAO1 + MCO1 + MDO1 + MJO1 + MAO2 + MCO2 + MDO2 + MJO2 <= 1
99) MBP1 + MCP1 + MDP1 + MFP1 + MJP1 + MBP2 + MCP2 + MDP2 + MFP2
+ MJP2 <= 1
100) MBQ1 + MFQ1 + MBQ2 + MFQ2 <= 1
101) MBR1 + MIR1 + MJR1 + MBR2 + MIR2 + MJR2 <= 1
102) MBS1 + MHS1 + MBS2 + MHS2 <= 1
103) MBT1 + MHT1 + MJT1 + MBT2 + MHT2 + MJT2 <= 1
104) MBE1 + MCE1 + MEE1 + MBE2 + MCE2 + MEE2 <= 1

CONSTRAINT ON THE LIFE OF TOOLS:

105) 270 X1AA1A1 + 540 X1AA1C1 + 360 X1AA1H1 + 270 X1AA2A1
+ 540 X1AA2C1 + 360 X1AA2H1 - 600 MAA1 - 600 MAA2 <= 0
106) 540 X1AB1A1 + 580 X1AB1C1 + 450 X1AB1H1 + 540 X1AB2A1
+ 580 X1AB2C1 + 450 X1AB2H1 - 350 MAB1 - 350 MAB2 <= 0
107) 450 X1BC1A2 + 840 X1BC1C2 + 450 X1BC2A2 + 840 X1BC2C2 - 1000 MBC1
- 1000 MBC2 <= 0
108) 210 X2CC1A1 + 900 X1CC1H2 + 210 X2CC2A1 + 900 X1CC2H2 - 1000 MCC1
- 1000 MCC2 <= 0
109) 240 X2CD1A1 + 900 X1CD1H2 + 240 X2CD2A1 + 900 X1CD2H2 - 400 MCD1
- 400 MCD2 <= 0
110) 540 X2BE1H1 + 540 X2BE2H1 - 500 MBE1 - 500 MBE2 <= 0
111) 180 X2CE1A2 + 180 X2CE2A2 - 500 MCE1 - 500 MCE2 <= 0
112) 300 X3EE1A1 + 405 X3EE1F2 + 300 X3EE2A1 + 405 X3EE2F2
- 500 MEE1 - 500 MEE2 <= 0
113) 720 X2BF1H1 + 720 X2BF2H1 - 1800 MBF1 - 1800 MBF2 <= 0
114) 240 X2CF1A2 + 240 X2CF2A2 - 1800 MCF1 - 1800 MCF2 <= 0
115) 270 X3EF1A1 + 360 X3EF1F2 + 270 X3EF2A1 + 360 X3EF2F2
- 1800 MEF1 - 1800 MEF2 <= 0
116) 350 X2HF1B2 + 425 X1HF1B3 + 360 X2HF1E2 + 90 X2HF1G2
+ 120 X2HF1I1 + 600 X2HF1M2 + 350 X2HF2B2 + 425 X1HF2B3 + 360 X2HF2E2
+ 90 X2HF2G2 + 120 X2HF2I1 + 600 X2HF2M2 - 1800 MHF1 - 1800 MHF2
<= 0
117) 160 X1GF1K2 + 400 X2GF1M1 + 160 X1GF2K2 + 400 X2GF2M1
- 1800 MGF1 - 1800 MGF2 <= 0
118) 200 X1AG1D1 + 200 X1AG2D1 - 1200 MAG1 - 1200 MAG2 <= 0
119) 900 X2CG1C1 + 840 X2CG1C2 + 900 X2CG2C1 + 840 X2CG2C2
- 1200 MCG1 - 1200 MCG2 <= 0
120) 390 X3EG1A2 + 130 X1EG1G1 + 270 X2EG1J2 + 390 X3EG2A2
+ 130 X1EG2G1 + 270 X2EG2J2 - 1200 MEG1 - 1200 MEG2 <= 0
121) 900 X2CH1C3 + 495 X1CH1F2 + 900 X2CH2C3 + 495 X1CH2F2
- 500 MCH1 - 500 MCH2 <= 0
122) 360 X3EH1A2 + 130 X1EH1G1 + 240 X2EH1J2 + 360 X3EH2A2
+ 130 X1EH2G1 + 240 X2EH2J2 - 500 MEH1 - 500 MEH2 <= 0
123) 180 X1GH1K2 + 440 X2GH1M1 + 180 X1GH2K2 + 440 X2GH2M1
- 500 MGH1 - 500 MGH2 <= 0
124) 500 X2HH1B2 + 650 X1HH1B3 + 300 X2HH1E2 + 150 X2HH1G2
+ 180 X2HH1I1 + 560 X2HH1M2 + 500 X2HH2B2 + 650 X1HH2B3 + 300 X2HH2E2
+ 150 X2HH2G2 + 180 X2HH2I1 + 560 X2HH2M2 - 500 MHH1 - 500 MHH2
<= 0
125) 400 X1AI1L1 + 400 X1AI1M1 + 400 X1AI2L1 + 400 X1AI2M1 - 600 MAI1
- 600 MAI2 <= 0
126) 840 X2CI1C1 + 900 X2CI1C2 + 840 X2CI2C1 + 900 X2CI2C2 - 600 MCI1
- 600 MCI2 <= 0
127) 450 X1DI1B1 + 500 X1DI1B2 + 450 X1DI2B1 + 500 X1DI2B2 - 600 MDI1
- 600 MDI2 <= 0
128) 840 X2CJ1C3 + 595 X1CJ1F2 + 840 X2CJ2C3 + 595 X1CJ2F2 - 800 MCJ1
- 800 MCJ2 <= 0
129) 650 X1DJ1B1 + 650 X1DJ1B2 + 650 X1DJ2B1 + 650 X1DJ2B2 - 800 MDJ1
- 800 MDJ2 <= 0
130) 120 X1FJ1J3 + 120 X1FJ2J3 - 800 MFJ1 - 800 MFJ2 <= 0
131) 400 X1AK1L1 + 400 X1AK1M1 + 400 X1AK2L1 + 400 X1AK2M1 - 280 MAK1
- 280 MAK2 <= 0
132) 150 X1FK1J3 + 150 X1FK2J3 - 280 MFK1 - 280 MFK2 <= 0
133) 800 X2IK1B3 + 800 X2IK2B3 - 280 MIK1 - 280 MIK2 <= 0
134) 450 X2GL1B1 + 360 X2GL1F1 + 240 X1GL1I1 + 210 X2GL1J3
+ 120 X1GL1K1 + 450 X2GL2B1 + 360 X2GL2F1 + 240 X1GL2I1 + 210 X2GL2J3
+ 120 X1GL2K1 - 580 MGL1 - 680 MGL2 <= 0
135) 145 X1AM1D1 + 145 X1AM2D1 - 500 MAM1 - 500 MAM2 <= 0
136) 840 X1BM1C3 + 840 X1BM2C3 - 500 MBM1 - 500 MBM2 <= 0
137) 225 X2GM1F1 + 150 X1GM1I1 + 100 X1GM1K1 + 225 X2GM2F1

+ 150 X1GM2I1 + 100 X1GM2K1 + 150 X2GM1J3 + 150 X2GM2J3 - 500 MGM1
- 500 MGM2 <= 0
138) 315 X1AN1F3 + 120 X1AN1J1 + 315 X1AN2F3 + 120 X1AN2J1 - 300 MAN1
- 300 MAN2 <= 0
139) 480 X1BN1C3 + 100 X1BN1D2 + 480 X1BN2C3 + 100 X1BN2D2 - 300 MBN1
- 300 MBN2 <= 0
140) 360 X1AO1F3 + 150 X1AO1J1 + 360 X1AO2F3 + 150 X1AO2J1
- 600 MAO1 - 600 MAO2 <= 0
141) 270 X2DO1F2 + 270 X2DO1H2 + 270 X2DO2F2 + 270 X2DO2H2
- 600 MDO1 - 600 MDO2 <= 0
142) 80 X2JO1D1 + 80 X2JO2D1 - 600 MJO1 - 600 MJO2 <= 0
143) 450 X2BP1F3 + 450 X2BP2F3 - 700 MBP1 - 700 MBP2 <= 0
144) 140 X2CP1D2 + 140 X2CP2D2 - 700 MCP1 - 700 MCP2 <= 0
145) 225 X2DP1F2 + 180 X2DP1H2 + 225 X2DP2F2 + 180 X2DP2H2 - 700 MDP1
- 700 MDP2 <= 0
146) 450 X1FP1F1 + 90 X1FP1G2 + 450 X1FP2F1 + 90 X1FP2G2 - 700 MFP1
- 700 MFP2 <= 0
147) 405 X3JP1F1 + 405 X3JP2F1 + 140 X2JP1D1 + 140 X2JP2D1 - 700 MJP1
- 700 MJP2 <= 0
148) 310 X1BQ1D2 + 405 X2BQ1F3 + 150 X2BQ1J1 + 310 X1BQ2D2
+ 405 X2BQ2F3 + 150 X2BQ2J1 - 1500 MBQ1 - 1500 MBQ2 <= 0
149) 300 X1FQ1E2 + 550 X1FQ1F1 + 140 X1FQ1G2 + 300 X1FQ2E2
+ 550 X1FQ2F1 + 140 X1FQ2G2 - 1500 MFQ1 - 1500 MFQ2 <= 0
150) 210 X1BR1J2 + 360 X1BR1M2 + 210 X1BR2J2 + 360 X1BR2M2 - 320 MBR1
- 320 MBR2 <= 0
151) 300 X2IR1E1 + 300 X2IR2E1 - 320 MIR1 - 320 MIR2 <= 0
152) 140 X2JR1G1 + 350 X1JR1L2 + 140 X2JR2G1 + 350 X1JR2L2 - 320 MJR1
- 320 MJR2 <= 0
153) 420 X1BS1J2 + 800 X1BS1M2 - 540 MBS1 - 540 MBS2 <= 0
154) 595 X3HS1F3 + 595 X3HS2F3 - 540 MHS1 - 540 MHS2 + 330 X1HS1E2
+ 330 X1HS2E2 <= 0
155) 270 X2BT1J1 + 270 X2BT2J1 - 300 MBT1 - 300 MBT2 <= 0
156) 450 X1HT1E1 + 720 X3HT1F3 + 450 X1HT2E1 + 720 X3HT2F3
- 300 MHT1 - 300 MHT2 <= 0
157) 130 X2JT1G1 + 250 X1JT1L2 + 130 X2JT2G1 + 250 X1JT2L2
- 300 MJT1 - 300 MJT2 <= 0
158) 510 X1HC1E1 + 510 X1HC2E1 - 1000 MHC1 - 1000 MHC2 <= 0

