OPTIMIZATION OF DIE STORAGE LOCATION CONSIDERING TRAVEL DISTANCE AND TIME: A CASE STUDY OF AN AUTOMOTIVE PARTS STAMPING SHOP

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DEDICATION

This thesis is dedicated to my family. Thank you for your support and constant inspiration.

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OPTIMIZATION OF DIE STORAGE LOCATION CONSIDERING TRAVEL DISTANCE AND TIME: A CASE STUDY OF AN AUTOMOTIVE PARTS STAMPING SHOP

by

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THESIS
Presented to the Graduate Faculty of
The University of Texas at San Antonio
in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE IN ADVANCED MANUFACTURING AND ENTERPRISE ENGINEERING

THE UNIVERSITY OF TEXAS AT SAN ANTONIO
College of Engineering
Department of Mechanical Engineering
May 2014

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ACKNOWLEDGEMENTS

I would like to sincerely thank Dr. F. Frank Chen, my supervisor and mentor, who has provided all kinds of support for me to conduct this research. His constant motivation and valuable guidance is the key for my completion of this thesis. I would also like to thank Dr. Hungda Wan and Dr. Krystel Castillo for providing their valuable inputs that improve the quality of my research.

I would also like to thank my family and friends for supporting and constantly inspiring me to overcome all obstacles during my two years of the graduate studies at UTSA.

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OPTIMIZATION OF DIE STORAGE LOCATION CONSIDERING TRAVEL DISTANCE AND TIME: A CASE STUDY OF AN AUTOMOTIVE PARTS STAMPING SHOP

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The University of Texas at San Antonio, 2014

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Every company seeks to have high volumes of production and distribution, using optimal allocation of stock inventories. The layout of warehouses is one of the important factors affecting the efficiency of the warehouse operations. The success of a manufacturing organization depends on the proper design of facilities supporting all production cycles. Out of all processes, order picking and restocking are receiving more attention, as they have been considered as very labor-intensive and costly operations. The assignment of stocks to locations is one of the most important issues that must be resolved in manufacturing system. The purpose of this research is to develop a dynamic die location planning system with the objective of reducing the overall stamping die handler's travel distance and time on the monthly basis. This research addresses a real warehouse logistic problem of an automotive stamping shop that performs picking and restocking of die sets with the attempt to generate an optimal layout for all die sets that will minimize the aggregate walking distance of operators handling the overhead crane. Given a set of production orders for die sets and their picking frequencies, the assignment of die

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sets to storage location is formulated as a 0-1 Linear Integer Programming (LIP) model. Optimal solution is generated with minimum run time by using LINGO version 14.0 software. Solutions derived from using heuristic algorithms are used to demonstrate the effectiveness of the proposed LIP model.

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CHAPTER ONE: INTRODUCTION

In today's market environment, every manufacturing company faces challenges and competitions on various fronts. These include cost, quality, delivery, flexibility and customer satisfaction. Logistics management is one of the most important activities for many companies. It includes order processing, storage layout, material handling, transportation and warehousing.

Warehousing plays an essential role in a supply chain, as products need to be placed someplace along the supply chain for temporary storages before reaching the end user. Warehousing plays five major roles described below. First, to combine products to reduce transportation cost by consolidating shipment in full capacity. Second, to comprehend economies of scale in manufacturing or purchasing. Similarly, the economics of manufacturing may sheer large batch sizes to pay off large setup costs, so that excess product must be stored. Third, to provide value-added processing. Increasingly, warehouses are being strained to slot in value-added processing such as light assembly. This is a result of manufacturing firms adopting a policy of adjournment of product differentiation, in which the final product is configured to the customer’s requirements as close to the delivery location as possible. Fourth, to reduce response time. A warehouse acts as a buffer between producers and customers to meet the changing market condition and to fortress against uncertainties (e.g., seasonality, demand fluctuations). And, fifth, to act as a single source of supply to customers [1].

Warehousing is one of the logistical activities that currently occupy very high cost and time. The layout of the warehouse will pull material handling or distance cost and consequently is indicative of efficiency of facility. Order picking and restocking is the foundation of the warehouse operation. It has been recognized as the most labor intensive and costly activity of any fast picking distribution center. Order picking is the process by which products are retrieved

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from storage to satisfy customer demand. In its easy term, an order arrives at the warehouse and an order picker is sent into the picking area with the customer's list to retrieve the requested items from storage. The task is to accomplish the set of production or customer order by reaching the right item location, placing into the location and, putting them back to the right location.

A great deal of research and time has been devoted to explore methods to retrieve products from storage as efficiently as possible. The intensive efforts are indicative that order picking is an extremely expensive activity. Considering the time required to pick an order, there are mainly three time components: traveling between items, picking of items, and remaining activities. Picking the items consists of a series of actions ranging from locating the picking mechanism to placing the picked items on a product carrier. In a typical warehouse environment, 70% of the total operating cost and time is attributed to order picking and restocking functions [2]. Thus, improvements in this area are of major concern and interest. Within a storage location, traveling is the most time consuming activity, as shown in Figure 1.

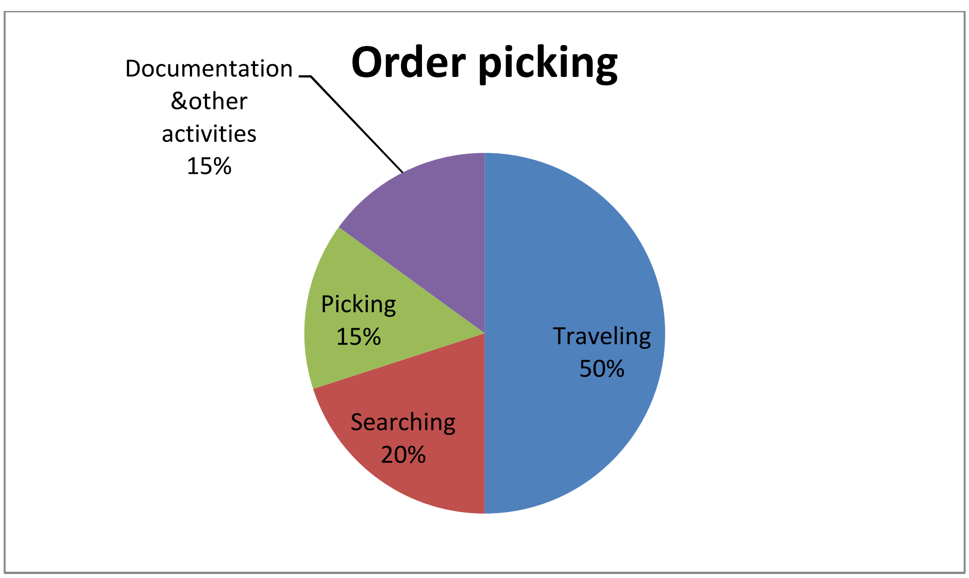

Figure 1 Percentage of time consumed in different activities [2]

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A common objective for order- picking systems is to maximize the service level subject to resource constraints such as labor, machines, and layout. The service level constitutes components such as response time, order integrity, and accuracy. A vital link between order picking and service level is that the faster an order is retrieved, the quicker it becomes available for production run or for shipping to customer. Minimizing the order retrieval time (or picking time) is, therefore, necessary for any order picking system.

In a typical distribution center, different types of order picking system subsist today, creating efficient and well-organized warehouse environments to increase output productivity. Most commonly used method is a picker-to-item system, where order pickers need to travel along the rack shelves to retrieve the items in their order list. For bulky weight size stock inventories, the items are picked one at a time and the order picker needs to return to pick the next order which will be time consuming if the layout of the inventory is not optimally planned. Thus, the distance or time of picking and restocking will be long and the efficiency will be poor.

The assignment of stock to locations is one of the most important and critical issues that must be overcome by decision makers in manufacturing facilities. The inventory must be arranged in an optimal way so that the interaction among functions (e.g., machines, inventories, person) and places (e.g., work location, depots) can be efficient. From a managerial point of view, performances of a storage area are based on two decision variables: the space area set aside for material allocation, and the time required for their handling. Decisions for space determination, layout design and storage system comprises the content for assignment of stock to locations.

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1.1 Focus of Research

Understanding the impact of traveling distance and time on efficiency of order picking and restocking operations, this research is intended to generate a SKU optimal layout that minimizes the overall walking distance traveled by the handler/picker. The storage location warehousing problem chosen for this research is based on a real automotive stamping shop that operates a picking and restocking system of die sets with a single order item picking and restocking. The current layout was evaluated and analyzed using monthly production run schedules of 3 different months. Optimization technique using 0-1 Linear Integer program was then employed to determine monthly die sets storage locations that result in the lowest overall traveling time and distance for crane operators. For each of the 3 months, die sets usage frequency was provided and optimal layout of locations of die sets was generated accordingly.

In the subsequent chapter, a literature review is presented that describes previous work done on warehousing layout design , assignment of stock to storage locations with the objective to reduce labor cost, time and travel distance in warehousing.

Chapter 3 introduces the problem structure of an automotive parts stamping shop. Then a 0-1 Linear Integer programming model is constructed to minimize the total traveling distance by team members (crane operators).

Chapter 4 describes the case study. A heuristic algorithm is also proposed that clearly demonstrates the effectiveness of the proposed LIP model.

Chapter 5 reports computational and heuristic solutions obtained and compared. Results show that significant savings in handling time and distance can be obtained with the proposed mathematical model.

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Chapter 6 summarizes and concludes this research, followed by proposed future research directions.

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CHAPTER TWO: LITERATURE REVIEW

As discussed in Section 1.1, the objective of this research is to develop a dynamic planning system for determining best optimal storage locations for die sets stored in the stamping shop bay area in order to reduce the total traveling distance and time crane operators. There are several documents and literature which provide insight to approaches to problems similar to that of our case study. The topics which are relevant to this research, and will be included in this review are the general definitions and activities of a warehousing, stock location assignment problems, mathematical and simulation models determining storage systems, and item classification system.

Warehouse layout is one of the significant factors affecting the order picking process. The overall layout design of the facility is a key factor in determining the effectiveness of warehouse operations. Caron, *et al* [3] determine that the warehouse layout has a considerable effect on order picking travel distance. They state that the layout design has an effect of over 60% on the total travel distance, and also find the relationship between warehouse layout and order picking travel distance. Therefore, warehouse layout has to be taken into account while scheming and designing the order picking system. Generally, the unit-load warehouse layout is based on a rectangular shape, in which SKUs arrive on pallets and leave on pallets [4]. The warehouse layout engage the decision of: a) number of racks and aisles- including length and width of aisles; b) orientation of aisles and picking racks; and c) location of input/output (I/O) points, which are the starting traveling points for order pickers and restockers, and incoming/outgoing doors dedicated for shipping [5].

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The travel distance by order pickers and restockers is considerably affected by the configuration chosen, i.e., if aisles are lengthy, there would be potentially more walking involved within the aisles, if too short, the traveling distance between aisles increases [2].

Literature review of previous work shows that there are two types of warehouse management: internal operation system management, and layout management. Order picking is a critical operation in managing a warehouse efficiently. It accounts for 65% of the total operating cost of a warehouse [5, 6]. The majority of papers engrossed on storage department layout problem in order to maximize performance of order picking, such as the utilization of Pareto rule for product grading and reducing average travel time.

Storage Location Assignment Problem (SLAP) has represented a captious factor in Operations Management and Operation Research ever since 1976, when Hausman, *et al* [7] initially introduced an orderly and accurate method of the possible storage location assignment policies of items within a warehouse: the problem concerns the assignment of stock to storage locations, and Hausman *et al* [7] and Petersen et al [8] describes the major criteria to be embraced, which Sharp [9] and Frazelle [10] did concur to classify in dedicated storage, randomized storage and class-based storage. A stochastic model was built by Jarvis and McDowell [11] for product location problem in warehouse.

As a result of the dynamic nature of customer demand in most local distribution centers, the class based dedicated storage policy might provide improved design for stock location. Goetshalckx and Ratliff [12] suggested shared storage policy based on the duration of stay for stock location problems. The shared storage can be recognized and take advantage of the enticement differences in lengths of time that individual items remain in storage.

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A compilation of mathematical models for storage layout and order picking operations problems are available in literature. Francis, *et al* [13] presented mathematical models for determining the size of the storage system and allocating items to storage locations. Ballou [14] devised a linear programming model to a parallel problem involving reserve storage and order picking areas. Malette and Francis [15] deployed a generalized assignment model to optimal facility layout taking into consideration the material-handling cost. Malmborg and Deutch [16] created a stock location model in which the inventory level and cost were considered. Liu [17] demonstrated a clustering model and developed a closed-form solution for ameliorating stock location and picking operations for a distribution center. Their results highlighted that the use of clustering techniques as well as mathematical models in solving stock location and order picking problems is quite encouraging. The realistic approach to storage systems design problems mainly considers the criteria of where stock items are to be positioned and how they should be exhibited in the warehouse.

The problems related to the subject of storage layout problems can be resolved by the applications of simulation technique. Dangelmaier and Bachers [18] designed a simulation system for material flow and warehouse design using a simulation software package, SIMULAP. Liu [17] build a simulation model using a visual interactive modeling system, WITNESS, for assessing stock location policies in a storage layout distribution center. Even though simulation technique can be applied to plan storage layout and order picking in a warehouse, the method is limited to account for the dynamic nature of order demand while not necessarily optimize the stock location. Hence, the demand order production rule, heuristic-based optimization technique can constitute a dynamic stock layout system for design planning and provides a useful tool for decision makers.

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CHAPTER THREE: MATHEMATICAL MODEL AND FORMULATION

3.1 Linear Integer Programming Model

Linear programming uses a mathematical model to express the problem of concern. It includes *scheduling of activities* to obtain an optimal result, i.e., a result that reaches the particular goal best (according to the mathematical model) among all feasible alternatives. The Mathematical formulation for our research is built to minimize the total traveling distance by operators or order pickers. The objective is to reduce the aggregate walking distance from the die pallets placed in front of the stamping presses to the die storage locations. The notations used are as follows:

i=die set index

j=storage position index

a_i=frequency of the die sets i used during a production horizon   i=1,2....I

b_j=distance between storage position j and die set pallets in front of the stamping presses j=1,2..J

3.1.1 Decision Variable

The bottom line for distance minimization in die set pick up and return relies on where the die sets are assigned in the storage position on the floor. In this way, the decision variable is defined as a 0-1 integer variable:

$$X_{ij} = \begin{cases} 1, \text{if die set i is assigned to storage location j;} \\ 0, \text{otherwise} \end{cases}$$

3.1.2 Objective Function

The problem to minimize traveling distance of die sets between die pallets in stamping

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presses and storage location can be expressed as follows:

$$\text{Min } Z = \sum_{j=1}^{J} \sum_{i=1}^{I} 4\, a_i\, b_j\, X_{ij} \qquad 3.1$$

Equation 3.1 will minimize the aggregate walking distances within pick-up and restoring the die sets back to the storage location. It can be observed that this equation have a linear structure.

3.1.3 Constraints

$$\sum_{i=1}^{I} X_{ij} \leq 1 \quad ; \quad \forall\ j=1,2\ldots\ldots\ldots J \qquad 3.2$$

$$\sum_{j=1}^{J} X_{ij} = 1 \quad ; \quad \forall\ i=1,2\ldots\ldots\ldots I \qquad 3.3$$

$$i \leq J \qquad 3.4$$

$$X_{ij} \in \{0,1\} \qquad 3.5$$

The objective function (3.1) expresses in a linear form seeking the minimization of the sum of distances between stamping press die pallets and storage locations. The value 4 multiplied with the rest of the terms in the equation represents the number of turns each individual die from die sets is moved to the stamping presses die pallets and moved back to its original position after the production run is over for that die set number. Since, each slot can hold only two dies so it has to travel 2 times for each individual die from group of 2, i.e., from storage locations to the pallets in front of the stamping presses and back to its original position.