LINEARIZATION CONSTRAINTS:

159) X1AA1A1 + X2CC1A1 - 2 F1 >= 0
160) X1AA1A1 + X2CD1A1 - 2 F2 >= 0
161) X1AB1A1 + X2CC1A1 - 2 F3 >= 0
162) X1AB1A1 + X2CD1A1 - 2 F4 >= 0
163) X2CC1A1 + X3EE1A1 - 2 F5 >= 0
164) X2CC1A1 + X3EF1A1 - 2 F6 >= 0
165) X2CD1A1 + X3EF1A1 - 2 F7 >= 0
166) X2CD1A1 + X3EE1A1 - 2 F8 >= 0
167) X1BD1A2 + X2CF1A2 - 2 F9 >= 0
168) X1BD1A2 + X2CE1A2 - 2 F10 >= 0
169) X1BC1A2 + X2CE1A2 - 2 F11 >= 0
170) X1BC1A2 + X2CF1A2 - 2 F12 >= 0
171) X2CF1A2 + X3EG1A2 - 2 F13 >= 0
172) X2CF1A2 + X3EH1A2 - 2 F14 >= 0
173) X2CE1A2 + X3EG1A2 - 2 F15 >= 0
174) X2CE1A2 + X3EH1A2 - 2 F16 >= 0
175) X1DI1B1 + X2GL1B1 - 2 F17 >= 0
176) X1DJ1B1 + X2GL1B1 - 2 F18 >= 0
177) X1DI1B2 + X2HF1B2 - 2 F19 >= 0
178) X1DI1B2 + X2HH1B2 - 2 F20 >= 0
179) X1DJ1B2 + X2HF1B2 - 2 F21 >= 0
180) X1DJ1B2 + X2HH1B2 - 2 F22 >= 0

181) X1HF1B3 + X2IK1B3 - 2 F23 >= 0
182) X1HH1B3 + X2IK1B3 - 2 F24 >= 0
183) X1AA1C1 + X2CG1C1 - 2 F25 >= 0
184) X1AA1C1 + X2CI1C1 - 2 F26 >= 0
185) X1AB1C1 + X2CG1C1 - 2 F27 >= 0
186) X1AB1C1 + X2CI1C1 - 2 F28 >= 0
187) X1BC1C2 + X2CI1C2 - 2 F29 >= 0
188) X1BC1C2 + X2CG1C2 - 2 F30 >= 0
189) X1BD1C2 + X2CI1C2 - 2 F31 >= 0
190) X1BD1C2 + X2CG1C2 - 2 F32 >= 0
191) X1BM1C3 + X2CH1C3 - 2 F33 >= 0
192) X1BM1C3 + X2CJ1C3 - 2 F34 >= 0
193) X1BN1C3 + X2CH1C3 - 2 F35 >= 0
194) X1BN1C3 + X2CJ1C3 - 2 F36 >= 0
195) X1AG1D1 - 2 F37 + X2JO1D1 >= 0
196) X1AG1D1 - 2 F38 + X2JP1D1 >= 0
197) X1AM1D1 - 2 F39 + X2JO1D1 >= 0
198) X1AM1D1 - 2 F40 + X2JP1D1 >= 0
199) X2CO1D2 - 2 F41 + X1BM1D2 >= 0
200) X2CP1D2 - 2 F42 + X1BM1D2 >= 0
201) X1BN1D2 + X2CO1D2 - 2 F43 >= 0
202) X1BN1D2 + X2CP1D2 - 2 F44 >= 0
203) X1HC1E1 + X2IR1E1 - 2 F45 >= 0
204) X1HT1E1 + X2IR1E1 - 2 F46 >= 0
205) X1FQ1E2 + X2HF1E2 - 2 F47 >= 0
206) X1FQ1E2 + X2HH1E2 - 2 F48 >= 0
207) X1FQ1F1 + X2GL1F1 - 2 F49 >= 0
208) X1FQ1F1 + X2GM1F1 - 2 F50 >= 0
209) X1FP1F1 + X2GL1F1 - 2 F51 >= 0
210) X1FP1F1 + X2GM1F1 - 2 F52 >= 0
211) X2GL1F1 + X3JO1F1 - 2 F53 >= 0
212) X2GL1F1 + X3JP1F1 - 2 F54 >= 0
213) X2GM1F1 + X3JO1F1 - 2 F55 >= 0
214) X2GM1F1 + X3JP1F1 - 2 F56 >= 0
215) X1CH1F2 + X2DO1F2 - 2 F57 >= 0
216) X1CH1F2 + X2DP1F2 - 2 F58 >= 0
217) X1CJ1F2 + X2DO1F2 - 2 F59 >= 0
218) X1CJ1F2 + X2DP1F2 - 2 F60 >= 0
219) X2DO1F2 + X3EE1F2 - 2 F61 >= 0
220) X2DO1F2 + X3EF1F2 - 2 F62 >= 0
221) X2DP1F2 + X3EE1F2 - 2 F63 >= 0
222) X2DP1F2 + X3EF1F2 - 2 F64 >= 0
223) X1AN1F3 + X2BQ1F3 - 2 F65 >= 0
224) X1AN1F3 + X2BP1F3 - 2 F66 >= 0
225) X1AO1F3 + X2BQ1F3 - 2 F67 >= 0
226) X1AO1F3 + X2BP1F3 - 2 F68 >= 0
227) X1EG1G1 + X2JT1G1 - 2 F69 >= 0
228) X1EG1G1 + X2JR1G1 - 2 F70 >= 0
229) X1EH1G1 + X2JT1G1 - 2 F71 >= 0
230) X1EH1G1 + X2JR1G1 - 2 F72 >= 0
231) X1FQ1G2 + X2HF1G2 - 2 F73 >= 0
232) X1FQ1G2 + X2HH1G2 - 2 F74 >= 0
233) X1FP1G2 + X2HF1G2 - 2 F75 >= 0
234) X1FP1G2 + X2HH1G2 - 2 F76 >= 0
235) X1AA1H1 + X2BE1H1 - 2 F77 >= 0
236) X1AA1H1 + X2BF1H1 - 2 F78 >= 0
237) X1AB1H1 + X2BE1H1 - 2 F79 >= 0
238) X1AB1H1 + X2BF1H1 - 2 F80 >= 0
239) X1CC1H2 + X2DO1H2 - 2 F81 >= 0
240) X1CC1H2 + X2DP1H2 - 2 F82 >= 0
241) X1CD1H2 + X2DO1H2 - 2 F83 >= 0
242) X1CD1H2 + X2DO1H2 - 2 F84 >= 0

243) X1GL1I1 + X2HF1I1 - 2 F85 >= 0
244) X1GL1I1 + X2HH1I1 - 2 F86 >= 0
245) X1GM1I1 + X2HF1I1 - 2 F87 >= 0
246) X1GM1I1 + X2HH1I1 - 2 F88 >= 0
247) X1AN1J1 + X2BQ1J1 - 2 F89 >= 0
248) X1AN1J1 + X2BT1J1 - 2 F90 >= 0
249) X1AO1J1 + X2BQ1J1 - 2 F91 >= 0
250) X1AO1J1 + X2BT1J1 - 2 F92 >= 0
251) X1BR1J2 + X2EG1J2 - 2 F93 >= 0
252) X1BR1J2 + X2EH1J2 - 2 F94 >= 0
253) X1BS1J2 + X2EG1J2 - 2 F95 >= 0
254) X1BS1J2 + X2EH1J2 - 2 F96 >= 0
255) X1FJ1J3 + X2GL1J3 - 2 F97 >= 0
256) X1FJ1J3 - 2 F98 + X2GM1J3 >= 0
257) X1FK1J3 + X2GL1J3 - 2 F99 >= 0
258) X1FK1J3 - 2 F100 + X2GM1J3 >= 0
259) X1AI1M1 + X2GF1M1 - 2 F101 >= 0
260) X1AI1M1 + X2GH1M1 - 2 F102 >= 0
261) X1AK1M1 + X2GF1M1 - 2 F103 >= 0
262) X1AK1M1 + X2GH1M1 - 2 F104 >= 0
263) X1BR1M2 + X2HF1M2 - 2 F105 >= 0
264) X1BR1M2 + X2HH1M2 - 2 F106 >= 0
265) X1BS1M2 - 2 F107 + X2H1FM2 >= 0
266) X1BS1M2 + X2HH1M2 - 2 F108 >= 0
267) X1AA1A1 + X2CC2A1 - 2 F1B >= 0
268) X1AA1A1 + X2CD2A1 - 2 F2B >= 0
269) X1AB1A1 + X2CC2A1 - 2 F3B >= 0
270) X1AB1A1 + X2CD2A1 - 2 F4B >= 0
271) X2CC1A1 + X3EE2A1 - 2 F5B >= 0
272) X2CC1A1 + X3EF2A1 - 2 F6B >= 0
273) X2CD1A1 + X3EF2A1 - 2 F7B >= 0
274) X2CD1A1 + X3EE2A1 - 2 F8B >= 0
275) X1BD1A2 + X2CF2A2 - 2 F9B >= 0
276) X1BD1A2 + X2CE2A2 - 2 F10B >= 0
277) X1BC1A2 + X2CE2A2 - 2 F11B >= 0
278) X1BC1A2 + X2CF2A2 - 2 F12B >= 0
279) X2CF1A2 + X3EG2A2 - 2 F13B >= 0
280) X2CF1A2 + X3EH2A2 - 2 F14B >= 0
281) X2CE1A2 + X3EG2A2 - 2 F15B >= 0
282) X2CE1A2 + X3EH2A2 - 2 F16B >= 0
283) X1DI1B1 + X2GL2B1 - 2 F17B >= 0
284) X1DJ1B1 + X2GL2B1 - 2 F18B >= 0
285) X1DI1B2 + X2HF2B2 - 2 F19B >= 0
286) X1DI1B2 + X2HH2B2 - 2 F20B >= 0
287) X1DJ1B2 + X2HF2B2 - 2 F21B >= 0
288) X1DJ1B2 + X2HH2B2 - 2 F22B >= 0
289) X1HF1B3 + X2IK2B3 - 2 F23B >= 0
290) X1HH1B3 + X2IK2B3 - 2 F24B >= 0
291) X1AA1C1 + X2CG2C1 - 2 F25B >= 0
292) X1AA1C1 + X2CI2C1 - 2 F26B >= 0
293) X1AB1C1 + X2CG2C1 - 2 F27B >= 0
294) X1AB1C1 + X2CI2C1 - 2 F28B >= 0
295) X1BC1C2 + X2CI2C2 - 2 F29B >= 0
296) X1BC1C2 + X2CG2C2 - 2 F30B >= 0
297) X1BD1C2 + X2CI2C2 - 2 F31B >= 0
298) X1BD1C2 + X2CG2C2 - 2 F32B >= 0
299) X1BM1C3 + X2CH2C3 - 2 F33B >= 0
300) X1BM1C3 + X2CJ2C3 - 2 F34B >= 0
301) X1BN1C3 + X2CH2C3 - 2 F35B >= 0
302) X1BN1C3 + X2CJ2C3 - 2 F36B >= 0
303) X1AG1D1 - 2 F37B + X2JO2D1 >= 0
304) X1AG1D1 - 2 F38B + X2JP2D1 >= 0

305) X1AM1D1 - 2 F39B + X2JO2D1 >= 0
306) X1AM1D1 - 2 F40B + X2JP2D1 >= 0
307) X2CO2D2 - 2 F41B + X1BM1D2 >= 0
308) X2CP2D2 - 2 F42B + X1BM1D2 >= 0
309) X1BN1D2 + X2CO2D2 - 2 F43B >= 0
310) X1BN1D2 + X2CP2D2 - 2 F44B >= 0
311) X1HC1E1 + X2IR2E1 - 2 F45B >= 0
312) X1HT1E1 + X2IR2E1 - 2 F46B >= 0
313) X1FQ1E2 + X2HF2E2 - 2 F47B >= 0
314) X1FQ1E2 + X2HH2E2 - 2 F48B >= 0
315) X1FQ1F1 + X2GL2F1 - 2 F49B >= 0
316) X1FQ1F1 + X2GM2F1 - 2 F50B >= 0
317) X1FP1F1 + X2GL2F1 - 2 F51B >= 0
318) X1FP1F1 + X2GM2F1 - 2 F52B >= 0
319) X2GL1F1 + X3JO2F1 - 2 F53B >= 0
320) X2GL1F1 + X3JP2F1 - 2 F54B >= 0
321) X2GM1F1 + X3JO2F1 - 2 F55B >= 0
322) X2GM1F1 + X3JP2F1 - 2 F56B >= 0
323) X1CH1F2 + X2DO2F2 - 2 F57B >= 0
324) X1CH1F2 + X2DP2F2 - 2 F58B >= 0
325) X1CJ1F2 + X2DO2F2 - 2 F59B >= 0
326) X1CJ1F2 + X2DP2F2 - 2 F60B >= 0
327) X2DO1F2 + X3EE2F2 - 2 F61B >= 0
328) X2DO1F2 + X3EF2F2 - 2 F62B >= 0
329) X2DP1F2 + X3EE2F2 - 2 F63B >= 0
330) X2DP1F2 + X3EF2F2 - 2 F64B >= 0
331) X1AN1F3 + X2BQ2F3 - 2 F65B >= 0
332) X1AN1F3 + X2BP2F3 - 2 F66B >= 0
333) X1AO1F3 + X2BQ2F3 - 2 F67B >= 0
334) X1AO1F3 + X2BP2F3 - 2 F68B >= 0
335) X1EG1G1 + X2JT2G1 - 2 F69B >= 0
336) X1EG1G1 + X2JR2G1 - 2 F70B >= 0
337) X1EH1G1 + X2JT2G1 - 2 F71B >= 0
338) X1EH1G1 + X2JR2G1 - 2 F72B >= 0
339) X1FQ1G2 + X2HF2G2 - 2 F73B >= 0
340) X1FQ1G2 + X2HH2G2 - 2 F74B >= 0
341) X1FP1G2 + X2HF2G2 - 2 F75B >= 0
342) X1FP1G2 + X2HH2G2 - 2 F76B >= 0
343) X1AA1H1 + X2BE2H1 - 2 F77B >= 0
344) X1AA1H1 + X2BF2H1 - 2 F78B >= 0
345) X1AB1H1 + X2BE2H1 - 2 F79B >= 0
346) X1AB1H1 + X2BF2H1 - 2 F80B >= 0
347) X1CC1H2 + X2DO2H2 - 2 F81B >= 0
348) X1CC1H2 + X2DP2H2 - 2 F82B >= 0
349) X1CD1H2 + X2DO2H2 - 2 F83B >= 0
350) X1CD1H2 + X2DO2H2 - 2 F84B >= 0
351) X1GL1I1 + X2HF2I1 - 2 F85B >= 0
352) X1GL1I1 + X2HH2I1 - 2 F86B >= 0
353) X1GM1I1 + X2HF2I1 - 2 F87B >= 0
354) X1GM1I1 + X2HH2I1 - 2 F88B >= 0
355) X1AN1J1 + X2BQ2J1 - 2 F89B >= 0
356) X1AN1J1 + X2BT2J1 - 2 F90B >= 0
357) X1AO1J1 + X2BQ2J1 - 2 F91B >= 0
358) X1AO1J1 + X2BT2J1 - 2 F92B >= 0
359) X1BR1J2 + X2EG2J2 - 2 F93B >= 0
360) X1BR1J2 + X2EH2J2 - 2 F94B >= 0
361) X1BS1J2 + X2EG2J2 - 2 F95B >= 0
362) X1BS1J2 + X2EH2J2 - 2 F96B >= 0
363) X1FJ1J3 + X2GL2J3 - 2 F97B >= 0
364) X1FJ1J3 - 2 F98B + X2GM2J3 >= 0
365) X1FK1J3 + X2GL2J3 - 2 F99B >= 0
366) X1FK1J3 - 2 F100B + X2GM2J3 >= 0

367) X1AI1M1 + X2GF2M1 - 2 F101B >= 0
368) X1AI1M1 + X2GH2M1 - 2 F102B >= 0
369) X1AK1M1 + X2GF2M1 - 2 F103B >= 0
370) X1AK1M1 + X2GH2M1 - 2 F104B >= 0
371) X1BR1M2 + X2HF2M2 - 2 F105B >= 0
372) X1BR1M2 + X2HH2M2 - 2 F106B >= 0
373) X1BS1M2 + X2HF2M2 - 2 F107B >= 0
374) X1BS1M2 + X2HH2M2 - 2 F108B >= 0
375) X2CC1A1 + X1AA2A1 - 2 F1C >= 0
376) X2CD1A1 + X1AA2A1 - 2 F2C >= 0
377) X2CC1A1 + X1AB2A1 - 2 F3C >= 0
378) X2CD1A1 + X1AB2A1 - 2 F4C >= 0
379) X3EE1A1 + X2CC2A1 - 2 F5C >= 0
380) X3EF1A1 + X2CC2A1 - 2 F6C >= 0
381) X3EF1A1 + X2CD2A1 - 2 F7C >= 0
382) X3EE1A1 + X2CD2A1 - 2 F8C >= 0
383) X2CF1A2 + X1BD2A2 - 2 F9C >= 0
384) X2CE1A2 + X1BD2A2 - 2 F10C >= 0
385) X2CE1A2 + X1BC2A2 - 2 F11C >= 0
386) X2CF1A2 + X1BC2A2 - 2 F12C >= 0
387) X3EG1A2 + X2CF2A2 - 2 F13C >= 0
388) X3EH1A2 + X2CF2A2 - 2 F14C >= 0
389) X3EG1A2 + X2CE2A2 - 2 F15C >= 0
390) X3EH1A2 + X2CE2A2 - 2 F16C >= 0
391) X2GL1B1 + X1DI2B1 - 2 F17C >= 0
392) X2GL1B1 + X1DJ2B1 - 2 F18C >= 0
393) X2HF1B2 + X1DI2B2 - 2 F19C >= 0
394) X2HH1B2 + X1DI2B2 - 2 F20C >= 0
395) X2HF1B2 + X1DJ2B2 - 2 F21C >= 0
396) X2HH1B2 + X1DJ2B2 - 2 F22C >= 0
397) X2IK1B3 + X1HF2B3 - 2 F23C >= 0
398) X2IK1B3 + X1HH2B3 - 2 F24C >= 0
399) X2CG1C1 + X1AA2C1 - 2 F25C >= 0
400) X2CI1C1 + X1AA2C1 - 2 F26C >= 0
401) X2CG1C1 + X1AB2C1 - 2 F27C >= 0
402) X2CI1C1 + X1AB2C1 - 2 F28C >= 0
403) X2CI1C2 + X1BC2C2 - 2 F29C >= 0
404) X2CG1C2 + X1BC2C2 - 2 F30C >= 0
405) X2CI1C2 + X1BD2C2 - 2 F31C >= 0
406) X2CG1C2 + X1BD2C2 - 2 F32C >= 0
407) X2CH1C3 + X1BM2C3 - 2 F33C >= 0
408) X2CJ1C3 + X1BM2C3 - 2 F34C >= 0
409) X2CH1C3 + X1BN2C3 - 2 F35C >= 0
410) X2CJ1C3 + X1BN2C3 - 2 F36C >= 0
411) X1AG2D1 - 2 F37C + X2JO1D1 >= 0
412) X1AG2D1 - 2 F38C + X2JP1D1 >= 0
413) X1AM2D1 - 2 F39C + X2JO1D1 >= 0
414) X1AM2D1 - 2 F40C + X2JP1D1 >= 0
415) X2CO1D2 - 2 F41C + X1BM2D2 >= 0
416) X2CP1D2 - 2 F42C + X1BM2D2 >= 0
417) X2CO1D2 + X1BN2D2 - 2 F43C >= 0
418) X2CP1D2 + X1BN2D2 - 2 F44C >= 0
419) X2IR1E1 + X1HC2E1 - 2 F45C >= 0
420) X2IR1E1 + X1HT2E1 - 2 F46C >= 0
421) X2HF1E2 + X1FQ2E2 - 2 F47C >= 0
422) X2HH1E2 + X1FQ2E2 - 2 F48C >= 0
423) X2GL1F1 + X1FQ2F1 - 2 F49C >= 0
424) X2GM1F1 + X1FQ2F1 - 2 F50C >= 0
425) X2GL1F1 + X1FP2F1 - 2 F51C >= 0
426) X2GM1F1 + X1FP2F1 - 2 F52C >= 0
427) X3JO1F1 + X2GL2F1 - 2 F53C >= 0
428) X3JP1F1 + X2GL2F1 - 2 F54C >= 0