Constraint (3.2) ensures that for each storage position, it can only be assigned with one die set out of available die sets. Constraint (3.3) avoids die sets to be assigned to more than one storage location. Constraint (3.4) ensures number of die sets in the storage locations for a fixed period should be less than or equal to the number of storage positions available.

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CHAPTER FOUR: CASE STUDY

This chapter first introduces the problem definition and the process of the selected case study to be analyzed and solved. Second, layout of the die sets based on storage area of the subject automotive parts stamping shop is discussed with some assumptions. Finally, four different methods of generating die locations are described. Method 1 randomly assign die sets to available slots in the storage area, Method 2 is the current layout method employed by the subject automotive stamping shop where the die sets are placed according to their usage frequency, team members experience and knowledge, Method 3 describes a proposed heuristic method and recommended layout considering all the possible scenarios using spreadsheet to generate die sets locations considering their weekly and monthly run demand for each of two different presses and finally Method 4 presents an optimal method using 0-1 Linear Integer Programming to minimize the total traveling distance by operators considering team members or operators work shift and production horizon.

4.1 Problem Statement and Process

As mentioned in Chapter 1, the problem under study represents one of the most important topics in logistics. The stamping shop under study uses over 30 die sets per stamping line. Die sets run in a 4 pattern rotation. The dies sets are laid out in a large grid type storage area behind the two presses. The purpose of this research is to develop a dynamic die location planning system with the objective of reducing the overall stamping die handler/mover's travel distance and time on the monthly basis based off the pattern of load and unload operations generated by monthly production plans. By developing an optimal model, the dynamic nature of the demand

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order for die pattern change can significantly lead to reduce aggregate handlers walking distance and time on monthly basis. The process flow diagram is shown in Figure 2.

For the first production run, say first day of the week and first shift, the team member or the operator operating the manual over head crane comes to the die set number which needs to be loaded to the die pallets in front of stamping presses. The dies one at a time is lifted by the hooks from the crane and moved in the constant speed to the respective pallet. It is then gradually lowered down and dropped to the pallet and secured firmly.

Subsequently, operator walks back to the storage location to lift the next die and again moves to the destination pallet. The loading of dies continues till all four pallets are loaded with dies and are ready for the first production run. The operator now moves to the next press which is situated adjacent to the current press and follows the same procedure to load up the dies to all pallets. Now, the operator returns back to the previous press and prepares the next set of dies and load them in front of die pallets in the opposite side of the press stations.

After the first production run, the die pallets loaded with dies moves out of press station and the operator now unload each dies with the help of manually operated overhead crane. Each die is unloaded from the station pallets and is returned to the storage location. The operator moves to the next die set number position to load it onto the station pallets for the next production run. So, each press requires 7-8 external changeovers of die sets during a production shift of 10.5 hours, 2 shifts per day.

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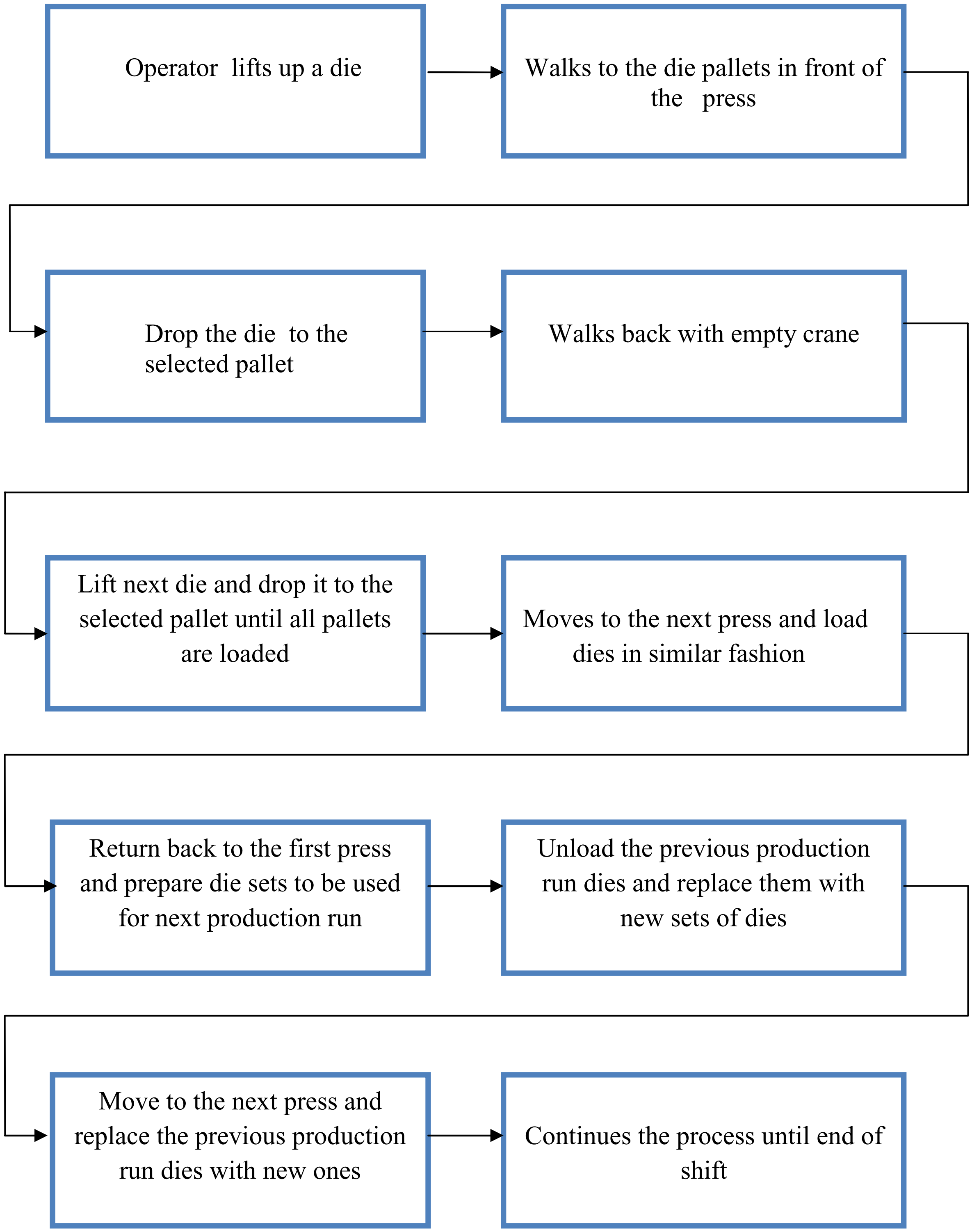

Figure 2 Automotive stamping shop process flow model

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4.2 Layout of Automotive Stamping Shop Die Storage Area

4.2.1 Storage layout

The die storage warehouse is a fixed dimensional rectangular storage area with multiple input and output points located at the back side of each of the 2A and 3A stamping press lines. Each line consists of 4 press stations. The storage area has multiple rows and columns to store required sets of dies for the monthly production run patterns. Figure 3 shows the layout of the storage area. Each slot holds 2 dies, one placed above the other. The dimension of each die is approximately 2x1 meter each and the total cubicle occupied by the dies is 2x1x2 m^3 in each slot. To increase the efficiency of operations, specifically by minimizing travel distance, a method for classification of items is introduced similarly in the die storage area. The current layout in use by the subject shop is based upon popularity of items. In this system the die sets are placed based upon their usage frequency, a proven system called ABC classification system. In this system die sets are categorized as either A, B or C depending upon their usage frequency. The most often used sets of dies are placed in the front rows and the remaining rows are filled with the rest of die sets in random fashion. Once the used dies after the production run in the press are picked up from the station pallets, they are placed back to immediate slots available in the die storage area. The storage area for both presses has multiple aisles with clearly marked rectangles to improve the order picking activities.

4.2.2 Single order picking

The team member picks only one die set at a time. The process begins from the I/O-point, picking one die set at a time with the manually operated crane and walking to the stamping station, dropping the die to the pallet in front of each station and returning back to the storage

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area for picking up next set of dies and repeating for the remaining stations. The team member travels up and down each aisle until all die set orders are picked for the stamping line. The external changeover time for each set of dies to load and unload takes about 25-30 minutes.

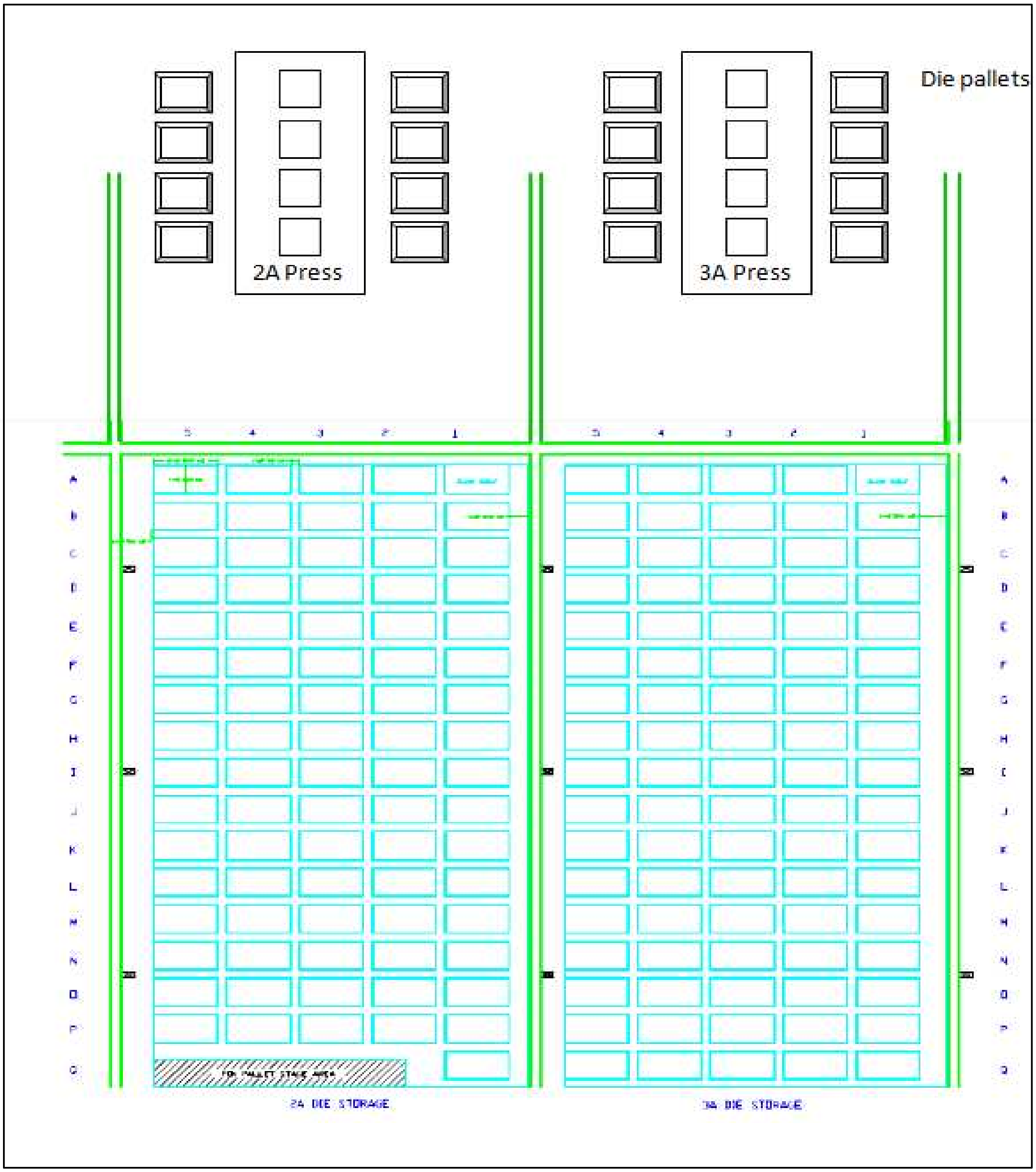

Figure 3 Design layout of Die based storage automotive stamping shop

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4.3 Assumptions

For this research, most of the factors considered are real, but the distance from each die storage location to the press stations is assumed to follow distance matrix below.

1) Table of Distance Matrix

Table 1 Distance from each die storage location to the stamping press stations (in feet)

		Column				
		1	2	3	4	5
Row	A	50	54	58	62	66
	B	55	59	63	67	71
	C	60	64	68	72	76
	D	65	69	73	77	81
	E	70	74	78	82	86
	F	75	79	83	87	91
	G	80	84	88	92	96
	H	85	89	93	97	101
	I	90	94	98	102	106
	J	95	99	103	107	111
	K	100	104	108	112	116
	L	105	109	113	117	121
	M	110	114	118	122	126
	N	115	119	123	127	131
	O	120	124	128	132	136
	P	125	129	133	137	141

2) Total number of rectangular slots available in the die storage area is assumed to be 80 with 5 columns and 16 rows.

3) 60 slots are used for the die sets including free pattern sets of dies needed for the monthly run pattern and the remaining slots are vacant.

4) Total floor space of the storage area is known.

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5) The length and width of the each storage slot is assumed to be 2x1 meters.

6) Each slot is assumed to hold a set of 2 dies, placing one above the other for, 30 die sets.

4.4 Methodology

The planning system considers dynamic nature of daily demand for dies in the stamping shops. From general point of view, the problem can be formulated by considering some input information as follows: the storage area (e.g. the layout of warehouse), the storage slots (e.g. number, dimensions), and the demand quantity. The model of the stamping shop storage area where the die sets are stored is created to represent the real situation with horizontal and vertical travel system among storage rectangles in the storage area, i.e., the team member can move both the way along the aisle floor. Each die sets has its own usage frequency. The usage frequency of each die set is defined as the number of times that die set is required in the production run pattern. The complexity of storing the die sets, picking and placing them back to the original locations tends to increase with the increase of run order. In the current problem, different die location assignment methods are generated and described in the following subsections.

4.5 Method 1: Random Storage Assignment

The first method we consider is a random generation of storage locations for all die sets. The concept of randomized storage is to simply assign every incoming die sets a location, randomly selected from all the vacant locations with equal probability. The layout can represents a real warehousing situation where the greatest benefit of random storage policy is its high space utilization, since any available space in the picking area becomes a entrant location for the arriving die sets. Also, in terms of productivity, the put away labor is reduced, which can be

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beneficial when there is a constant quantity of die sets that need to be put away as soon as possible. Nevertheless, the amount of travel involved in the retrieval will increase. Table 2 shows the random allocation of die sets into the available rectangular slots. There are 80 slots available in the storage area, out of which 60 position are randomly occupied by the die sets. There are total 30 die sets which are considered for the allocation based on the plant data provided by the automotive stamping shop. Each die sets contain a total of 3 or 4 dies to be used by the stamping stations following the production run. Table 3 shows the random allocation of die sets 3A press station to the available rectangular slots. There are a total of 30 die sets available for this press station. Similarly, Tables 4 and 5 show random allocation of die sets for 2A and 3A press stations for March 2014 production run pattern, and Tables 6 and 7 show random allocations of die sets for 2A and 3A press stations for the month of April 2014.

Table 2 Random allocation of die sets for 2A press for October 2013 Run Pattern.