429) X3JO1F1 + X2GM2F1 - 2 F55C >= 0
430) X3JP1F1 + X2GM2F1 - 2 F56C >= 0
431) X2DO1F2 + X1CH2F2 - 2 F57C >= 0
432) X2DP1F2 + X1CH2F2 - 2 F58C >= 0
433) X2DO1F2 + X1CJ2F2 - 2 F59C >= 0
434) X2DP1F2 + X1CJ2F2 - 2 F60C >= 0
435) X3EE1F2 + X2DO2F2 - 2 F61C >= 0
436) X3EF1F2 + X2DO2F2 - 2 F62C >= 0
437) X3EE1F2 + X2DP2F2 - 2 F63C >= 0
438) X3EF1F2 + X2DP2F2 - 2 F64C >= 0
439) X2BQ1F3 + X1AN2F3 - 2 F65C >= 0
440) X2BP1F3 + X1AN2F3 - 2 F66C >= 0
441) X2BQ1F3 + X1AO2F3 - 2 F67C >= 0
442) X2BP1F3 + X1AO2F3 - 2 F68C >= 0
443) X2JT1G1 + X1EG2G1 - 2 F69C >= 0
444) X2JR1G1 + X1EG2G1 - 2 F70C >= 0
445) X2JT1G1 + X1EH2G1 - 2 F71C >= 0
446) X2JR1G1 + X1EH2G1 - 2 F72C >= 0
447) X2HF1G2 + X1FQ2G2 - 2 F73C >= 0
448) X2HH1G2 + X1FQ2G2 - 2 F74C >= 0
449) X2HF1G2 + X1FP2G2 - 2 F75C >= 0
450) X2HH1G2 + X1FP2G2 - 2 F76C >= 0
451) X2BE1H1 + X1AA2H1 - 2 F77C >= 0
452) X2BF1H1 + X1AA2H1 - 2 F78C >= 0
453) X2BE1H1 + X1AB2H1 - 2 F79C >= 0
454) X2BF1H1 + X1AB2H1 - 2 F80C >= 0
455) X2DO1H2 + X1CC2H2 - 2 F81C >= 0
456) X2DP1H2 + X1CC2H2 - 2 F82C >= 0
457) X2DO1H2 + X1CD2H2 - 2 F83C >= 0
458) X2DO1H2 + X1CD2H2 - 2 F84C >= 0
459) X2HF1I1 + X1GL2I1 - 2 F85C >= 0
460) X2HH1I1 + X1GL2I1 - 2 F86C >= 0
461) X2HF1I1 + X1GM2I1 - 2 F87C >= 0
462) X2HH1I1 + X1GM2I1 - 2 F88C >= 0
463) X2BQ1J1 + X1AN2J1 - 2 F89C >= 0
464) X2BT1J1 + X1AN2J1 - 2 F90C >= 0
465) X2BQ1J1 + X1AO2J1 - 2 F91C >= 0
466) X2BT1J1 + X1AO2J1 - 2 F92C >= 0
467) X2EG1J2 + X1BR2J2 - 2 F93C >= 0
468) X2EH1J2 + X1BR2J2 - 2 F94C >= 0
469) X2EG1J2 + X1BS2J2 - 2 F95C >= 0
470) X2EH1J2 + X1BS2J2 - 2 F96C >= 0
471) X2GL1J3 + X1FJ2J3 - 2 F97C >= 0
472) X1FJ2J3 - 2 F98C + X2GM1J3 >= 0
473) X2GL1J3 + X1FK2J3 - 2 F99C >= 0
474) X1FK2J3 - 2 F100C + X2GM1J3 >= 0
475) X2GF1M1 + X1AI2M1 - 2 F101C >= 0
476) X2GH1M1 + X1AI2M1 - 2 F102C >= 0
477) X2GF1M1 + X1AK2M1 - 2 F103C >= 0
478) X2GH1M1 + X1AK2M1 - 2 F104C >= 0
479) X2HF1M2 + X1BR2M2 - 2 F105C >= 0
480) X2HH1M2 + X1BR2M2 - 2 F106C >= 0
481) X2HF1M2 + X1BS2M2 - 2 F107C >= 0
482) X2HH1M2 + X1BS2M2 - 2 F108C >= 0
483) X1AA2A1 + X2CC2A1 - 2 F1D >= 0
484) X1AA2A1 + X2CD2A1 - 2 F2D >= 0
485) X1AB2A1 + X2CC2A1 - 2 F3D >= 0
486) X1AB2A1 + X2CD2A1 - 2 F4D >= 0
487) X2CC2A1 + X3EE2A1 - 2 F5D >= 0
488) X2CC2A1 + X3EF2A1 - 2 F6D >= 0
489) X2CD2A1 + X3EF2A1 - 2 F7D >= 0
490) X2CD2A1 + X3EE2A1 - 2 F8D >= 0

491) X1BD2A2 + X2CF2A2 - 2 F9D >= 0
492) X1BD2A2 + X2CE2A2 - 2 F10D >= 0
493) X1BC2A2 + X2CE2A2 - 2 F11D >= 0
494) X1BC2A2 + X2CF2A2 - 2 F12D >= 0
495) X2CF2A2 + X3EG2A2 - 2 F13D >= 0
496) X2CF2A2 + X3EH2A2 - 2 F14D >= 0
497) X2CE2A2 + X3EG2A2 - 2 F15D >= 0
498) X2CE2A2 + X3EH2A2 - 2 F16D >= 0
499) X1DI2B1 + X2GL2B1 - 2 F17D >= 0
500) X1DJ2B1 + X2GL2B1 - 2 F18D >= 0
501) X1DI2B2 + X2HF2B2 - 2 F19D >= 0
502) X1DI2B2 + X2HH2B2 - 2 F20D >= 0
503) X1DJ2B2 + X2HF2B2 - 2 F21D >= 0
504) X1DJ2B2 + X2HH2B2 - 2 F22D >= 0
505) X1HF2B3 + X2IK2B3 - 2 F23D >= 0
506) X1HH2B3 + X2IK2B3 - 2 F24D >= 0
507) X1AA2C1 + X2CG2C1 - 2 F25D >= 0
508) X1AA2C1 + X2CI2C1 - 2 F26D >= 0
509) X1AB2C1 + X2CG2C1 - 2 F27D >= 0
510) X1AB2C1 + X2CI2C1 - 2 F28D >= 0
511) X1BC2C2 + X2CI2C2 - 2 F29D >= 0
512) X1BC2C2 + X2CG2C2 - 2 F30D >= 0
513) X1BD2C2 + X2CI2C2 - 2 F31D >= 0
514) X1BD2C2 + X2CG2C2 - 2 F32D >= 0
515) X1BM2C3 + X2CH2C3 - 2 F33D >= 0
516) X1BM2C3 + X2CJ2C3 - 2 F34D >= 0
517) X1BN2C3 + X2CH2C3 - 2 F35D >= 0
518) X1BN2C3 + X2CJ2C3 - 2 F36D >= 0
519) X1AG2D1 - 2 F37D + X2JO2D1 >= 0
520) X1AG2D1 - 2 F38D + X2JP2D1 >= 0
521) X1AM2D1 - 2 F39D + X2JO2D1 >= 0
522) X1AM2D1 - 2 F40D + X2JP2D1 >= 0
523) X2CO2D2 - 2 F41D + X1BM2D2 >= 0
524) X2CP2D2 - 2 F42D + X1BM2D2 >= 0
525) X1BN2D2 + X2CO2D2 - 2 F43D >= 0
526) X1BN2D2 + X2CP2D2 - 2 F44D >= 0
527) X1HC2E1 + X2IR2E1 - 2 F45D >= 0
528) X1HT2E1 + X2IR2E1 - 2 F46D >= 0
529) X1FQ2E2 + X2HF2E2 - 2 F47D >= 0
530) X1FQ2E2 + X2HH2E2 - 2 F48D >= 0
531) X1FQ2F1 + X2GL2F1 - 2 F49D >= 0
532) X1FQ2F1 + X2GM2F1 - 2 F50D >= 0
533) X1FP2F1 + X2GL2F1 - 2 F51D >= 0
534) X1FP2F1 + X2GM2F1 - 2 F52D >= 0
535) X2GL2F1 + X3JO2F1 - 2 F53D >= 0
536) X2GL2F1 + X3JP2F1 - 2 F54D >= 0
537) X2GM2F1 + X3JO2F1 - 2 F55D >= 0
538) X2GM2F1 + X3JP2F1 - 2 F56D >= 0
539) X1CH2F2 + X2DO2F2 - 2 F57D >= 0
540) X1CH2F2 + X2DP2F2 - 2 F58D >= 0
541) X1CJ2F2 + X2DO2F2 - 2 F59D >= 0
542) X1CJ2F2 + X2DP2F2 - 2 F60D >= 0
543) X2DO2F2 + X3EE2F2 - 2 F61D >= 0
544) X2DO2F2 + X3EF2F2 - 2 F62D >= 0
545) X2DP2F2 + X3EE2F2 - 2 F63D >= 0
546) X2DP2F2 + X3EF2F2 - 2 F64D >= 0
547) X1AN2F3 + X2BQ2F3 - 2 F65D >= 0
548) X1AN2F3 + X2BP2F3 - 2 F66D >= 0
549) X1AO2F3 + X2BQ2F3 - 2 F67D >= 0
550) X1AO2F3 + X2BP2F3 - 2 F68D >= 0
551) X1EG2G1 + X2JT2G1 - 2 F69D >= 0
552) X1EG2G1 + X2JR2G1 - 2 F70D >= 0