	1	2	3	4	5
A	61	61	37	41	41
B	40	70	37	40	70
C	75	43	75	43	45
D	10	10	47	73	45
E	94	22	47	94	73
F	36	22	51	87	52
G	84	84	51	87	52
H	36	48	92	44	92
I	57	7	53	7	59
J	53	59	16	44	48
K	31	11	57	16	33
L	66	33	66	11	31
M					
N					
O					
P					

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Table 3 Random allocation of die sets for 3A press for October 2013 Run Pattern

	1	2	3	4	5
A	50	50	35	23	23
B	69	30	35	30	69
C	42	13	74	95	74
D	42	34	13	95	34
E	17	15	17	76	15
F	82	81	67	85	82
G	12	81	46	76	12
H	9	6	32	85	9
I	38	46	67	38	6
J	93	4	8	5	4
K	93	5	32	58	8
L	14	14	58	86	86
M					
N					
O					
P					

Table 4 Random allocation of die sets for 2A press for March 2014 Run Pattern

	1	2	3	4	5
A	80	75	75	24	24
B	70	70	41	41	80
C	94	45	45	43	43
D	37	37	10	10	94
E	73	47	47	40	40
F	48	48	92	92	73
G	52	87	87	36	36
H	84	84	51	51	52
I	66	31	31	44	44
J	57	57	11	11	66
K	16	53	53	59	59
L	33	33	7	7	16
M					
N					
O					
P					

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Table 5 Random allocation of die sets for 3A press for March 2014 Run Pattern

	1	2	3	4	5
A	30	60	60	55	55
B	42	42	50	50	30
C	17	13	13	74	74
D	81	81	76	76	17
E	35	34	34	15	15
F	12	12	82	82	35
G	46	67	67	95	95
H	9	9	38	38	46
I	32	6	6	85	85
J	8	8	93	93	32
K	58	4	4	5	5
L	86	86	14	14	58
M					
N					
O					
P					

Table 6 Random allocation of die sets for 2A press for April 2014 Run Pattern

	1	2	3	4	5
A	73	75	75	28	28
B	41	41	80	80	73
C	45	43	43	70	70
D	37	37	10	10	45
E	92	47	47	40	40
F	48	48	94	94	92
G	52	87	87	36	36
H	84	84	51	51	52
I	66	31	31	44	44
J	57	57	11	11	66
K	16	53	53	59	59
L	33	33	7	7	16
M					
N					
O					
P					

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Table 7 Random allocation of die sets for 3A press for April 2014 Run Pattern

	1	2	3	4	5
A	30	64	64	72	72
B	76	76	50	50	30
C	13	74	74	42	42
D	81	81	17	17	13
E	35	34	34	15	15
F	12	12	82	82	35
G	46	67	67	95	95
H	9	9	38	38	46
I	32	6	6	85	85
J	8	8	93	93	32
K	58	4	4	5	5
L	86	86	14	14	58
M					
N					
O					
P					

4.6 Method 2: Current way of Die Storage Assignment

As discussed earlier in Section 4.2.1, the assignment of die sets to the storage locations in use by the subject stamping shop considers the simple ABC classification. The die sets with the maximum usage class A die sets are provided with the position in the front few rows and the remaining of the rows are then filled with rest of die sets depending upon the weekly and monthly run pattern. Also, when the die sets are returned back to the storage area from the stamping stations, they are placed wherever they can find the immediate available spots in the storage area. They may or may end up being placed to the original position assigned in the beginning of each month. Tables 8, 10 and 12 and Table 9, 11 and 13 represent similar layout of

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die sets for 2A and 3A press station for the month of October 2013, March and April 2014 respectively, with the similar quantity of die sets used in random storage assignment method.

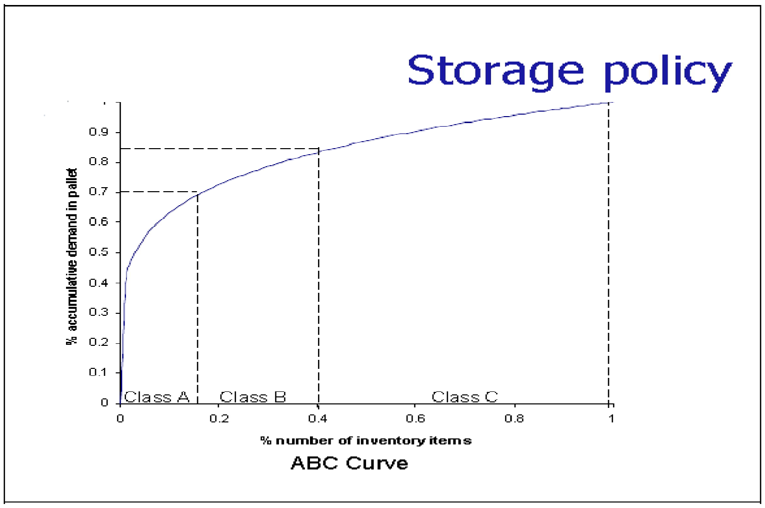

Figure 4 Class based storage assignment [1]

Table 8 Method 2 layout based on Monthly run pattern of 2A press for October 2013

	1	2	3	4	5
A	33	11	7	59	16
B	33	53	7	59	16
C	11	53	61	61	84
D	57	57	94	51	22
E	22	84	94	51	10
F	52	66	36	48	40
G	40	66	36	48	37
H	47	37	47	73	44
I	44	31	31	73	52
J	10	87	87	45	92
K	75	75	43	45	92
L	43	70	70	41	41
M					
N					
O					
P					

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Table 9 Method 2 layout based on Monthly run pattern of 3A press for October 2013

	1	2	3	4	5
A	86	14	76	4	5
B	86	14	76	4	5
C	93	93	69	69	95
D	12	12	81	82	95
E	15	6	81	82	15
F	85	6	50	85	9
G	23	30	50	74	9
H	17	35	35	74	67
I	17	32	13	34	67
J	30	32	13	34	23
K	42	42	46	46	38
L	58	58	8	8	38
M					
N					
O					
P					

Table 10 Method 2 layout based on Monthly run pattern of 2A press for March 2014

	1	2	3	4	5
A	33	11	7	59	16
B	33	53	7	59	16
C	11	53	80	80	84
D	57	57	94	51	24
E	24	84	94	51	10
F	52	66	36	48	40
G	40	66	36	48	37
H	47	37	47	73	44
I	44	31	31	73	52
J	10	87	87	45	92
K	75	75	43	45	92
L	43	70	70	41	41
M					
N					
O					
P					

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Table 11 Method 2 layout based on Monthly run pattern of 3A press for March 2014

	1	2	3	4	5
A	86	14	76	4	5
B	86	14	76	4	5
C	93	93	60	60	95
D	12	12	81	82	95
E	15	6	81	82	15
F	85	6	50	85	9
G	55	30	50	74	9
H	17	35	35	74	67
I	17	32	13	34	67
J	30	32	13	34	55
K	42	42	46	46	38
L	58	58	8	8	38
M					
N					
O					
P					

Table 12 Method 2 layout based on Monthly run pattern of 2A press for April 2014

	1	2	3	4	5
A	33	11	7	59	16
B	33	53	7	59	16
C	11	53	28	94	84
D	57	57	28	51	22
E	22	84	94	51	10
F	52	66	36	48	40
G	40	66	36	48	37
H	47	37	47	73	44
I	44	31	31	73	52
J	10	87	87	45	92
K	75	75	43	45	92
L	43	70	70	41	41
M					
N					
O					
P					

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Table 13 Method 2 layout based on Monthly run pattern of 3A press for April 2014

	1	2	3	4	5
A	86	14	76	4	5
B	86	14	76	4	5
C	93	93	64	64	95
D	12	12	81	82	95
E	15	6	81	82	15
F	85	6	50	85	9
G	72	30	50	74	9
H	17	35	35	74	67
I	17	32	13	34	67
J	30	32	13	34	72
K	42	42	46	46	38
L	58	58	8	8	38
M					
N					
O					
P					

4.7 Method 3: Heuristic method to generate recommended layout

"Heuristic" is derived from Greek word which refers “To Determine". This is a methodology for selectively searching a feasible solution space. It steers our search route along the line that has high probability of success in finding a near optimal solution. There has been a vast number of heuristics which are used by human beings in problem solving. These methods are actually not fool proof, although, it does generate a good solution to the problem. Since the subject case study has a moderate size of die sets, the time taken to generate optimum solution may increase dramatically with the increase in number of die sets and storage positions. Hence, using a heuristic solution approach to generate a feasible solution can be a good way its effectiveness against results from Method 1 and Method 2.

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Step 1: Identify the die sets based on weekly and monthly run order. The crucial step now is to determine each set of dies with their frequency or demand usage for the week and later on for the month. Here, the planning system starts to take an active role. The MS-Excel component of MS office suite is used which will generate a spreadsheet layout for die sets considering their weekly and monthly run demand. The storage area is now divided into different pool of usage of die sets corresponding to their respective row and column numbers.

Step 2: Allocate first 2-3 rows with sets of dies which are to be used each day and for each shift based on the operation days in a week. Then, the next couple of rows will follow the same procedure based on their weekly run demand. The rest of the rows will contain the sets of dies which are needed for the subsequent week of schedule based on production order.

Step 3: Allocate sets of dies to their respective rows. This is done by the spreadsheet program which contains sets of codes to determine the best position of each die sets based on their run order for each day of the week. The subsequent week schedule can then be generated similarly, but the key point over here is that the subsequent week schedule might not require most of the die sets to be replaced with the new ones. For any changeover in the production pattern for die sets that are required, another spreadsheet will generate the layout of die sets for the subsequent week and will automatically replace the current position of dies for the previous week schedule in their respective rows and columns. This will continue for the whole month following the run pattern. So, the dynamic nature of the problem can be dealt with more effectively and efficiently using this heuristic based planning system.

Figures 5 and 6 for 2A and 3A presses show the recommended storage locations for die sets using the heuristic method for the month of October 2013 production data provided by the

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stamping shop. Similarly Figure 7, 8, 9 and 10 summarize storage locations of die sets each for 2A and 3A presses for the other 2 months of production data.

From Figure 5, it can be seen that Column E is used to feed the die numbers and Column F to usage frequency for the complete month. Now in next step, die sets are segregated based on their usage frequency. This is achieved by identifying the dies which will be used 40 times in a month, 20 times in a month, and so on. For this purpose, Columns I and J are both used to create Columns N to R. Now, once die sets are affiliated with usage frequency, their positions are identified in rows meaning not only in which row they will fit in but exactly where in rows they will fit. Rows will be decided based on the dies used in week 1, week 2, and so on. Formula used in Columns L to P identifies what all dies from pool of 40 frequency are required in Week 1, similarly, dies which we have identified in pool of 20 frequency, what all dies will be used on Week 1 and in which order, so the formula will give results only when it is necessary else it will create a vacant slot so here we need to add for week 2 as well and for rest of the week based on this information from Columns S to W. The formulae will automatically give error message if it fails to find the suitable fitment.

In this way, we generate the schedule of dies for week 1, now once the placement of dies for week 2 is known; repeat the formula in Columns S to W for generating their placement order in Columns Y to AC.

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E	F	I	J	L	M	N	O	P	R	S	T	U	V	W	Y	Z	AA	AB	AC
				Die sets to be allocated based on their usage in a Month					Die sets allocation										
									Week 1-4 die sets position placement						Placing Die sets number as per allocation				
Dies	Frequency	Dies	Frequency	Number of times # 40	Number of times # 20	Number of times # 12	Number of times #8	Number of times #6	Die	#40 pool	#20 pool	#12 pool	#8 pool	#6 pool	First row	Second row	Third row	Fourth row	Fifth row
7	20	33	40	33					7		Second row				0	7	0	0	0
16	20	7	20		7				16		Second row				0	16	0	0	0
53	20	92	20		92				53		Second row				0	53	0	0	0
59	20	22	20		22				59		Second row				0	59	0	0	0
57	20	87	20		87				57		Second row				0	57	0	0	0
11	20	84	20		84				11		Second row				0	11	0	0	0
66	20	66	20		66				66		Second row				0	66	0	0	0
31	20	59	20		59				31		Second row				0	31	0	0	0
44	20	57	20		57				44		Second row				0	44	0	0	0
84	20	53	20		53				84		Second row				0	84	0	0	0
51	20	52	20		52				51		Second row				0	51	0	0	0
52	20	51	20		51				52		Second row				0	52	0	0	0
87	20	48	20		48				87		Second row				0	87	0	0	0
36	20	44	20		44				36		Second row				0	36	0	0	0
73	12	36	20		36				73			Third row			0	0	73	0	0
47	12	31	20		31				47			Third row			0	0	47	0	0
33	40	16	20		16				33	First row					33	0	0	0	0
40	8	11	20		11				40				Fourth row		0	0	0	40	0
37	8	94	12			94			37				Fourth row		0	0	0	37	0
48	20	75	12			75			48		Second row				0	48	0	0	0
10	12	73	12			73			10			Third row			0	0	10	0	0
94	12	70	12			70			94			Third row			0	0	94	0	0
45	12	47	12			47			45			Third row			0	0	45	0	0
92	20	45	12			45			92		Second row				0	92	0	0	0
75	12	43	12			43			75			Third row			0	0	75	0	0
43	12	41	12			41			43			Third row			0	0	43	0	0
70	12	10	12			10			70			Third row			0	0	70	0	0
22	20	40	8				40		22		Second row				0	22	0	0	0
41	12	37	8				37		41			Third row			0	0	41	0	0
61	6	61	6					61	61					Fifth row	0	0	0	0	61

Figure 5 Spreadsheet to generate die storage locations for 2A Press , October 2013

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E	F	I	J	L	M	N	O	P	R	S	T	U	V	W	Y	Z	AA	AB	AC
										Week 1-4 die sets position placement					Placing Die sets number as per allocation				
Dies	Frequency	Dies	Frequency	Number of times # 40	Number of times # 20	Number of times # 12	Number of times #8	Number of times #6	Die	#40 pool	#20 pool	#12 pool	#8 pool	#6 pool	First row	Second row	Third row	Fourth row	Fifth row
14	20	86	40	86					14		Second row				0	14	0	0	0
86	40	14	20		14				86	First row					86	0	0	0	0
15	12	58	20		58				15			Third row			0	0	15	0	0
58	20	4	20		4				58		Second row				0	58	0	0	0
4	20	5	20		5				4		Second row				0	4	0	0	0
5	20	8	20		8				5		Second row				0	5	0	0	0
8	20	93	20		93				8		Second row				0	8	0	0	0
81	12	32	20		32				81			Third row			0	0	81	0	0
93	20	6	20		6				93		Second row				0	93	0	0	0
32	20	85	20		85				32		Second row				0	32	0	0	0
76	12	9	20		9				76			Third row			0	0	76	0	0
6	20	38	20		38				6		Second row				0	6	0	0	0
85	20	46	20		46				85		Second row				0	85	0	0	0
17	12	67	20		67				17			Third row			0	0	17	0	0
9	20	12	20		12				9		Second row				0	9	0	0	0
38	20	82	20		82				38		Second row				0	38	0	0	0
13	12	15	12			15			13			Third row			0	0	13	0	0
46	20	81	12			81			46		Second row				0	46	0	0	0
67	20	76	12			76			67		Second row				0	67	0	0	0
95	12	17	12			17			95			Third row			0	0	95	0	0
12	20	13	12			13			12		Second row				0	12	0	0	0
82	20	95	12			95			82		Second row				0	82	0	0	0
35	8	74	12			74			35				Fourth row		0	0	0	35	0
74	12	34	12			34			74			Third row			0	0	74	0	0
50	8	42	12			42			50				Fourth row		0	0	0	50	0
30	8	35	8				35		30				Fourth row		0	0	0	30	0
34	12	50	8				50		34			Third row			0	0	34	0	0
42	12	30	8				30		42			Third row			0	0	42	0	0
23	6	23	6					23	23					Fifth row	0	0	0	0	23
69	6	69	6					69	69					Fifth row	0	0	0	0	69

Figure 6 Spreadsheet to generate die storage locations for 3A Press, October 2013

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E	F	I	J	L	M	N	O	P	R	S	T	U	V	W	Y	Z	AA	AB	AC
										Week 1-4 die sets position placement					Placing Die sets number as per allocation				
Dies	Frequency	Dies	Frequency	Number of times # 40	Number of times # 20	Number of times # 12	Number of times #8	Number of times #6	Die	#40 pool	#20 pool	#12 pool	#8 pool	#6 pool	First row	Second row	Third row	Fourth row	Fifth row
7	20	33	40	33					7		Second row				0	7	0	0	0
16	20	7	20		7				16		Second row				0	16	0	0	0
53	20	16	20		16				53		Second row				0	53	0	0	0
59	20	53	20		53				59		Second row				0	59	0	0	0
57	20	59	20		59				57		Second row				0	57	0	0	0
11	20	57	20		57				11		Second row				0	11	0	0	0
66	20	11	20		11				66		Second row				0	66	0	0	0
31	20	66	20		66				31		Second row				0	31	0	0	0
44	20	31	20		31				44		Second row				0	44	0	0	0
84	20	44	20		44				84		Second row				0	84	0	0	0
51	20	84	20		84				51		Second row				0	51	0	0	0
52	20	51	20		51				52		Second row				0	52	0	0	0
87	20	52	20		52				87		Second row				0	87	0	0	0
36	20	87	20		87				36		Second row				0	36	0	0	0
73	12	36	20		36				73			Third row			0	0	73	0	0
47	12	48	20		48				47			Third row			0	0	47	0	0
33	40	92	20		92				33	First row					33	0	0	0	0
40	12	73	12			73			40			Third row			0	0	40	0	0
37	12	47	12			47			37			Third row			0	0	37	0	0
48	20	40	12			40			48		Second row				0	48	0	0	0
10	12	37	12			37			10			Third row			0	0	10	0	0
94	12	10	12			10			94			Third row			0	0	94	0	0
45	12	94	12			94			45			Third row			0	0	45	0	0
92	20	45	12			45			92		Second row				0	92	0	0	0
75	8	43	12			43			75				Fourth row		0	0	0	75	0
43	12	70	12			70			43			Third row			0	0	43	0	0
70	12	41	12			41			70			Third row			0	0	70	0	0
24	6	80	12			80			24					Fifth row	0	0	0	0	24
41	12	75	8				75		41			Third row			0	0	41	0	0
80	12	24	6					24	80			Third row			0	0	80	0	0

Figure 7 Spreadsheet to generate die storage locations for 2A Press , March 2014

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									Week 1-4 die sets position placement						Placing Die sets number as per allocation				
Dies	Frequency	Dies	Frequency	Number of times # 40	Number of times # 20	Number of times # 12	Number of times #8	Number of times #6	Die	#40 pool	#20 pool	#12 pool	#8 pool	#6 pool	First row	Second row	Third row	Fourth row	Fifth row
14	20	86	40	86					14		Second row				0	14	0	0	0
86	40	14	20		14				86	First row					86	0	0	0	0
15	12	58	20		58				15			Third row			0	0	15	0	0
58	20	4	20		4				58		Second row				0	58	0	0	0
4	20	5	20		5				4		Second row				0	4	0	0	0
5	20	8	20		8				5		Second row				0	5	0	0	0
8	20	93	20		93				8		Second row				0	8	0	0	0
81	12	32	20		32				81			Third row			0	0	81	0	0
93	20	6	20		6				93		Second row				0	93	0	0	0
32	20	85	20		85				32		Second row				0	32	0	0	0
76	12	9	20		9				76			Third row			0	0	76	0	0
6	20	38	20		38				6		Second row				0	6	0	0	0
85	20	46	20		46				85		Second row				0	85	0	0	0
17	12	67	20		67				17			Third row			0	0	17	0	0
9	20	95	20		95				9		Second row				0	9	0	0	0
38	20	12	20		12				38		Second row				0	38	0	0	0
13	12	82	20		82				13			Third row			0	0	13	0	0
46	20	35	20		35				46		Second row				0	46	0	0	0
67	20	34	20		34				67		Second row				0	67	0	0	0
95	20	15	12			15			95		Second row				0	95	0	0	0
12	20	81	12			81			12		Second row				0	12	0	0	0
82	20	76	12			76			82		Second row				0	82	0	0	0
35	20	17	12			17			35		Second row				0	35	0	0	0
74	12	13	12			13			74			Third row			0	0	74	0	0
50	8	74	12			74			50				Fourth row		0	0	0	50	0
30	8	42	12			42			30				Fourth row		0	0	0	30	0
34	20	50	8				50		34		Second row				0	34	0	0	0
42	12	30	8				30		42			Third row			0	0	42	0	0
60	6	60	6					60	60					Fifth row	0	0	0	0	60
55	6	55	6					55	55					Fifth row	0	0	0	0	55

Figure 8 Spreadsheet to generate die storage locations for 3A Press, March 2014

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									Week 1-4 die sets position placement						Placing Die sets number as per allocation				
Dies	Frequency	Dies	Frequency	Number of times # 40	Number of times # 20	Number of times # 12	Number of times #8	Number of times #6	Die	#40 pool	#20 pool	#12 pool	#8 pool	#6 pool	First row	Second row	Third row	Fourth row	Fifth row
7	20	33	40	33					7		Second row				0	7	0	0	0
16	20	7	20		7				16		Second row				0	16	0	0	0
53	20	16	20		16				53		Second row				0	53	0	0	0
59	20	53	20		53				59		Second row				0	59	0	0	0
57	20	59	20		59				57		Second row				0	57	0	0	0
11	20	57	20		57				11		Second row				0	11	0	0	0
66	20	11	20		11				66		Second row				0	66	0	0	0
31	20	66	20		66				31		Second row				0	31	0	0	0
44	20	31	20		31				44		Second row				0	44	0	0	0
84	20	44	20		44				84		Second row				0	84	0	0	0
51	20	84	20		84				51		Second row				0	51	0	0	0
52	20	51	20		51				52		Second row				0	52	0	0	0
87	20	52	20		52				87		Second row				0	87	0	0	0
36	20	87	20		87				36		Second row				0	36	0	0	0
73	8	36	20		36				73				Fourth row		0	0	0	73	0
47	12	48	20		48				47			Third row			0	0	47	0	0
33	40	94	20		94				33	First row					33	0	0	0	0
40	12	92	20		92				40			Third row			0	0	40	0	0
37	12	47	12			47			37			Third row			0	0	37	0	0
48	20	40	12			40			48		Second row				0	48	0	0	0
10	12	37	12			37			10			Third row			0	0	10	0	0
94	20	10	12			10			94		Second row				0	94	0	0	0
45	12	45	12			45			45			Third row			0	0	45	0	0
92	20	43	12			43			92		Second row				0	92	0	0	0
75	6	70	12			70			75					Fifth row	0	0	0	0	75
43	12	41	12			41			43			Third row			0	0	43	0	0
70	12	80	12			80			70			Third row			0	0	70	0	0
28	6	73	8				73		28					Fifth row	0	0	0	0	28
41	12	75	6					75	41			Third row			0	0	41	0	0
80	12	28	6					28	80			Third row			0	0	80	0	0

Figure 9 Spreadsheet to generate die storage locations for 2A Press, April 2014

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E	F	I	J	L	M	N	O	P	R	S	T	U	V	W	Y	Z	AA	AB	AC
									Week 1-4 die sets position placement						Placing Die sets number as per allocation				
Dies	Frequency	Dies	Frequency	Number of times # 40	Number of times # 20	Number of times # 12	Number of times #8	Number of times #6	Die	#40 pool	#20 pool	#12 pool	#8 pool	#6 pool	First row	Second row	Third row	Fourth row	Fifth row
14	20	86	40	86					14		Second row				0	14	0	0	0
86	40	14	20		14				86	First row					86	0	0	0	0
15	12	58	20		58				15			Third row			0	0	15	0	0
58	20	4	20		4				58		Second row				0	58	0	0	0
4	20	5	20		5				4		Second row				0	4	0	0	0
5	20	8	20		8				5		Second row				0	5	0	0	0
8	20	93	20		93				8		Second row				0	8	0	0	0
81	12	32	20		32				81			Third row			0	0	81	0	0
93	20	6	20		6				93		Second row				0	93	0	0	0
32	20	85	20		85				32		Second row				0	32	0	0	0
76	8	9	20		9				76				Fourth row		0	0	0	76	0
6	20	38	20		38				6		Second row				0	6	0	0	0
85	20	46	20		46				85		Second row				0	85	0	0	0
17	12	67	20		67				17			Third row			0	0	17	0	0
9	20	95	20		95				9		Second row				0	9	0	0	0
38	20	12	20		12				38		Second row				0	38	0	0	0
13	12	82	20		82				13			Third row			0	0	13	0	0
46	20	35	20		35				46		Second row				0	46	0	0	0
67	20	34	20		34				67		Second row				0	67	0	0	0
95	20	15	12			15			95		Second row				0	95	0	0	0
12	20	81	12			81			12		Second row				0	12	0	0	0
82	20	17	12			17			82		Second row				0	82	0	0	0
35	20	13	12			13			35		Second row				0	35	0	0	0
74	12	74	12			74			74			Third row			0	0	74	0	0
50	8	42	12			42			50				Fourth row		0	0	0	50	0
30	8	76	8				76		30				Fourth row		0	0	0	30	0
34	20	50	8				50		34		Second row				0	34	0	0	0
42	12	30	8				30		42			Third row			0	0	42	0	0
64	6	64	6					64	64					Fifth row	0	0	0	0	64
72	6	72	6					72	72					Fifth row	0	0	0	0	72

Figure 10 Spreadsheet to generate die storage locations for 3A Press, April 2014

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4.8 Method 4: 0-1 Linear Integer Programming Method

As discussed in all previous methods, the objective of our problem is to minimize the aggregate walking distance of team member or operator. The cycle time for external changeover of die sets to load and unload is about to 25-30 minutes which shows that the task is time consuming and the team member must make long trips. Considerable travel time saving can be realized if the die sets are placed in there optimal locations for a fixed period of time (month). After defining the problem, the next phase is to reformulate the problem in a form that is convenient for analysis. The Conventional Operation Research approach for our problem is to construct a mathematical model that will represent the essence of problem which is already discussed in Chapter 3 in great detail.

4.8.1 0-1Linear Integer Programming Solver-LINGO

In order to solve the 0-1 Linear Integer programming mathematical model, an optimization solver software is used. For our problem, the LINGO software (version 14.0) was employed. LINGO has the ability to model large systems by expressing similar type of expression and constraints into SETS. A set may be a list of SKU's, locations, or items. Each member in the set may contain one or more characteristics associated with it. In our model, the SETS are: die sets with their numbers, storage locations, and their usage frequency. The decision variable X_{ij} as discussed in Section 3.1.1 would then be derived to specify die sets and their storage locations because all possible combinations of assigning a die set to a storage location are evaluated. SETS describe the structure of the data; the DATA section provides the data to create a specific class of problem. In our problem, from Table 14, 15,16,17,18 and 19; the data

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we know is the die set number , the usage frequency and from Tables 4.1 we know the distance between each storage position and the stamping station die pallets for both 2A and 3A presses.

Table 14 Die set number and usage frequency for 2A press, October 2013

Die set Number	Frequency	Die set number	Frequency
33	40	31	20
7	20	16	20
92	20	11	20
22	20	94	12
87	20	75	12
84	20	73	12
66	20	70	12
59	20	47	12
57	20	45	12
53	20	43	12
52	20	41	12
51	20	10	12
48	20	40	8
44	20	37	8
36	20	61	6

Table 15 Die set number and usage frequency for 3A press, October 2013

Die set Number	Frequency	Die set number	Frequency
86	40	82	20
14	20	15	12
58	20	81	12
4	20	76	12
5	20	17	12
8	20	13	12
93	20	95	12
32	20	74	12
6	20	34	12
85	20	42	12
9	20	35	8
38	20	50	8
46	20	30	8
67	20	23	6
12	20	69	6

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Table 16 Die set number and usage frequency for 2A press, March 2014

Die set Number	Frequency	Die set number	Frequency
33	40	48	20
7	20	92	20
16	20	73	12
53	20	47	12
59	20	40	12
57	20	37	12
11	20	10	12
66	20	94	12
31	20	45	12
44	20	43	12
84	20	70	12
51	20	41	12
52	20	80	12
87	20	75	8
36	20	24	6

Table 17 Die set number and usage frequency for 3A press, March 2014

Die set Number	Frequency	Die set number	Frequency
86	40	12	20
14	20	82	20
58	20	35	20
4	20	34	20
5	20	15	12
8	20	81	12
93	20	76	12
32	20	17	12
6	20	13	12
85	20	74	12
9	20	42	12
38	20	50	8
46	20	30	8
67	20	60	6
95	20	55	6

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Table 18 Die set number and usage frequency for 2A press, April 2014

Die set Number	Frequency	Die set number	Frequency
33	40	48	20
7	20	94	20
16	20	92	20
53	20	47	12
59	20	40	12
57	20	37	12
11	20	10	12
66	20	45	12
31	20	43	12
44	20	70	12
84	20	41	12
51	20	80	12
52	20	73	8
87	20	75	8
36	20	25	6

Table 19 Die set number and usage frequency for 3A press, April 2014

Die set Number	Frequency	Die set number	Frequency
86	40	12	20
14	20	82	20
58	20	35	20
4	20	34	20
5	20	15	12
8	20	81	12
93	20	17	12
32	20	13	12
6	20	74	12
85	20	42	12
9	20	76	8
38	20	50	8
46	20	30	8
67	20	64	6
95	20	72	6

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4.8.4 LINGO Solver Status Window

When solving a problem in LINGO, a solver status window is displayed which is useful for observing the progress of the solver and the magnitudes of the model. The solver status window is shown in Figure 11.

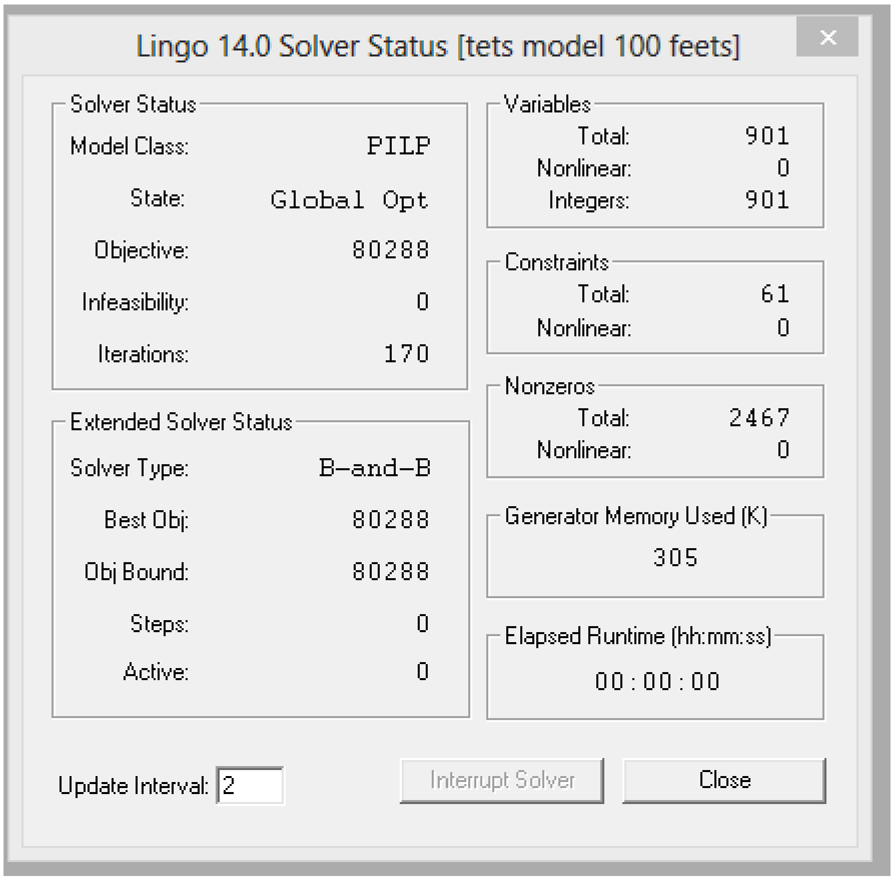

Figure 11 LINGO solver status window

Four important factors of the solver status window are discussed: state, solver type, best objective, and objective bound.