553) X1EH2G1 + X2JT2G1 - 2 F71D >= 0
554) X1EH2G1 + X2JR2G1 - 2 F72D >= 0
555) X1FQ2G2 + X2HF2G2 - 2 F73D >= 0
556) X1FQ2G2 + X2HH2G2 - 2 F74D >= 0
557) X1FP2G2 + X2HF2G2 - 2 F75D >= 0
558) X1FP2G2 + X2HH2G2 - 2 F76D >= 0
559) X1AA2H1 + X2BE2H1 - 2 F77D >= 0
560) X1AA2H1 + X2BF2H1 - 2 F78D >= 0
561) X1AB2H1 + X2BE2H1 - 2 F79D >= 0
562) X1AB2H1 + X2BF2H1 - 2 F80D >= 0
563) X1CC2H2 + X2DO2H2 - 2 F81D >= 0
564) X1CC2H2 + X2DP2H2 - 2 F82D >= 0
565) X1CD2H2 + X2DO2H2 - 2 F83D >= 0
566) X1CD2H2 + X2DO2H2 - 2 F84D >= 0
567) X1GL2I1 + X2HF2I1 - 2 F85D >= 0
568) X1GL2I1 + X2HH2I1 - 2 F86D >= 0
569) X1GM2I1 + X2HF2I1 - 2 F87D >= 0
570) X1GM2I1 + X2HH2I1 - 2 F88D >= 0
571) X1AN2J1 + X2BQ2J1 - 2 F89D >= 0
572) X1AN2J1 + X2BT2J1 - 2 F90D >= 0
573) X1AO2J1 + X2BQ2J1 - 2 F91D >= 0
574) X1AO2J1 + X2BT2J1 - 2 F92D >= 0
575) X1BR2J2 + X2EG2J2 - 2 F93D >= 0
576) X1BR2J2 + X2EH2J2 - 2 F94D >= 0
577) X1BS2J2 + X2EG2J2 - 2 F95D >= 0
578) X1BS2J2 + X2EH2J2 - 2 F96D >= 0
579) X1FJ2J3 + X2GL2J3 - 2 F97D >= 0
580) X1FJ2J3 - 2 F98D + X2GM2J3 >= 0
581) X1FK2J3 + X2GL2J3 - 2 F99D >= 0
582) X1FK2J3 - 2 F100D + X2GM2J3 >= 0
583) X1AI2M1 + X2GF2M1 - 2 F101D >= 0
584) X1AI2M1 + X2GH2M1 - 2 F102D >= 0
585) X1AK2M1 + X2GF2M1 - 2 F103D >= 0
586) X1AK2M1 + X2GH2M1 - 2 F104D >= 0
587) X1BR2M2 + X2HF2M2 - 2 F105D >= 0
588) X1BR2M2 + X2HH2M2 - 2 F106D >= 0
589) X1BS2M2 + X2HF2M2 - 2 F107D >= 0
590) X1BS2M2 + X2HH2M2 - 2 F108D >= 0
591) X1AA1A1 + X2CC1A1 - F1 <= 1
592) X1AA1A1 + X2CD1A1 - F2 <= 1
593) X1AB1A1 + X2CC1A1 - F3 <= 1
594) X1AB1A1 + X2CD1A1 - F4 <= 1
595) X2CC1A1 + X3EE1A1 - F5 <= 1
596) X2CC1A1 + X3EF1A1 - F6 <= 1
597) X2CD1A1 + X3EF1A1 - F7 <= 1
598) X2CD1A1 + X3EE1A1 - F8 <= 1
599) X1BD1A2 + X2CF1A2 - F9 <= 1
600) X1BD1A2 + X2CE1A2 - F10 <= 1
601) X1BC1A2 + X2CE1A2 - F11 <= 1
602) X1BC1A2 + X2CF1A2 - F12 <= 1
603) X2CF1A2 + X3EG1A2 - F13 <= 1
604) X2CF1A2 + X3EH1A2 - F14 <= 1
605) X2CE1A2 + X3EG1A2 - F15 <= 1
606) X2CE1A2 + X3EH1A2 - F16 <= 1
607) X1DI1B1 + X2GL1B1 - F17 <= 1
608) X1DJ1B1 + X2GL1B1 - F18 <= 1
609) X1DI1B2 + X2HF1B2 - F19 <= 1
610) X1DI1B2 + X2HH1B2 - F20 <= 1
611) X1DJ1B2 + X2HF1B2 - F21 <= 1
612) X1DJ1B2 + X2HH1B2 - F22 <= 1
613) X1HF1B3 + X2IK1B3 - F23 <= 1
614) X1HH1B3 + X2IK1B3 - F24 <= 1

615) X1AA1C1 + X2CG1C1 - F25 <= 1
616) X1AA1C1 + X2CI1C1 - F26 <= 1
617) X1AB1C1 + X2CG1C1 - F27 <= 1
618) X1AB1C1 + X2CI1C1 - F28 <= 1
619) X1BC1C2 + X2CI1C2 - F29 <= 1
620) X1BC1C2 + X2CG1C2 - F30 <= 1
621) X1BD1C2 + X2CI1C2 - F31 <= 1
622) X1BD1C2 + X2CG1C2 - F32 <= 1
623) X1BM1C3 + X2CH1C3 - F33 <= 1
624) X1BM1C3 + X2CJ1C3 - F34 <= 1
625) X1BN1C3 + X2CH1C3 - F35 <= 1
626) X1BN1C3 + X2CJ1C3 - F36 <= 1
627) X1AG1D1 - F37 + X2JO1D1 <= 1
628) X1AG1D1 - F38 + X2JP1D1 <= 1
629) X1AM1D1 - F39 + X2JO1D1 <= 1
630) X1AM1D1 - F40 + X2JP1D1 <= 1
631) X2CO1D2 - F41 + X1BM1D2 <= 1
632) X2CP1D2 - F42 + X1BM1D2 <= 1
633) X1BN1D2 + X2CO1D2 - F43 <= 1
634) X1BN1D2 + X2CP1D2 - F44 <= 1
635) X1HC1E1 + X2IR1E1 - F45 <= 1
636) X1HT1E1 + X2IR1E1 - F46 <= 1
637) X1FQ1E2 + X2HF1E2 - F47 <= 1
638) X1FQ1E2 + X2HH1E2 - F48 <= 1
639) X1FQ1F1 + X2GL1F1 - F49 <= 1
640) X1FQ1F1 + X2GM1F1 - F50 <= 1
641) X1FP1F1 + X2GL1F1 - F51 <= 1
642) X1FP1F1 + X2GM1F1 - F52 <= 1
643) X2GL1F1 + X3JO1F1 - F53 <= 1
644) X2GL1F1 + X3JP1F1 - F54 <= 1
645) X2GM1F1 + X3JO1F1 - F55 <= 1
646) X2GM1F1 + X3JP1F1 - F56 <= 1
647) X1CH1F2 + X2DO1F2 - F57 <= 1
648) X1CH1F2 + X2DP1F2 - F58 <= 1
649) X1CJ1F2 + X2DO1F2 - F59 <= 1
650) X1CJ1F2 + X2DP1F2 - F60 <= 1
651) X2DO1F2 + X3EE1F2 - F61 <= 1
652) X2DO1F2 + X3EF1F2 - F62 <= 1
653) X2DP1F2 + X3EE1F2 - F63 <= 1
654) X2DP1F2 + X3EF1F2 - F64 <= 1
655) X1AN1F3 + X2BQ1F3 - F65 <= 1
656) X1AN1F3 + X2BP1F3 - F66 <= 1
657) X1AO1F3 + X2BQ1F3 - F67 <= 1
658) X1AO1F3 + X2BP1F3 - F68 <= 1
659) X1EG1G1 + X2JT1G1 - F69 <= 1
660) X1EG1G1 + X2JR1G1 - F70 <= 1
661) X1EH1G1 + X2JT1G1 - F71 <= 1
662) X1EH1G1 + X2JR1G1 - F72 <= 1
663) X1FQ1G2 + X2HF1G2 - F73 <= 1
664) X1FQ1G2 + X2HH1G2 - F74 <= 1
665) X1FP1G2 + X2HF1G2 - F75 <= 1
666) X1FP1G2 + X2HH1G2 - F76 <= 1
667) X1AA1H1 + X2BE1H1 - F77 <= 1
668) X1AA1H1 + X2BF1H1 - F78 <= 1
669) X1AB1H1 + X2BE1H1 - F79 <= 1
670) X1AB1H1 + X2BF1H1 - F80 <= 1
671) X1CC1H2 + X2DO1H2 - F81 <= 1
672) X1CC1H2 + X2DP1H2 - F82 <= 1
673) X1CD1H2 + X2DO1H2 - F83 <= 1
674) X1CD1H2 + X2DO1H2 - F84 <= 1
675) X1GL1I1 + X2HF1I1 - F85 <= 1
676) X1GL1I1 + X2HH1I1 - F86 <= 1

677) X1GM1I1 + X2HF1I1 - F87 <= 1
678) X1GM1I1 + X2HH1I1 - F88 <= 1
679) X1AN1J1 + X2BQ1J1 - F89 <= 1
680) X1AN1J1 + X2BT1J1 - F90 <= 1
681) X1AO1J1 + X2BQ1J1 - F91 <= 1
682) X1AO1J1 + X2BT1J1 - F92 <= 1
683) X1BR1J2 + X2EG1J2 - F93 <= 1
684) X1BR1J2 + X2EH1J2 - F94 <= 1
685) X1BS1J2 + X2EG1J2 - F95 <= 1
686) X1BS1J2 + X2EH1J2 - F96 <= 1
687) X1FJ1J3 + X2GL1J3 - F97 <= 1
688) X1FJ1J3 - F98 + X2GM1J3 <= 1
689) X1FK1J3 + X2GL1J3 - F99 <= 1
690) X1FK1J3 - F100 + X2GM1J3 <= 1
691) X1AI1M1 + X2GF1M1 - F101 <= 1
692) X1AI1M1 + X2GH1M1 - F102 <= 1
693) X1AK1M1 + X2GF1M1 - F103 <= 1
694) X1AK1M1 + X2GH1M1 - F104 <= 1
695) X1BR1M2 + X2HF1M2 - F105 <= 1
696) X1BR1M2 + X2HH1M2 - F106 <= 1
697) X1BS1M2 + X2HF1M2 - F107 <= 1
698) X1BS1M2 + X2HH1M2 - F108 <= 1
699) X1AA1A1 + X2CC2A1 - F1B <= 1
700) X1AA1A1 + X2CD2A1 - F2B <= 1
701) X1AB1A1 + X2CC2A1 - F3B <= 1
702) X1AB1A1 + X2CD2A1 - F4B <= 1
703) X2CC1A1 + X3EE2A1 - F5B <= 1
704) X2CC1A1 + X3EF2A1 - F6B <= 1
705) X2CD1A1 + X3EF2A1 - F7B <= 1
706) X2CD1A1 + X3EE2A1 - F8B <= 1
707) X1BD1A2 + X2CF2A2 - F9B <= 1
708) X1BD1A2 + X2CE2A2 - F10B <= 1
709) X1BC1A2 + X2CE2A2 - F11B <= 1
710) X1BC1A2 + X2CF2A2 - F12B <= 1
711) X2CF1A2 + X3EG2A2 - F13B <= 1
712) X2CF1A2 + X3EH2A2 - F14B <= 1
713) X2CE1A2 + X3EG2A2 - F15B <= 1
714) X2CE1A2 + X3EH2A2 - F16B <= 1
715) X1DI1B1 + X2GL2B1 - F17B <= 1
716) X1DJ1B1 + X2GL2B1 - F18B <= 1
717) X1DI1B2 + X2HF2B2 - F19B <= 1
718) X1DI1B2 + X2HH2B2 - F20B <= 1
719) X1DJ1B2 + X2HF2B2 - F21B <= 1
720) X1DJ1B2 + X2HH2B2 - F22B <= 1
721) X1HF1B3 + X2IK2B3 - F23B <= 1
722) X1HH1B3 + X2IK2B3 - F24B <= 1
723) X1AA1C1 + X2CG2C1 - F25B <= 1
724) X1AA1C1 + X2CI2C1 - F26B <= 1
725) X1AB1C1 + X2CG2C1 - F27B <= 1
726) X1AB1C1 + X2CI2C1 - F28B <= 1
727) X1BC1C2 + X2CI2C2 - F29B <= 1
728) X1BC1C2 + X2CG2C2 - F30B <= 1
729) X1BD1C2 + X2CI2C2 - F31B <= 1
730) X1BD1C2 + X2CG2C2 - F32B <= 1
731) X1BM1C3 + X2CH2C3 - F33B <= 1
732) X1BM1C3 + X2CJ2C3 - F34B <= 1
733) X1BN1C3 + X2CH2C3 - F35B <= 1
734) X1BN1C3 + X2CJ2C3 - F36B <= 1
735) X1AG1D1 - F37B + X2JO2D1 <= 1
736) X1AG1D1 - F38B + X2JP2D1 <= 1
737) X1AM1D1 - F39B + X2JO2D1 <= 1
738) X1AM1D1 - F40B + X2JP2D1 <= 1

739) X2CO2D2 - F41B + X1BM1D2 <= 1
740) X2CP2D2 - F42B + X1BM1D2 <= 1
741) X1BN1D2 + X2CO2D2 - F43B <= 1
742) X1BN1D2 + X2CP2D2 - F44B <= 1
743) X1HC1E1 + X2IR2E1 - F45B <= 1
744) X1HT1E1 + X2IR2E1 - F46B <= 1
745) X1FQ1E2 + X2HF2E2 - F47B <= 1
746) X1FQ1E2 + X2HH2E2 - F48B <= 1
747) X1FQ1F1 + X2GL2F1 - F49B <= 1
748) X1FQ1F1 + X2GM2F1 - F50B <= 1
749) X1FP1F1 + X2GL2F1 - F51B <= 1
750) X1FP1F1 + X2GM2F1 - F52B <= 1
751) X2GL1F1 + X3JO2F1 - F53B <= 1
752) X2GL1F1 + X3JP2F1 - F54B <= 1
753) X2GM1F1 + X3JO2F1 - F55B <= 1
754) X2GM1F1 + X3JP2F1 - F56B <= 1
755) X1CH1F2 + X2DO2F2 - F57B <= 1
756) X1CH1F2 + X2DP2F2 - F58B <= 1
757) X1CJ1F2 + X2DO2F2 - F59B <= 1
758) X1CJ1F2 + X2DP2F2 - F60B <= 1
759) X2DO1F2 + X3EE2F2 - F61B <= 1
760) X2DO1F2 + X3EF2F2 - F62B <= 1
761) X2DP1F2 + X3EE2F2 - F63B <= 1
762) X2DP1F2 + X3EF2F2 - F64B <= 1
763) X1AN1F3 + X2BQ2F3 - F65B <= 1
764) X1AN1F3 + X2BP2F3 - F66B <= 1
765) X1AO1F3 + X2BQ2F3 - F67B <= 1
766) X1AO1F3 + X2BP2F3 - F68B <= 1
767) X1EG1G1 + X2JT2G1 - F69B <= 1
768) X1EG1G1 + X2JR2G1 - F70B <= 1
769) X1EH1G1 + X2JT2G1 - F71B <= 1
770) X1EH1G1 + X2JR2G1 - F72B <= 1
771) X1FQ1G2 + X2HF2G2 - F73B <= 1
772) X1FQ1G2 + X2HH2G2 - F74B <= 1
773) X1FP1G2 + X2HF2G2 - F75B <= 1
774) X1FP1G2 + X2HH2G2 - F76B <= 1
775) X1AA1H1 + X2BE2H1 - F77B <= 1
776) X1AA1H1 + X2BF2H1 - F78B <= 1
777) X1AB1H1 + X2BE2H1 - F79B <= 1
778) X1AB1H1 + X2BF2H1 - F80B <= 1
779) X1CC1H2 + X2DO2H2 - F81B <= 1
780) X1CC1H2 + X2DP2H2 - F82B <= 1
781) X1CD1H2 + X2DO2H2 - F83B <= 1
782) X1CD1H2 + X2DO2H2 - F84B <= 1
783) X1GL1I1 + X2HF2I1 - F85B <= 1
784) X1GL1I1 + X2HH2I1 - F86B <= 1
785) X1GM1I1 + X2HF2I1 - F87B <= 1
786) X1GM1I1 + X2HH2I1 - F88B <= 1
787) X1AN1J1 + X2BQ2J1 - F89B <= 1
788) X1AN1J1 + X2BT2J1 - F90B <= 1
789) X1AO1J1 + X2BQ2J1 - F91B <= 1
790) X1AO1J1 + X2BT2J1 - F92B <= 1
791) X1BR1J2 + X2EG2J2 - F93B <= 1
792) X1BR1J2 + X2EH2J2 - F94B <= 1
793) X1BS1J2 + X2EG2J2 - F95B <= 1
794) X1BS1J2 + X2EH2J2 - F96B <= 1
795) X1FJ1J3 + X2GL2J3 - F97B <= 1
796) X1FJ1J3 - F98B + X2GM2J3 <= 1
797) X1FK1J3 + X2GL2J3 - F99B <= 1
798) X1FK1J3 - F100B + X2GM2J3 <= 1
799) X1AI1M1 + X2GF2M1 - F101B <= 1
800) X1AI1M1 + X2GH2M1 - F102B <= 1