State: Give the status of the current solution. Possible states which the software can incur are "Global Optimum", "Feasible", "Infeasible", "Unbound", "Interrupted", and "Undetermined".

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Once the solver is inept to find a better solutions to the model, all optimized linear models will lapse in the global optimum state.

Solver type: Our model is an integer programming model, LINGO deploys an optimization strategy called Branch-and-Bound (B-and-B). Branch -and- bound is a systematic method for effectively and efficiently exploring the search space solution without having to numerate all possible combinatory solutions.

Best objective: It displays the best feasible objective value found so far.

Objective bound: This field states or displays the bound on the objective function. This bound sets a limit on how far the solver will be able to upgrade the objective function. At some instances, the value of both the objective bound and the best objective might become close or the same. The close or same value indicates that LINGO's current best solution is either the optimal solution, or close to it.

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CHAPTER FIVE: ANALYSIS OF RESULTS

The results of the subject case study applying four different solution methods are presented in this Chapter. An analysis on the performance of each of the different methods and their objective functions is described.

5.1 Performance evaluation of different methods

For the October 2013 run pattern schedule of 2A press die sets, the results shows that Method 4 which is our 0-1 Linear Integer Programming method provides the least objective function value at 284,064 feet travelled. The highest value is given by Method 1, as expected, which is the random assignment method by allocating die sets in the storage locations in a random fashion. Figure 12 shows the objective function values of all methods.

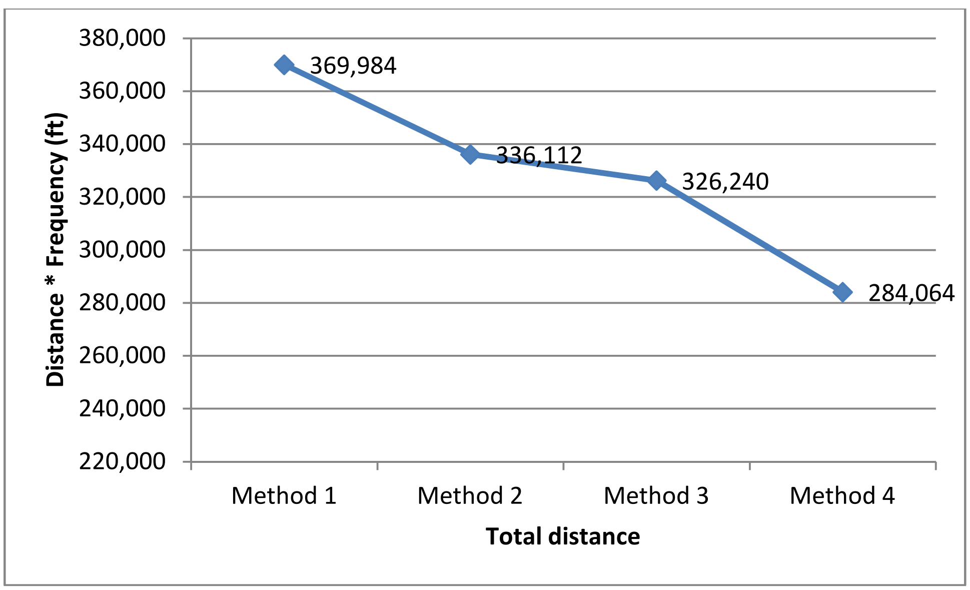

Figure 12 Comparison of total distance travelled, 2A press, October 2013

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Similarly for 3A press as shown in Figure 13, Method 4 gives the least objective function value .The rest of the Figures 14, 15, 16 and 17 also support Method 4 and produces the least objective function value.

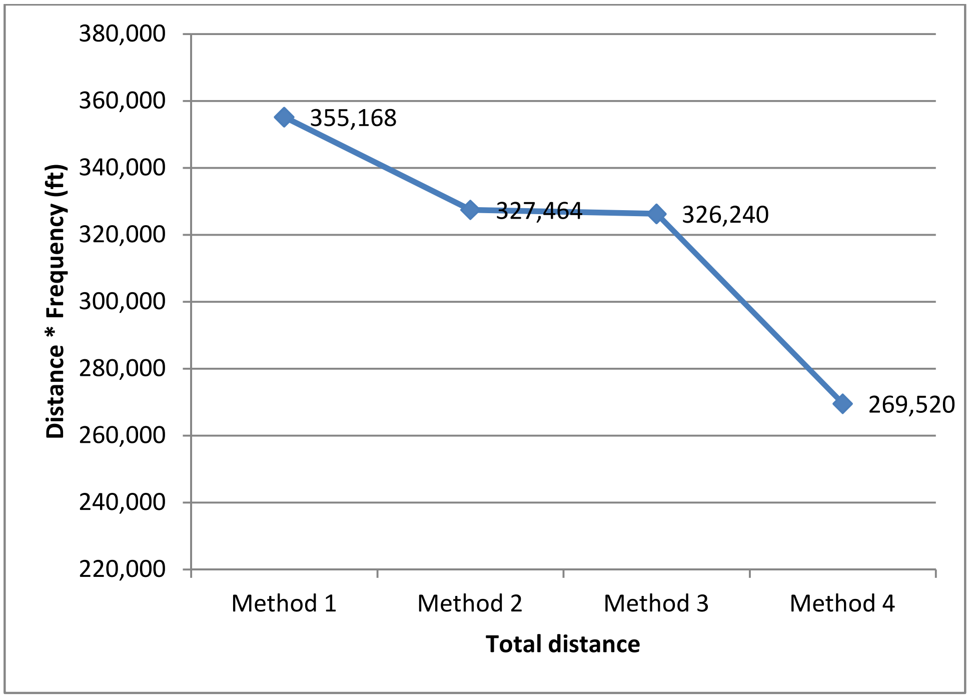

Figure 13 Comparison of total distance travelled, 3A press, October 2013

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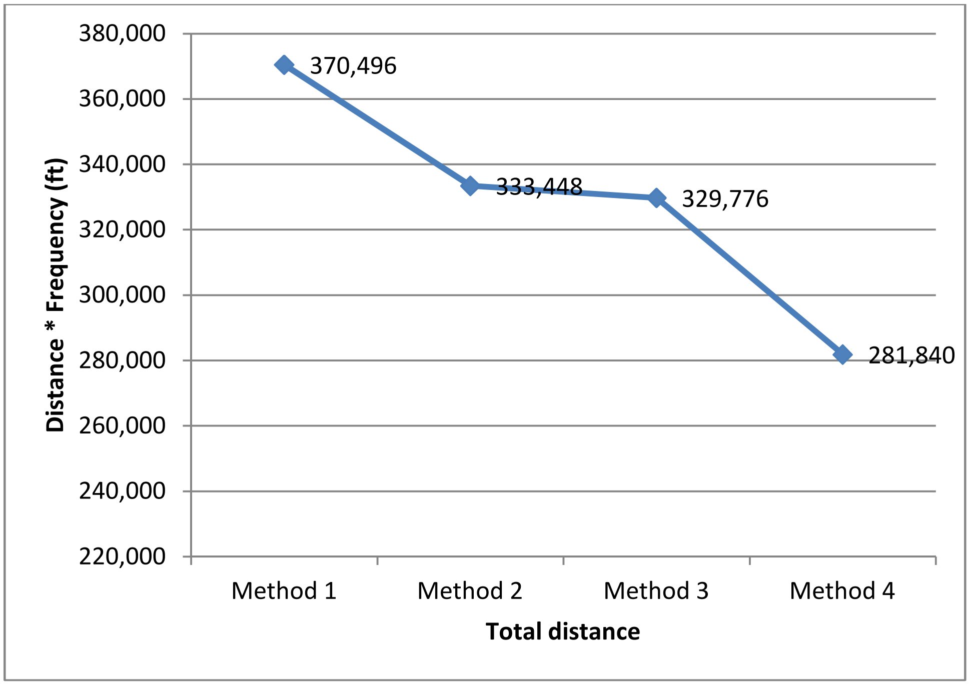

Figure 14 Comparison of total distance travelled, 2A press, March 2014

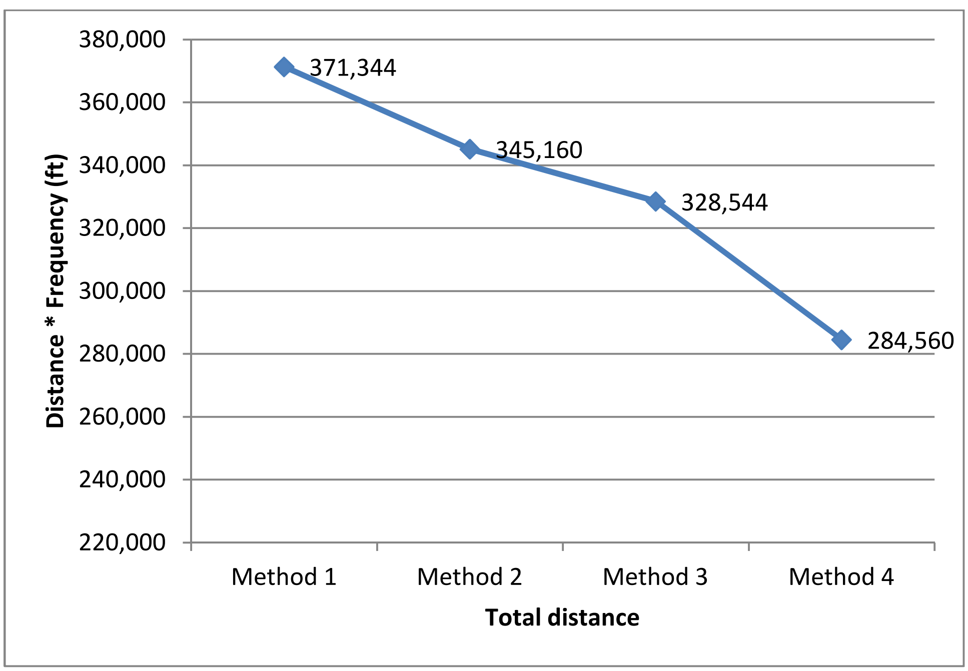

Figure 15 Comparison of total distance travelled, 3A press, March 2014

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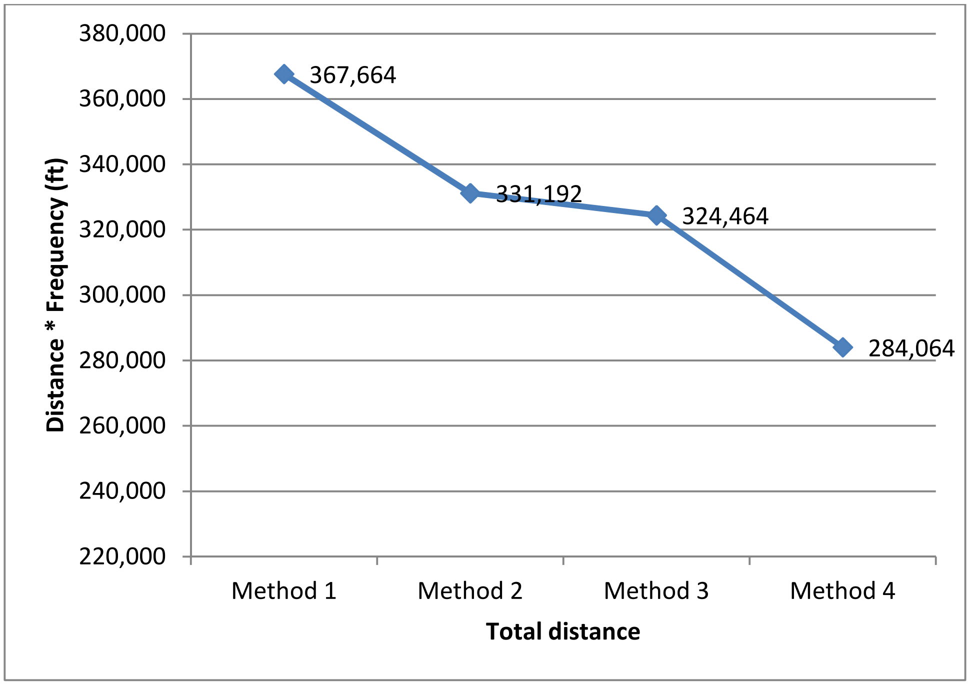

Figure 16 Comparison of total distance travelled, 2A press, April 2014

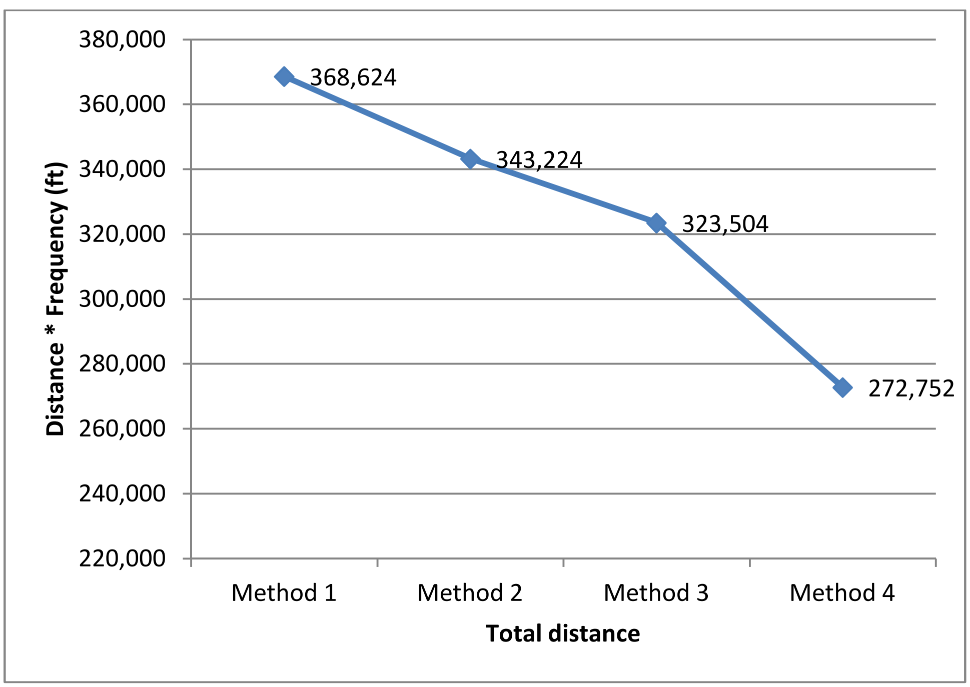

Figure 17 Comparison of total distance travelled, 3A press, April 2014

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The LINGO software solution window (shown in Figures 18 and 19) provides both the objective function value with solver iterations and the optimal allocation of die sets, respectively, based on their usage frequency. Note that the first number in Figure 19 under the index X represents die set number and the last represents the optimal position.