801) X1AK1M1 + X2GF2M1 - F103B <= 1
802) X1AK1M1 + X2GH2M1 - F104B <= 1
803) X1BR1M2 + X2HF2M2 - F105B <= 1
804) X1BR1M2 + X2HH2M2 - F106B <= 1
805) X1BS1M2 + X2HF2M2 - F107B <= 1
806) X1BS1M2 + X2HH2M2 - F108B <= 1
807) X2CC1A1 + X1AA2A1 - F1C <= 1
808) X2CD1A1 + X1AA2A1 - F2C <= 1
809) X2CC1A1 + X1AB2A1 - F3C <= 1
810) X2CD1A1 + X1AB2A1 - F4C <= 1
811) X3EE1A1 + X2CC2A1 - F5C <= 1
812) X3EF1A1 + X2CC2A1 - F6C <= 1
813) X3EF1A1 + X2CD2A1 - F7C <= 1
814) X3EE1A1 + X2CD2A1 - F8C <= 1
815) X2CF1A2 + X1BD2A2 - F9C <= 1
816) X2CE1A2 + X1BD2A2 - F10C <= 1
817) X2CE1A2 + X1BC2A2 - F11C <= 1
818) X2CF1A2 + X1BC2A2 - F12C <= 1
819) X3EG1A2 + X2CF2A2 - F13C <= 1
820) X3EH1A2 + X2CF2A2 - F14C <= 1
821) X3EG1A2 + X2CE2A2 - F15C <= 1
822) X3EH1A2 + X2CE2A2 - F16C <= 1
823) X2GL1B1 + X1DI2B1 - F17C <= 1
824) X2GL1B1 + X1DJ2B1 - F18C <= 1
825) X2HF1B2 + X1DI2B2 - F19C <= 1
826) X2HH1B2 + X1DI2B2 - F20C <= 1
827) X2HF1B2 + X1DJ2B2 - F21C <= 1
828) X2HH1B2 + X1DJ2B2 - F22C <= 1
829) X2IK1B3 + X1HF2B3 - F23C <= 1
830) X2IK1B3 + X1HH2B3 - F24C <= 1
831) X2CG1C1 + X1AA2C1 - F25C <= 1
832) X2CI1C1 + X1AA2C1 - F26C <= 1
833) X2CG1C1 + X1AB2C1 - F27C <= 1
834) X2CI1C1 + X1AB2C1 - F28C <= 1
835) X2CI1C2 + X1BC2C2 - F29C <= 1
836) X2CG1C2 + X1BC2C2 - F30C <= 1
837) X2CI1C2 + X1BD2C2 - F31C <= 1
838) X2CG1C2 + X1BD2C2 - F32C <= 1
839) X2CH1C3 + X1BM2C3 - F33C <= 1
840) X2CJ1C3 + X1BM2C3 - F34C <= 1
841) X2CH1C3 + X1BN2C3 - F35C <= 1
842) X2CJ1C3 + X1BN2C3 - F36C <= 1
843) X1AG2D1 - F37C + X2JO1D1 <= 1
844) X1AG2D1 - F38C + X2JP1D1 <= 1
845) X1AM2D1 - F39C + X2JO1D1 <= 1
846) X1AM2D1 - F40C + X2JP1D1 <= 1
847) X2CO1D2 - F41C + X1BM2D2 <= 1
848) X2CP1D2 - F42C + X1BM2D2 <= 1
849) X2CO1D2 + X1BN2D2 - F43C <= 1
850) X2CP1D2 + X1BN2D2 - F44C <= 1
851) X2IR1E1 + X1HC2E1 - F45C <= 1
852) X2IR1E1 + X1HT2E1 - F46C <= 1
853) X2HF1E2 + X1FQ2E2 - F47C <= 1
854) X2HH1E2 + X1FQ2E2 - F48C <= 1
855) X2GL1F1 + X1FQ2F1 - F49C <= 1
856) X2GM1F1 + X1FQ2F1 - F50C <= 1
857) X2GL1F1 + X1FP2F1 - F51C <= 1
858) X2GM1F1 + X1FP2F1 - F52C <= 1
859) X3JO1F1 + X2GL2F1 - F53C <= 1
860) X3JP1F1 + X2GL2F1 - F54C <= 1
861) X3JO1F1 + X2GM2F1 - F55C <= 1
862) X3JP1F1 + X2GM2F1 - F56C <= 1

863) X2DO1F2 + X1CH2F2 - F57C <= 1
864) X2DP1F2 + X1CH2F2 - F58C <= 1
865) X2DO1F2 + X1CJ2F2 - F59C <= 1
866) X2DP1F2 + X1CJ2F2 - F60C <= 1
867) X3EE1F2 + X2DO2F2 - F61C <= 1
868) X3EF1F2 + X2DO2F2 - F62C <= 1
869) X3EE1F2 + X2DP2F2 - F63C <= 1
870) X3EF1F2 + X2DP2F2 - F64C <= 1
871) X2BQ1F3 + X1AN2F3 - F65C <= 1
872) X2BP1F3 + X1AN2F3 - F66C <= 1
873) X2BQ1F3 + X1AO2F3 - F67C <= 1
874) X2BP1F3 + X1AO2F3 - F68C <= 1
875) X2JT1G1 + X1EG2G1 - F69C <= 1
876) X2JR1G1 + X1EG2G1 - F70C <= 1
877) X2JT1G1 + X1EH2G1 - F71C <= 1
878) X2JR1G1 + X1EH2G1 - F72C <= 1
879) X2HF1G2 + X1FQ2G2 - F73C <= 1
880) X2HH1G2 + X1FQ2G2 - F74C <= 1
881) X2HF1G2 + X1FP2G2 - F75C <= 1
882) X2HH1G2 + X1FP2G2 - F76C <= 1
883) X2BE1H1 + X1AA2H1 - F77C <= 1
884) X2BF1H1 + X1AA2H1 - F78C <= 1
885) X2BE1H1 + X1AB2H1 - F79C <= 1
886) X2BF1H1 + X1AB2H1 - F80C <= 1
887) X2DO1H2 + X1CC2H2 - F81C <= 1
888) X2DP1H2 + X1CC2H2 - F82C <= 1
889) X2DO1H2 + X1CD2H2 - F83C <= 1
890) X2DO1H2 + X1CD2H2 - F84C <= 1
891) X2HF1I1 + X1GL2I1 - F85C <= 1
892) X2HH1I1 + X1GL2I1 - F86C <= 1
893) X2HF1I1 + X1GM2I1 - F87C <= 1
894) X2HH1I1 + X1GM2I1 - F88C <= 1
895) X2BQ1J1 + X1AN2J1 - F89C <= 1
896) X2BT1J1 + X1AN2J1 - F90C <= 1
897) X2BQ1J1 + X1AO2J1 - F91C <= 1
898) X2BT1J1 + X1AO2J1 - F92C <= 1
899) X2EG1J2 + X1BR2J2 - F93C <= 1
900) X2EH1J2 + X1BR2J2 - F94C <= 1
901) X2EG1J2 + X1BS2J2 - F95C <= 1
902) X2EH1J2 + X1BS2J2 - F96C <= 1
903) X2GL1J3 + X1FJ2J3 - F97C <= 1
904) X1FJ2J3 - F98C + X2GM1J3 <= 1
905) X2GL1J3 + X1FK2J3 - F99C <= 1
906) X1FK2J3 - F100C + X2GM1J3 <= 1
907) X2GF1M1 + X1AI2M1 - F101C <= 1
908) X2GH1M1 + X1AI2M1 - F102C <= 1
909) X2GF1M1 + X1AK2M1 - F103C <= 1
910) X2GH1M1 + X1AK2M1 - F104C <= 1
911) X2HF1M2 + X1BR2M2 - F105C <= 1
912) X2HH1M2 + X1BR2M2 - F106C <= 1
913) X2HF1M2 + X1BS2M2 - F107C <= 1
914) X2HH1M2 + X1BS2M2 - F108C <= 1
915) X1AA2A1 + X2CC2A1 - F1D <= 1
916) X1AA2A1 + X2CD2A1 - F2D <= 1
917) X1AB2A1 + X2CC2A1 - F3D <= 1
918) X1AB2A1 + X2CD2A1 - F4D <= 1
919) X2CC2A1 + X3EE2A1 - F5D <= 1
920) X2CC2A1 + X3EF2A1 - F6D <= 1
921) X2CD2A1 + X3EF2A1 - F7D <= 1
922) X2CD2A1 + X3EE2A1 - F8D <= 1
923) X1BD2A2 + X2CF2A2 - F9D <= 1
924) X1BD2A2 + X2CE2A2 - F10D <= 1