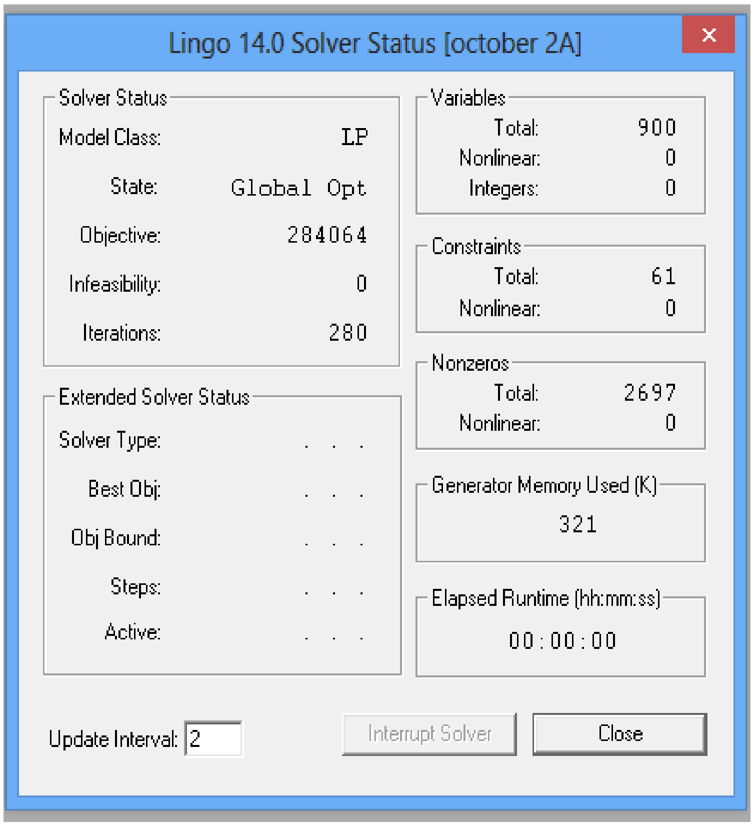

Figure 18 Solver status window representing objective function value and other features

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```
Global optimal solution found.
Objective value:                              284064.0
Infeasibilities:                              0.000000
Total solver iterations:                           280
Elapsed runtime seconds:                          0.06

Model Class:                                        LP

Total variables:                    900
Nonlinear variables:                  0
Integer variables:                    0

Total constraints:                   61
Nonlinear constraints:                0

Total nonzeros:                    2697
Nonlinear nonzeros:                   0
```

Variable	Value	Reduced Cost
X7_1	0.000000	0.000000
X7_2	0.000000	0.000000
X7_3	0.000000	0.000000
X7_4	0.000000	0.000000
X7_5	0.000000	0.000000
X7_6	0.000000	0.000000
X7_7	0.000000	0.000000
X7_8	0.000000	0.000000
X7_9	0.000000	0.000000
X7_10	0.000000	0.000000
X7_11	0.000000	0.000000
X7_12	0.000000	0.000000
X7_13	0.000000	0.000000
X7_14	0.000000	0.000000
X7_15	0.000000	0.000000
X7_16	0.000000	0.000000
X7_17	1.000000	0.000000
X7_18	0.000000	32.00000
X7_19	0.000000	64.00000
X7_20	0.000000	576.0000
X7_21	0.000000	128.0000
X7_22	0.000000	640.0000
X7_23	0.000000	672.0000
X7_24	0.000000	704.0000
X7_25	0.000000	1216.000
X7_26	0.000000	768.0000
X7_27	0.000000	1280.000

Figure 19 Solver status report with objective function value and optimal positions

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As seen from discussion in Section 5.1, the minimum value is derived by using Method 4 which is the 0-1 Linear Integer Programming method. So the allocation of die sets will be done based on the solution results from LINGO software. Table 20 shows optimal positions of die sets with their die set numbers. The total postions are actually 60 for 30 die sets but for the ease of understanding each position with its adjacent is considered to accomodate 4 dies with a set of 2 . Similarly, Tables 21, 22, 23, 24 and 25 give the optimal postions od die sets for 2A and 3A presses for 3 other different months.

Table 20 Optimal positions for 2A press die sets , October 2013

Die Set number	Position	Die Set number	Position
33	1	44	16
36	2	7	17
22	3	47	18
31	4	73	19
87	5	92	20
52	6	75	21
66	7	94	22
11	8	45	23
59	9	41	24
57	10	43	25
51	11	10	26
84	12	70	27
48	13	40	28
53	14	37	29
16	15	61	30

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Table 21 Optimal positions for 3A press die sets , October 2013

Die set number	Positions	Die set number	Positions
86	1	58	16
6	2	76	17
38	3	34	18
67	4	13	19
12	5	95	20
5	6	15	21
82	7	81	22
85	8	74	23
46	9	42	24
8	10	35	25
4	11	17	26
93	12	50	27
9	13	30	28
32	14	23	29
14	15	69	30

Table 22 Optimal positions for 2A press die sets , March 2014

Die set number	Positions	Die set number	Positions
33	1	7	16
31	2	41	17
87	3	80	18
36	4	47	19
84	5	92	20
48	6	37	21
44	7	10	22
51	8	43	23
53	9	94	24
57	10	45	25
52	11	70	26
11	12	40	27
59	13	73	28
66	14	75	29
16	15	24	30

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Table 23 Optimal positions for 3A press die sets , March 2014

Die set number	Positions	Die set number	Positions
86	1	46	16
34	2	67	17
82	3	93	18
38	4	76	19
85	5	95	20
12	6	13	21
9	7	15	22
4	8	74	23
35	9	17	24
8	10	81	25
6	11	42	26
5	12	50	27
32	13	30	28
58	14	55	29
14	15	60	30

Table 24 Optimal positions for 2A press die sets , April 2014

Die set number	Positions	Die set number	Positions
33	1	66	16
51	2	7	17
48	3	37	18
94	4	41	19
31	5	92	20
87	6	47	21
52	7	80	22
11	8	40	23
53	9	10	24
57	10	70	25
36	11	45	26
84	12	43	27
44	13	73	28
59	14	75	29
16	15	28	30

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Table 25 Optimal positions for 3A press die sets , April 2014

Die set number	Positions	Die set number	Positions
14	18	34	8
15	22	46	1
58	13	67	9
4	14	95	2
8	16	82	6
81	23	13	19
93	17	74	21
32	12	50	27
76	28	30	25
35	3	42	24
6	7	64	29
85	5	72	30
17	26	86	15
9	11	5	10
38	4	12	20

The objective function value of subject automotive stamping shop has an improvement of 9.69% of travelling distance from Method 1 which is random assignment of die sets , 11.52 % of the proposed heuristic algorithm and 23.2 9% for 0-1 Linear Integer Programming method as summarized in Table 26. Table 27 presents the percentage improvement of objective function from Method 2 compared to results Methods 3 and 4.

Similarly, comparing to the results for 3A press, the results presented in Tables 28 and 29 show that Method 4 has more significant reduction in walking distance from Methods 1 and 2, respectively.

Table 26 Overall % improvement in traveling distance from Method 1 for 2A press

Method	Overall % improvement
2	9.69
3	11.52
4	23.29

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Table 27 Overall % improvement in traveling distance from Method 2 for 2A press

Method	Overall % improvement
3	2.02
4	15.06

Table 28 Overall % improvement in traveling distance from Method 1 for 3A press

Method	Overall % improvement
2	7.23
3	10.66
4	24.49

Table 29 Overall % improvement in traveling distance from Method 2 for 3A press

Method	Overall % improvement
3	3.69
4	18.6

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CHAPTER SIX: CONCLUSIONS AND FUTURE RESEARCH

6.1 Research Summary

Order picking and restocking area is the most labor intensive and costly activities of any logistic distribution center, as traveling report for up to 50% of the total labor time. Therefore, this research focused on similar kind of environment of a subject automotive stamping shop, also can be considered as storage assignment problem in a broader sense where die sets need to be stored in their optimal positions after picking and restocking so that the team member aggregate walking distance is minimized overall. The previous SKU assignment literature had covered or was limited to account for the dynamic nature of order demand and to optimize stock location accordingly. Hence, the aim of this study was to develop a dynamic planning system for die sets allocations based on the monthly or fixed period demand pattern for a month.

In this research, a stock assignment problem considering the demand pattern and usage frequency of die sets for 3 different months was considered. The problem was formulated first by heuristic based approach using spreadsheet program to generate the recommended layout for die sets and then a mathematical 0-1 Linear Integer Programming (LIP) model was formulated. The LIP model was successfully solved by using the LINGO solver (Version 14.0) .

For the first month which is October 2013 for 2A press line die sets, the results using LINGO solver was achieved after 280 iterations and picking random seed generator as 1031. For the second press line, the result was generated after 274 iterations and using same random seed generator.

It was observed that there is a linear relation between distance and die usage frequency. From Figure 20 we can see that the most frequently used dies are placed in near or front locations and the least frequently used dies are placed farther.

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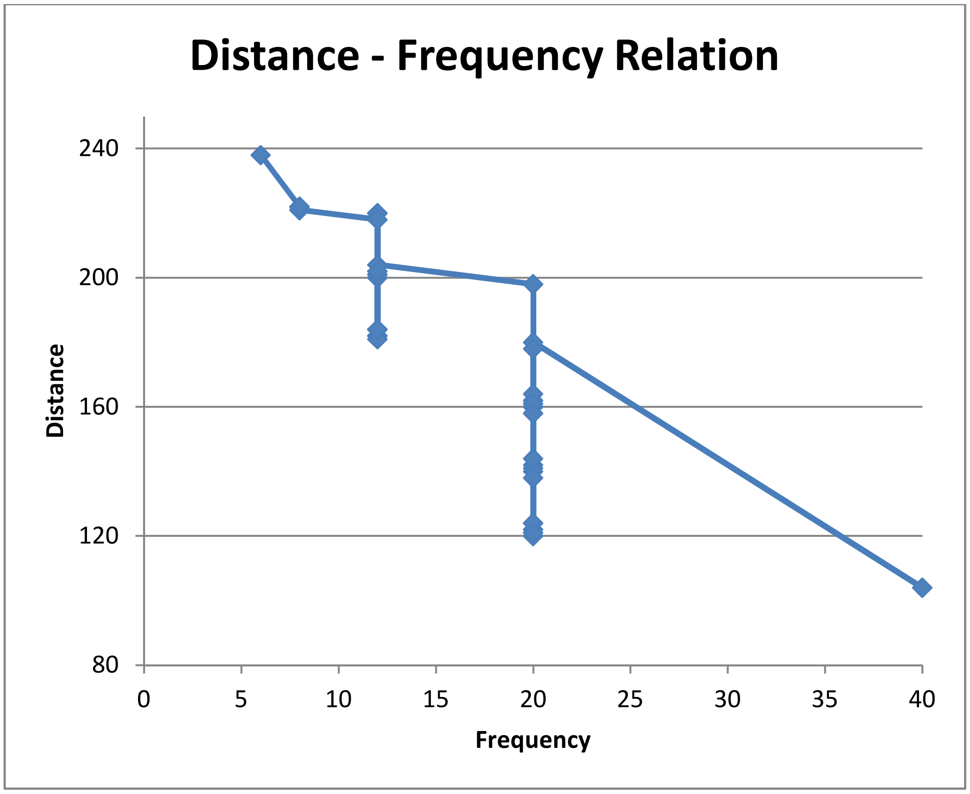

Figure 20 Relation between distance and frequency

From the series of case problems it can be concluded that the LIP model assigns die sets in a most accurate way such that the overall traveling distances for team members involved in picking and restocking is minimized. The solutions obtained by the LIP model delivered less walking distance compared to the other methods tested.

6.2 Future Research

In the future, there is a scope of implementing multi-agent system in this scenario with the inclusion of meta-heuristics. Also, Stochastic based algorithm selection such as Bayesian network or Neural network can be introduced to add more complexities in the current problem design.

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APPENDIX

A.1 LINGO SETS Code for 2A Press pattern

```
MIN  8320X7_1 + 9600X7_2 + 9680X7_3 + 9760X7_4 + 11040X7_5 + 9920X7_6 +
11200X7_7 + 11280X7_8 + 11360X7_9 + 12640X7_10 + 11520X7_11 + 12800X7_12 +
12880X7_13 + 12960X7_14 + 14240X7_15 + 13120X7_16 + 14400X7_17 +
14480X7_18+14560X7_19 + 15840X7_20 + 14720X7_21 + 16000X7_22 + 16080X7_23 +
16160X7_24 + 17440X7_25 + 16320X7_26 + 17600X7_27 + 17680X7_28+17760X7_29 +
19040X7_30 + 8320X16_1 + 9600X16_2 + 9680X16_3 + 9760X16_4 + 11040X16_5 +
9920X16_6 + 11200X16_7 + 11280X16_8 + 11360X16_9 + 12640X16_10 + 11520X16_11
+ 12800X16_12 + 12880X16_13 + 12960X16_14 + 14240X16_16+14400X16_17 +
14480X16_18 + 14560X16_19 + 15840X16_20 + 14720X16_21 + 16000X16_22 +
16080X16_23 + 16160X16_24 + 17440X16_25 + 16320X16_26 + 17600X16_27 +
17680X16_28+17760X16_29 + 19040X16_30 + 4992X10_1 + 5760X10_2 + 5808X10_3 +
5856X10_4 + 6624X10_5 + 5952X10_6 + 6720X10_7 + 6768X10_8 + 6816X10_9 +
7584X10_10 + 6912X10_11 + 7680X10_12+ 7728X10_13 + 7776X10_14 + 8544X10_15 +
7872X10_16 + 8640X10_17 + 8688X10_18 + 8736X10_19 + 9504X10_20 + 8832X10_21 +
9600X10_22 + 9648X10_23 + 9696X10_24 + 10464X10_25 + 9792X10_26 + 10560X10_27
+ 10608X10_28+10656X10_29 + 11424X10_30 + 8320X53_1+9600X53_2 + 9680X53_3 +
9760X53_4 + 11040X53_5 + 9920X53_6 + 11200X53_7 + 11280X53_8 +
11360X53_9+12640X53_10+11520X53_11 + 12800X53_12 + 12880X53_13 + 12960X53_14
+ 14240X53_15 + 13120X53_16 + 14400X53_17 + 14480X53_18 + 14560X53_19 +
15840X53_20 + 14720X53_21 + 16000X53_22+16080X53_23+16160X53_24 + 17440X53_25
+ 16320X53_26 + 17600X53_27 + 17680X53_28 + 17760X53_29 + 19040X53_30 +
8320X59_1 + 9600X59_2 + 9680X59_3 + 9760X59_4 + 11040X59_5 + 9920X59_6 +
11200X59_7 + 11280X59_8 + 11360X59_9 + 12640X59_10 + 11520X59_11 +
12800X59_12 + 12880X59_13 + 12960X59_14 + 14240X59_15 + 13120X59_16 +
14400X59_17 + 14480X59_18 + 14560X59_19 + 15840X59_20 + 14720X59_21 +
16000X59_22 + 16080X59_23 + 16160X59_24 + 17440X59_25 + 16320X59_26 +
17600X59_27+17680X59_28 + 17760X59_29 + 19040X59_30 + 8320X57_1 + 9600X57_2 +
9680X57_3 + 9760X57_4 + 11040X57_5 + 9920X57_6 + 11200X57_7 + 11280X57_8 +
11360X57_9+12640X53_10 + 11520X57_11 + 12800X57_12 + 12880X57_13 +
12960X57_14 + 14240X57_15 + 13120X57_16 + 14400X57_17+14480X57_18+14560X57_19
+ 15840X57_20+14720X57_21 + 16000X57_22 + 16080X57_23 + 16160X57_24 +
17440X57_25 + 16320X57_26 + 17600X57_27+17680X57_28+17760X57_29 + 19040X57_30
+ 4992X94_1 + 5760X94_2 + 5808X94_3 + 5856X94_4 + 6624X94_5 + 5952X94_6 +
6720X94_7 + 6768X94_8 + 6816X94_9 + 7584X94_10 + 6912X94_11 + 7680X94_12 +
7728X94_13 + 7776X94_14 + 8544X94_15 + 7872X94_16 + 8640X94_17 + 8688X94_18 +
8736X94_19 + 9504X94_20+8832X94_21 + 9600X94_22 + 9648X94_23 + 9696X94_24 +
10464X94_25 + 9792X94_26 + 10560X94_27 + 10608X94_28 +
10656X94_29+11424X94_30+8320X11_1 + 9600X11_2 + 9680X11_3 + 9760X11_4 +
11040X11_5 + 9920X11_6 + 11200X11_7 + 11280X11_8 + 11360X11_9+12640X11_10 +
11520X11_11 + 12800X11_12 + 12880X11_13 + 12960X11_14 + 14240X11_15 +
13120X11_16 + 14400X11_17+14480X11_18+14560X11_19 + 15840X11_20+14720X11_21 +
16000X11_22 + 16080X11_23 + 16160X11_24 + 17440X11_25 + 16320X11_26 +
17600X11_27 + 17680X11_28 + 17760X11_29+19040X11_30 + 8320X66_1+9600X66_2 +
9680X66_3 + 9760X66_4 + 11040X66_5 + 9920X66_6 + 11200X66_7 + 11280X66_8 +
11360X66_9+12640X66_10 + 11520X66_11 + 12800X66_12 + 12880X66_13 +
12960X66_14 + 14240X66_15 + 13120X66_16 + 14400X66_17+14480X66_18+14560X66_19
+ 15840X66_20+14720X66_21 + 16000X66_22 + 16080X66_23 + 16160X66_24 +
17440X66_25 + 16320X66_26 + 17600X66_27+17680X66_28+17760X66_29 +
19040X66_30+4992X45_1 + 5760X45_2 + 5808X45_3 + 5856X45_4 + 6624X45_5 +
5952X45_6 + 6720X45_7 + 6768X45_8 + 6816X45_9+7584X45_10 + 6912X45_11 +
7680X45_12 + 7728X45_13 + 7776X45_14 + 8544X45_15 + 7872X45_16 +
```


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8640X45_17+8688X45_18+8736X45_19 + 9504X45_20 + 8832X45_21 + 9600X45_22 + 9648X45_23 + 9696X45_24 + 10464X45_25 + 9792X45_26 + 10560X45_27+10608X45_28+10656X45_29 + 11424X45_30+8320X31_1+9600X31_2 + 9680X31_3 + 9760X31_4 + 11040X31_5 + 9920X31_6 + 11200X31_7 + 11280X31_8 + 11360X31_9+12640X31_10 + 11520X31_11 + 12800X31_12 + 12880X31_13 + 12960X31_14 + 14240X31_15 + 13120X31_16 + 14400X31_17+14480X31_18+14560X31_19 + 15840X31_20+14720X31_21 + 16000X31_22+16080X31_23 + 16160X31_24 + 17440X31_25 + 16320X31_26 + 17600X31_27 + 17680X31_28 + 17760X31_29 + 19040X31_30 + 4992X70_1 + 5760X70_2 + 5808X70_3 + 5856X70_4 + 6624X70_5 + 5952X70_6 + 6720X70_7 + 6768X70_8 + 6816X70_9+7584X70_10 + 6912X70_11 + 7680X70_12 + 7728X70_13 + 7776X70_14 + 8544X70_15 + 7872X70_16 + 8640X70_17+8688X70_18+8736X70_19 + 9504X70_20+8832X70_21 + 9600X70_22 + 9648X70_23 + 9696X70_24 + 10464X70_25 + 9792X70_26 + 10560X70_27+10608X70_28+10656X70_29 + 11424X70_30+8320X44_1+9600X44_2 + 9680X44_3 + 9760X44_4 + 11040X44_5 + 9920X44_6 + 11200X44_7 + 11280X44_8 + 11360X44_9+12640X44_10 + 11520X44_11 + 12800X44_12 + 12880X44_13 + 12960X44_14 + 14240X44_15 + 13120X44_16 + 14400X44_17+14480X44_18+14560X44_19 + 15840X44_20+14720X44_21 + 16000X44_22 + 16080X44_23 + 16160X44_24 + 17440X44_25 + 16320X44_26 + 17600X44_27+17680X44_28+17760X44_29+19040X44_30+8320X84_1 + 9600X84_2 + 9680X84_3 + 9760X84_4 + 11040X84_5 + 9920X84_6 + 11200X84_7 + 11280X84_8 + 11360X84_9+12640X84_10 + 11520X84_11 + 12800X84_12 + 12880X84_13 + 12960X84_14 + 14240X84_15 + 13120X84_16 + 14400X84_17+14480X84_18+14560X84_19 + 15840X84_20+14720X84_21 + 16000X84_22 + 16080X84_23 + 16160X84_24 + 17440X84_25 + 16320X84_26 + 17600X84_27+17680X84_28+17760X84_29 + 19040X84_30 + 8320X51_1+9600X51_2 + 9680X51_3 + 9760X51_4 + 11040X51_5 + 9920X51_6 + 11200X51_7 + 11280X51_8 + 11360X51_9+12640X51_10 + 11520X51_11 + 12800X51_12 + 12880X51_13 + 12960X51_14 + 14240X51_15 + 13120X51_16 + 14400X51_17+14480X51_18+14560X51_19 + 15840X51_20+14720X51_21 + 16000X51_22 + 16080X51_23 + 16160X51_24 + 17440X51_25 + 16320X51_26 + 17600X51_27+17680X51_28+17760X51_29 + 19040X51_30+8320X52_1 + 9600X52_2 + 9680X52_3 + 9760X52_4 + 11040X52_5 + 9920X52_6 + 11200X52_7 + 11280X52_8 + 11360X52_9+12640X52_10 + 11520X52_11 + 12800X52_12 + 12880X52_13 + 12960X52_14 + 14240X52_15 + 13120X52_16 + 14400X52_17+14480X52_18+14560X52_19 + 15840X52_20+14720X52_21 + 16000X52_22 + 16080X52_23 + 16160X52_24 + 17440X52_25 + 16320X52_26 + 17600X52_27+17680X52_28+17760X52_29 + 19040X52_30+8320X87_1+9600X87_2 + 9680X87_3 + 9760X87_4 + 11040X87_5 + 9920X87_6 + 11200X87_7 + 11280X87_8 + 11360X87_9+12640X87_10 + 11520X87_11 + 12800X87_12 + 12880X87_13 + 12960X87_14 + 14240X87_15 + 13120X87_16 + 14400X87_17+14480X87_18+14560X87_19 + 15840X87_20+14720X87_21 + 16000X87_22 + 16080X87_23 + 16160X87_24 + 17440X87_25 + 16320X87_26 + 17600X87_27+17680X87_28+17760X87_29 + 19040X87_30 + 8320X36_1 + 9600X36_2 + 9680X36_3 + 9760X36_4 + 11040X36_5 + 9920X36_6 + 11200X36_7 + 11280X36_8 + 11360X36_9+12640X36_10 + 11520X36_11 + 12800X36_12 + 12880X36_13 + 12960X36_14 + 14240X36_15 + 13120X36_16 + 14400X36_17+14480X36_18+14560X36_19 + 15840X36_20+14720X36_21 + 16000X36_22 + 16080X36_23 + 16160X36_24 + 17440X36_25 + 16320X36_26 + 17600X36_27+17680X36_28+17760X36_29 + 19040X36_30+4992X73_1+5760X73_2 + 5808X73_3 + 5856X73_4 + 6624X73_5 + 5952X73_6 + 6720X73_7 + 6768X73_8 + 6816X73_9+7584X73_10 + 6912X73_11 + 7680X73_12 + 7728X73_13 + 7776X73_14 + 8544X73_15 + 7872X73_16 + 8640X73_17+8688X73_18+8736X73_19 + 9504X73_20+8832X73_21 + 9600X73_22 + 9648X73_23 + 9696X73_24 + 10464X73_25 + 9792X73_26 + 10560X73_27+10608X73_28+10656X73_29 + 11424X73_30+4992X47_1 + 5760X47_2 + 5808X47_3 + 5856X47_4 + 6624X47_5 + 5952X47_6 + 6720X47_7 + 6768X47_8 + 6816X47_9+7584X47_10 + 6912X47_11 + 7680X47_12 + 7728X47_13 + 7776X47_14 + 8544X47_15 + 7872X47_16 + 8640X47_17+8688X47_18+8736X47_19 +

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9504X47_20+8832X47_21 + 9600X47_22 + 9648X47_23 + 9696X47_24 + 10464X47_25 + 9792X47_26 + 10560X47_27+10608X47_28+10656X47_29 + 11424X47_30 + 8320X48_1+9600X48_2 + 9680X48_3 + 9760X48_4 + 11040X48_5 + 9920X48_6 + 11200X48_7 + 11280X48_8 + 11360X48_9+12640X48_10 + 11520X48_11 + 12800X48_12 + 12880X48_13 + 12960X48_14 + 14240X48_15 + 13120X48_16 + 14400X48_17+14480X48_18+14560X48_19 + 15840X48_20+14720X48_21 + 16000X48_22 + 16080X48_23 + 16160X48_24 + 17440X48_25 + 16320X48_26 + 17600X48_27+17680X48_28+17760X48_29 + 19040X48_30+8320X92_1 + 9600X92_2 + 9680X92_3 + 9760X92_4 + 11040X92_5 + 9920X92_6 + 11200X92_7 + 11280X92_8 + 11360X92_9+12640X92_10 + 11520X92_11 + 12800X92_12 + 12880X92_13 + 12960X92_14 + 14240X92_15 + 13120X92_16 + 14400X92_17+14480X92_18+14560X92_19 + 15840X92_21 + 16000X92_22 + 16080X92_23 + 16160X92_24 + 17440X92_25 + 16320X92_26 + 17600X92_27+17680X92_28+17760X92_29 + 19040X92_30+16640X33_1+19200X33_2 + 19360X33_3 + 19520X33_4 + 22080X33_5 + 19840X33_6 + 22400X33_7 + 22560X33_8 + 22720X33_9+25280X33_10 + 23040X33_11 + 25600X33_12 + 25760X33_13 + 25920X33_14 + 28480X33_15 + 26240X33_16 + 28800X33_17+28960X33_18+29120X33_19 + 31680X33_20+29440X33_21 + 32000X33_22 + 32160X33_23 + 32320X33_24 + 34880X33_25 + 32640X33_26 + 35200X33_27+35360X33_28+35520X33_29 + 38080X33_30 + 4992X41_1 + 5760X41_2 + 5808X41_3 + 5856X41_4 + 6624X41_5 + 5952X41_6 + 6720X41_7 + 6768X41_8 + 6816X41_9+7584X41_10 + 6912X41_11 + 7680X41_12 + 7728X41_13 + 7776X41_14 + 8544X41_15 + 7872X41_16 + 8640X41_17+8688X41_18+8736X41_19 + 9504X41_20+8832X41_21 + 9600X41_22 + 9648X41_23 + 9696X41_24 + 10464X41_25 + 9792X41_26 + 10560X41_27+10608X41_28+10656X41_29 + 11424X41_30+4992X75_1+5760X75_2 + 5808X75_3 + 5856X75_4 + 6624X75_5 + 5952X75_6 + 6720X75_7 + 6768X75_8 + 6816X75_9+7584X75_10 + 6912X75_11 + 7680X75_12 + 7728X75_13 + 7776X75_14 + 8544X75_15 + 7872X75_16 + 8640X75_17+8688X75_18+8736X75_19 + 9504X75_20+8832X75_21 + 9600X75_22 + 9648X75_23 + 9696X75_24 + 10464X75_25 + 9792X75_26 + 10560X75_27+10608X75_28+10656X75_29 + 11424X75_30+4992X43_1 + 5760X43_2 + 5808X43_3 + 5856X43_4 + 6624X43_5 + 5952X43_6 + 6720X43_7 + 6768X43_8 + 6816X43_9+7584X43_10 + 6912X43_11 + 7680X43_12 + 7728X43_13 + 7776X43_14 + 8544X43_15 + 7872X43_16 + 8640X43_17+8688X43_18+8736X43_19 + 9504X43_20+8832X43_21 + 9600X43_22 + 9648X43_23 + 9696X43_24 + 10464X43_25 + 9792X43_26 + 10560X43_27+10608X43_28+10656X43_29 + 11424X43_30 + 8320X22_1+9600X22_2 + 9680X22_3 + 9760X22_4 + 11040X22_5 + 9920X22_6 + 11200X22_7 + 11280X22_8 + 11360X22_9+12640X22_10 + 11520X22_11 + 12800X22_12 + 12880X22_13 + 12960X22_14 + 14240X22_15 + 13120X22_16 + 14400X22_17+14480X22_18+14560X22_19 + 15840X22_20+14720X22_21 + 16000X22_22 + 16080X22_23 + 16160X22_24 + 17440X22_25 + 16320X22_26 + 17600X22_27+17680X22_28+17760X22_29 + 19040X22_30+2496X61_1 + 2880X61_2 + 2904X61_3 + 2928X61_4 + 3312X61_5 + 2976X61_6 + 3360X61_7 + 3384X61_8 + 3408X61_9+3792X61_10 + 3456X61_11 + 3840X61_12 + 3864X61_13 + 3888X61_14 + 4272X61_15 + 3936X61_16 + 4320X61_17+4344X61_18+4368X61_19 + 4752X61_20+4416X61_21 + 4800X61_22 + 4824X61_23 + 4848X61_24 + 5232X61_25 + 4896X61_26 + 5280X61_27+5304X61_28+5328X61_29 + 5712X61_30+3328X40_1+3840X40_2 + 3872X40_3 + 3904X40_4 + 4416X40_5 + 3968X40_6 + 4480X40_7 + 4512X40_8 + 4544X40_9+5056X40_10 + 4608X40_11 + 5120X40_12 + 5152X40_13 + 5184X40_14 + 5696X40_15 + 5248X40_16 + 5760X40_17+5792X40_18+5824X40_19 + 6336X40_20+5888X40_21 + 6400X40_22 + 6432X40_23 + 6464X40_24 + 6976X40_25 + 6528X40_26 + 7040X40_27+7072X40_28+7104X40_29 + 7616X40_30 + 3328X37_1 + 3840X37_2 + 3872X37_3 + 3904X37_4 + 4416X37_5 + 3968X37_6 + 4480X37_7 + 4512X37_8 + 4544X37_9+5056X37_10 + 4608X37_11 + 5120X37_12 + 5152X37_13 + 5184X37_14 + 5696X37_15 + 5248X37_16 + 5760X37_17+5792X37_18+5824X37_19 +