925) X1BC2A2 + X2CE2A2 - F11D <= 1

926) X1BC2A2 + X2CF2A2 - F12D <= 1

927) X2CF2A2 + X3EG2A2 - F13D <= 1

928) X2CF2A2 + X3EH2A2 - F14D <= 1

929) X2CE2A2 + X3EG2A2 - F15D <= 1

930) X2CE2A2 + X3EH2A2 - F16D <= 1

931) X1DI2B1 + X2GL2B1 - F17D <= 1

932) X1DJ2B1 + X2GL2B1 - F18D <= 1

933) X1DI2B2 + X2HF2B2 - F19D <= 1

934) X1DI2B2 + X2HH2B2 - F20D <= 1

935) X1DJ2B2 + X2HF2B2 - F21D <= 1

936) X1DJ2B2 + X2HH2B2 - F22D <= 1

937) X1HF2B3 + X2IK2B3 - F23D <= 1

938) X1HH2B3 + X2IK2B3 - F24D <= 1

939) X1AA2C1 + X2CG2C1 - F25D <= 1

940) X1AA2C1 + X2CI2C1 - F26D <= 1

941) X1AB2C1 + X2CG2C1 - F27D <= 1

942) X1AB2C1 + X2CI2C1 - F28D <= 1

943) X1BC2C2 + X2CI2C2 - F29D <= 1

944) X1BC2C2 + X2CG2C2 - F30D <= 1

945) X1BD2C2 + X2CI2C2 - F31D <= 1

946) X1BD2C2 + X2CG2C2 - F32D <= 1

947) X1BM2C3 + X2CH2C3 - F33D <= 1

948) X1BM2C3 + X2CJ2C3 - F34D <= 1

949) X1BN2C3 + X2CH2C3 - F35D <= 1

950) X1BN2C3 + X2CJ2C3 - F36D <= 1

951) X1AG2D1 - F37D + X2JO2D1 <= 1

952) X1AG2D1 - F38D + X2JP2D1 <= 1

953) X1AM2D1 - F39D + X2JO2D1 <= 1

954) X1AM2D1 - F40D + X2JP2D1 <= 1

955) X2CO2D2 - F41D + X1BM2D2 <= 1

956) X2CP2D2 - F42D + X1BM2D2 <= 1

957) X1BN2D2 + X2CO2D2 - F43D <= 1

958) X1BN2D2 + X2CP2D2 - F44D <= 1

959) X1HC2E1 + X2IR2E1 - F45D <= 1

960) X1HT2E1 + X2IR2E1 - F46D <= 1

961) X1FQ2E2 + X2HF2E2 - F47D <= 1

962) X1FQ2E2 + X2HH2E2 - F48D <= 1

963) X1FQ2F1 + X2GL2F1 - F49D <= 1

964) X1FQ2F1 + X2GM2F1 - F50D <= 1

965) X1FP2F1 + X2GL2F1 - F51D <= 1

966) X1FP2F1 + X2GM2F1 - F52D <= 1

967) X2GL2F1 + X3JO2F1 - F53D <= 1

968) X2GL2F1 + X3JP2F1 - F54D <= 1

969) X2GM2F1 + X3JO2F1 - F55D <= 1

970) X2GM2F1 + X3JP2F1 - F56D <= 1

971) X1CH2F2 + X2DO2F2 - F57D <= 1

972) X1CH2F2 + X2DP2F2 - F58D <= 1

973) X1CJ2F2 + X2DO2F2 - F59D <= 1

974) X1CJ2F2 + X2DP2F2 - F60D <= 1

975) X2DO2F2 + X3EE2F2 - F61D <= 1

976) X2DO2F2 + X3EF2F2 - F62D <= 1

977) X2DP2F2 + X3EE2F2 - F63D <= 1

978) X2DP2F2 + X3EF2F2 - F64D <= 1

979) X1AN2F3 + X2BQ2F3 - F65D <= 1

980) X1AN2F3 + X2BP2F3 - F66D <= 1

981) X1AO2F3 + X2BQ2F3 - F67D <= 1

982) X1AO2F3 + X2BP2F3 - F68D <= 1

983) X1EG2G1 + X2JT2G1 - F69D <= 1

984) X1EG2G1 + X2JR2G1 - F70D <= 1

985) X1EH2G1 + X2JT2G1 - F71D <= 1

986) X1EH2G1 + X2JR2G1 - F72D <= 1

987) X1FQ2G2 + X2HF2G2 - F73D <= 1

988) X1FQ2G2 + X2HH2G2 - F74D <= 1

989) X1FP2G2 + X2HF2G2 - F75D <= 1

990) X1FP2G2 + X2HH2G2 - F76D <= 1

991) X1AA2H1 + X2BE2H1 - F77D <= 1

992) X1AA2H1 + X2BF2H1 - F78D <= 1

993) X1AB2H1 + X2BE2H1 - F79D <= 1

994) X1AB2H1 + X2BF2H1 - F80D <= 1

995) X1CC2H2 + X2DO2H2 - F81D <= 1

996) X1CC2H2 + X2DP2H2 - F82D <= 1

997) X1CD2H2 + X2DO2H2 - F83D <= 1

998) X1CD2H2 + X2DO2H2 - F84D <= 1

999) X1GL2I1 + X2HF2I1 - F85D <= 1

1000) X1GL2I1 + X2HH2I1 - F86D <= 1

1001) X1GM2I1 + X2HF2I1 - F87D <= 1

1002) X1GM2I1 + X2HH2I1 - F88D <= 1

1003) X1AN2J1 + X2BQ2J1 - F89D <= 1

1004) X1AN2J1 + X2BT2J1 - F90D <= 1

1005) X1AO2J1 + X2BQ2J1 - F91D <= 1

1006) X1AO2J1 + X2BT2J1 - F92D <= 1

1007) X1BR2J2 + X2EG2J2 - F93D <= 1

1008) X1BR2J2 + X2EH2J2 - F94D <= 1

1009) X1BS2J2 + X2EG2J2 - F95D <= 1

1010) X1BS2J2 + X2EH2J2 - F96D <= 1

1011) X1FJ2J3 + X2GL2J3 - F97D <= 1

1012) X1FJ2J3 - F98D + X2GM2J3 <= 1

1013) X1FK2J3 + X2GL2J3 - F99D <= 1

1014) X1FK2J3 - F100D + X2GM2J3 <= 1

1015) X1AI2M1 + X2GF2M1 - F101D <= 1

1016) X1AI2M1 + X2GH2M1 - F102D <= 1

1017) X1AK2M1 + X2GF2M1 - F103D <= 1

1018) X1AK2M1 + X2GH2M1 - F104D <= 1

1019) X1BR2M2 + X2HF2M2 - F105D <= 1

1020) X1BR2M2 + X2HH2M2 - F106D <= 1

1021) X1BS2M2 + X2HF2M2 - F107D <= 1

1022) X1BS2M2 + X2HH2M2 - F108D <= 1

VITA AUCTORIS

The author was born in Nazareth, TamilNadu, India, on December 21, 1972.

EDUCATION

Sept. 1995--present **M.A.Sc in Industrial and Manufacturing Systems Engineering**
University of Windsor
Windsor, Ontario, Canada.

Aug. 1990--May 1994 **B.E. in Mechanical Engineering**
Coimbatore Institute of Technology
Coimbatore, TamilNadu, India

WORK EXPERIENCE

Sept. 1995--present **Research Assistant**
Department of Industrial and Manufacturing Systems Engineering
University of Windsor

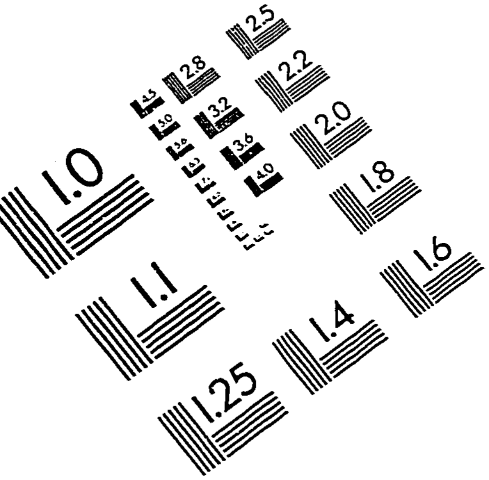
Sept. 1995--May 1996 **Teaching Assistant**
& Sept. 1996--present Faculty of Engineering
University of Windsor

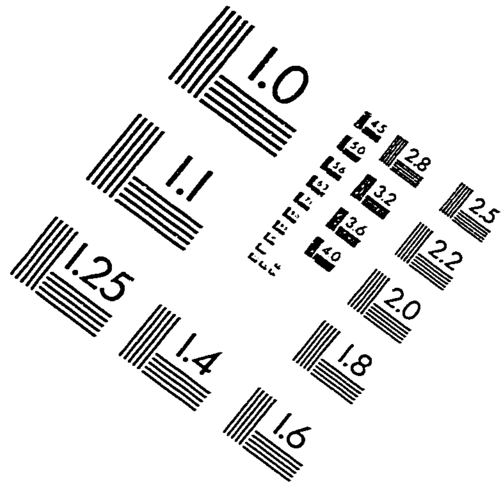
Jun. 1994--Sept 1995 **Production Engineer**
Noble Industries
Madras, TamilNadu, India

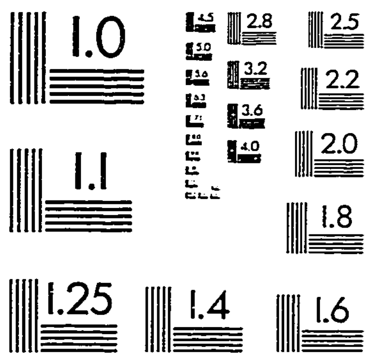
AFFILIATION

Institute of Industrial Engineers
Norcross, Georgia, U.S.A.

IMAGE EVALUATION TEST TARGET (QA-3)

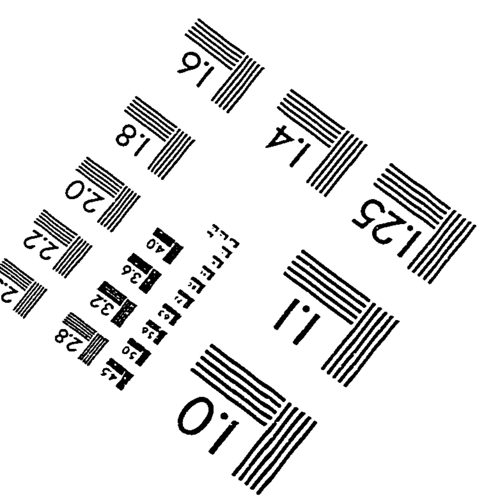


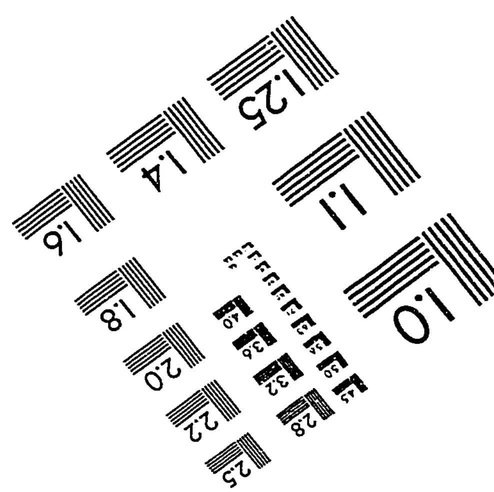




150mm

6″





APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989