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```
6336X37_20+5888X37_21 + 6400X37_22 + 6432X37_23 + 6464X37_24 + 6976X37_25 +
6528X37_26 + 7040X37_27+7072X37_28+7104X37_29 + 7616X37_30


SUBJECT TO

X7_1 + X7_2 + X7_3+X7_4 + X7_5 + X7_6+X7_7 + X7_8 + X7_9+X7_10 + X7_11 +
X7_12+X7_13 + X7_14 + X7_15+X7_16 + X7_17 + X7_18+X7_19 + X7_20 + X7_21+X7_22
+ X7_23 + X7_24+X7_25 + X7_26 + X7_27+X7_28 + X7_29 + X7_30 = 1
X16_1 + X16_2 + X16_3+X16_4 + X16_5 + X16_6+X16_7 + X16_8 + X16_9+X16_10 +
X16_11 + X16_12+X16_13 + X16_14 + X16_15+X16_16 + X16_17 + X16_18+X16_19 +
X16_20 + X16_21+X16_22 + X16_23 + X16_24+X16_25 + X16_26 + X16_27+X16_28 +
X16_29 + X16_30 = 1
X10_1 + X10_2 + X10_3+X10_4 + X10_5 + X10_6+X10_7 + X10_8 + X10_9+X10_10 +
X10_11 + X10_12+X10_13 + X10_14 + X10_15+X10_16 + X10_17 + X10_18+X10_19 +
X10_20+X10_21+X10_22 + X10_23 + X10_24+X10_25 + X10_26 + X10_27+X10_28 +
X10_29 + X10_30=1
X53_1 + X53_2 + X53_3+X53_4 + X53_5 + X53_6+X53_7 + X53_8 + X53_9+X53_10 +
X53_11 + X53_12+X53_13 + X53_14 + X53_15+X53_16 + X53_17 + X53_18+X53_19 +
X53_20 + X53_21+X53_22 + X53_23 + X53_24+X53_25 + X53_26 + X53_27+X53_28 +
X53_29 + X53_30=1
X59_1 + X59_2 + X59_3+X59_4 + X59_5 + X59_6+X59_7 + X59_8 + X59_9+X59_10 +
X59_11 + X59_12+X59_13 + X59_14 + X59_15+X59_16 + X59_17 + X59_18+X59_19 +
X59_20+X59_21 + X59_22 + X59_23+X59_24 + X59_25 + X59_26+X59_27 + X59_28 +
X59_29+X59_30=1
X57_1 + X57_2 + X57_3+X57_4 + X57_5 + X57_6+X57_7 + X57_8 + X57_9+X57_10 +
X57_11 + X57_12+X57_13 + X57_14 + X57_15+X57_16 + X57_17 + X57_18+X57_19 +
X57_20 + X57_21 + X57_22+X57_23 + X57_24 + X57_25+X57_26 + X57_27 +
X57_28+X57_29 + X57_30=1
X94_1 + X94_2 + X94_3+X94_4 + X94_5 + X94_6+X94_7 + X94_8 + X94_9+X94_10 +
X94_11 + X94_12+X94_13 + X94_14 + X94_15+X94_16 + X94_17 + X94_18+X94_19 +
X94_20 + X94_21 + X94_22+X94_23 + X94_24 + X94_25+X94_26 + X94_27 +
X94_28+X94_29 + X94_30=1
X11_1 + X11_2 + X11_3+X11_4 + X11_5 + X11_6+X11_7 + X11_8 + X11_9+X11_10 +
X11_11 + X11_12+X11_13 + X11_14 + X11_15+X11_16 + X11_17 + X11_18+X11_19 +
X11_20 + X11_21+X11_22 + X11_23 + X11_24+X11_25 + X11_26 + X11_27+X11_28 +
X11_29 + X11_30=1
X66_1 + X66_2 + X66_3+X66_4 + X66_5 + X66_6+X66_7 + X66_8 + X66_9+X66_10 +
X66_11 + X66_12+X66_13 + X66_14 + X66_15+X66_16 + X66_17 + X66_18+X66_19 +
X66_20 + X66_21+X66_22 + X66_23 + X66_24+X66_25 + X66_26 + X66_27+X66_28 +
X66_29 + X66_30=1
X45_1 + X45_2 + X45_3+X45_4 + X45_5 + X45_6+X45_7 + X45_8 + X45_9+X45_10 +
X45_11 + X45_12+X45_13 + X45_14 + X45_15+X45_16 + X45_17 + X45_18+X45_19 +
X45_20 + X45_21+X45_22 + X45_23 + X45_24+X45_25 + X45_26 + X45_27+X45_28 +
X45_29 + X45_30=1
X31_1 + X31_2 + X31_3+X31_4 + X31_5 + X31_6+X31_7 + X31_8 + X31_9+X31_10 +
X31_11 + X31_12+X31_13 + X31_14 + X31_15+X31_16 + X31_17 + X31_18+X31_19 +
X31_20 + X31_21 + X31_22+X31_23 + X31_24 + X31_25+X31_26 + X31_27 +
X31_28+X31_29 + X31_30=1
X70_1 + X70_2 + X70_3+X70_4 + X70_5 + X70_6+X70_7 + X70_8 + X70_9+X70_10 +
X70_11 + X70_12+X70_13 + X70_14 + X70_15+X70_16 + X70_17 + X70_18+X70_19 +
X70_20 + X70_21+X70_22 + X70_23 + X70_24+X70_25 + X70_26 + X70_27+X70_28 +
X70_29 + X70_30=1
X44_1 + X44_2 + X44_3+X44_4 + X44_5 + X44_6+X44_7 + X44_8 + X44_9+X44_10 +
X44_11 + X44_12+X44_13 + X44_14 + X44_15+X44_16 + X44_17 + X44_18+X44_19 +
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X44_20 + X44_21 + X44_22+X44_23 + X44_24 + X44_25+X44_26 + X44_27 + X44_28+X44_29 + X44_30=1
X84_1 + X84_2 + X84_3+X84_4 + X84_5 + X84_6+X84_7 + X84_8 + X84_9+X84_10 + X84_11 + X84_12+X84_13 + X84_14 + X84_15+X84_16 + X84_17 + X84_18+X84_19 + X84_20 + X84_21 + X84_22+X84_23 + X84_24 + X84_25+X84_26 + X84_27 + X84_28+X84_29 + X84_30=1
X51_1 + X51_2 + X51_3+X51_4 + X51_5 + X51_6+X51_7 + X51_8 + X51_9+X51_10 + X51_11 + X51_12+X51_13 + X51_14 + X51_15+X51_16 + X51_17 + X51_18+X51_19 + X51_20 + X51_21 + X51_22+X51_23 + X51_24 + X51_25+X51_26 + X51_27 + X51_28+X51_29 + X51_30=1
X52_1 + X52_2 + X52_3+X52_4 + X52_5 + X52_6+X52_7 + X52_8 + X52_9+X52_10 + X52_11 + X52_12+X52_13 + X52_14 + X52_15+X52_16 + X52_17 + X52_18+X52_19 + X52_20+X52_21 + X52_22 + X52_23+X52_24 + X52_25 + X52_26+X52_27 + X52_28 + X52_29+X52_30=1
X87_1 + X87_2 + X87_3+X87_4 + X87_5 + X87_6+X87_7 + X87_8 + X87_9+X87_10 + X87_11 + X87_12+X87_13 + X87_14 + X87_15+X87_16 + X87_17 + X87_18+X87_19 + X87_20+X87_21 + X87_22 + X87_23+X87_24 + X87_25 + X87_26+X87_27 + X87_28 + X87_29+X87_30=1
X36_1 + X36_2 + X36_3+X36_4 + X36_5 + X36_6+X36_7 + X36_8 + X36_9+X36_10 + X36_11 + X36_12+X36_13 + X36_14 + X36_15+X36_16 + X36_17 + X36_18+X36_19 + X36_20 + X36_21+X36_22 + X36_23 + X36_24+X36_25 + X36_26 + X36_27+X36_28 + X36_29 + X36_30=1
X73_1 + X73_2 + X73_3+X73_4 + X73_5 + X73_6+X73_7 + X73_8 + X73_9+X73_10 + X73_11 + X73_12+X73_13 + X73_14 + X73_15+X73_16 + X73_17 + X73_18+X73_19 + X73_20 + X73_21+X73_22 + X73_23 + X73_24+X73_25 + X73_26 + X73_27+X73_28 + X73_29 + X73_30=1
X47_1 + X47_2 + X47_3+X47_4 + X47_5 + X47_6+X47_7 + X47_8 + X47_9+X47_10 + X47_11 + X47_12+X47_13 + X47_14 + X47_15+X47_16 + X47_17 + X47_18+X47_19 + X47_20 + X47_21 + X47_22+X47_23 + X47_24 + X47_25+X47_26 + X47_27 + X47_28+X47_29 + X47_30=1
X48_1 + X48_2 + X48_3+X48_4 + X48_5 + X48_6+X48_7 + X48_8 + X48_9+X48_10 + X48_11 + X48_12+X48_13 + X48_14 + X48_15+X48_16 + X48_17 + X48_18+X48_19 + X48_20 + X48_21 + X48_22+X48_23 + X48_24 + X48_25+X48_26 + X48_27 + X48_28+X48_29 + X48_30=1
X92_1 + X92_2 + X92_3+X92_4 + X92_5 + X92_6+X92_7 + X92_8 + X92_9+X92_10 + X92_11 + X92_12+X92_13 + X92_14 + X92_15+X92_16 + X92_17 + X92_18+X92_19 + X92_20 + X92_21 + X92_22+X92_23 + X92_24 + X92_25+X92_26 + X92_27 + X92_28+X92_29 + X92_30=1
X33_1 + X33_2 + X33_3+X33_4 + X33_5 + X33_6+X33_7 + X33_8 + X33_9+X33_10 + X33_11 + X33_12+X33_13 + X33_14 + X33_15+X33_16 + X33_17 + X33_18+X33_19 + X33_20 + X33_21 + X33_22+X33_23 + X33_24 + X33_25+X33_26 + X33_27 + X33_28+X33_29 + X33_30=1
X41_1 + X41_2 + X41_3+X41_4 + X41_5 + X41_6+X41_7 + X41_8 + X41_9+X41_10 + X41_11 + X41_12+X41_13 + X41_14 + X41_15+X41_16 + X41_17 + X41_18+X41_19 + X41_20 + X41_21 + X41_22+X41_23 + X41_24 + X41_25+X41_26 + X41_27 + X41_28+X41_29 + X41_30=1
X75_1 + X75_2 + X75_3+X75_4 + X75_5 + X75_6+X75_7 + X75_8 + X75_9+X75_10 + X75_11 + X75_12+X75_13 + X75_14 + X75_15+X75_16 + X75_17 + X75_18+X75_19 + X75_20 + X75_21 + X75_22+X75_23 + X75_24 + X75_25+X75_26 + X75_27 + X75_28+X75_29 + X75_30=1
X43_1 + X43_2 + X43_3+X43_4 + X43_5 + X43_6+X43_7 + X43_8 + X43_9+X43_10 + X43_11 + X43_12+X43_13 + X43_14 + X43_15+X43_16 + X43_17 + X43_18+X43_19 + X43_20 + X43_21 + X43_22+X43_23 + X43_24 + X43_25+X43_26 + X43_27 + X43_28+X43_29 + X43_30=1
X22_1 + X22_2 + X22_3+X22_4 + X22_5 + X22_6+X22_7 + X22_8 + X22_9+X22_10 + X22_11 + X22_12+X22_13 + X22_14 + X22_15+X22_16 + X22_17 + X22_18+X22_19 +

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X22_20 + X22_21 + X22_22+X22_23 + X22_24 + X22_25+X22_26 + X22_27 +
X22_28+X22_29 + X22_30=1
X61_1 + X61_2 + X61_3+X61_4 + X61_5 + X61_6+X61_7 + X61_8 + X61_9+X61_10 +
X61_11 + X61_12+X61_13 + X61_14 + X61_15+X61_16 + X61_17 + X61_18+X61_19 +
X61_20 + X61_21 + X61_22+X61_23 + X61_24 + X61_25+X61_26 + X61_27 +
X61_28+X61_29 + X61_30=1
X40_1 + X40_2 + X40_3+X40_4 + X40_5 + X40_6+X40_7 + X40_8 + X40_9+X40_10 +
X40_11 + X40_12+X40_13 + X40_14 + X40_15+X40_16 + X40_17 + X40_18+X40_19 +
X40_20 + X40_21 + X40_22+X40_23 + X40_24 + X40_25+X40_26 + X40_27 +
X40_28+X40_29 + X40_30=1
X37_1 + X37_2 + X37_3+X37_4 + X37_5 + X37_6+X37_7 + X37_8 + X37_9+X37_10 +
X37_11 + X37_12+X37_13 + X37_14 + X37_15+X37_16 + X37_17 + X37_18+X37_19 +
X37_20 + X37_21 + X37_22+X37_23 + X37_24 + X37_25+X37_26 + X37_27 +
X37_28+X37_29 + X37_30=1
X7_1 + X16_1 + X10_1 + X53_1 + X59_1 + X57_1 + X94_1 + X11_1 + X66_1 + X45_1
+ X31_1 + X70_1 + X44_1 + X84_1 + X51_1 + X52_1 + X87_1 + X36_1 + X73_1 +
X47_1 + X48_1 + X92_1 + X33_1 + X41_1 + X75_1 + X43_1 + X22_1 + X61_1 + X40_1
+ X37_1<1
X7_2 + X16_2 + X10_2 + X53_2 + X59_2 + X57_2 + X94_2 + X11_2 + X66_2 + X45_2
+ X31_2 + X70_2 + X44_2 + X84_2 + X51_2 + X52_2 + X87_2 + X36_2 + X73_2 +
X47_2+X48_2 + X92_2 + X33_2 + X41_2 + X75_2 + X43_2 + X22_2 + X61_2 + X40_2 +
X37_2<1
X7_3 + X16_3 + X10_3 + X53_3 + X59_3 + X57_3 + X94_3 + X11_3 + X66_3 + X45_3
+ X31_3 + X70_3 + X44_3 + X84_3 + X51_3 + X52_3 + X87_3 + X36_3 + X73_3 +
X47_3+X48_3 + X92_3 + X33_3 + X41_3 + X75_3 + X43_3 + X22_3 + X61_3 + X40_3 +
X37_3<1
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+ X31_4 + X70_4 + X44_4 + X84_4 + X51_4 + X52_4 + X87_4 + X36_4 + X73_4 +
X47_4 + X48_4 + X92_4 + X33_4 + X41_4 + X75_4 + X43_4 + X22_4 + X61_4 + X40_4
+ X37_4<1
X7_5 + X16_5 + X10_5 + X53_5 + X59_5 + X57_5 + X94_5 + X11_5 + X66_5 + X45_5
+ X31_5 + X70_5 + X44_5 + X84_5 + X51_5 + X52_5 + X87_5 + X36_5 + X73_5 +
X47_5 + X48_5 + X92_5 + X33_5 + X41_5 + X75_5 + X43_5 + X22_5 + X61_5 + X40_5
+ X37_5<1
X7_6 + X16_6 + X10_6 + X53_6 + X59_6 + X57_6 + X94_6 + X11_6 + X66_6 + X45_6
+ X31_6 + X70_6 + X44_6 + X84_6 + X51_6 + X52_6 + X87_6 + X36_6 + X73_6 +
X47_6 + X48_6 + X92_6 + X33_6 + X41_6 + X75_6 + X43_6 + X22_6 + X61_6 + X40_6
+ X37_6<1
X7_7 + X16_7 + X10_7 + X53_7 + X59_7 + X57_7 + X94_7 + X11_7 + X66_7 + X45_7
+ X31_7 + X70_7 + X44_7 + X84_7 + X51_7 + X52_7 + X87_7 + X36_7 + X73_7 +
X47_7 + X48_7 + X92_7 + X33_7 + X41_7 + X75_7 + X43_7 + X22_7 + X61_7 + X40_7
+ X37_7<1
X7_8 + X16_8 + X10_8 + X53_8 + X59_8 + X57_8 + X94_8 + X11_8 + X66_8 + X45_8
+ X31_8 + X70_8 + X44_8 + X84_8 + X51_8 + X52_8 + X87_8 + X36_8 + X73_8 +
X47_8 + X48_8 + X92_8 + X33_8 + X41_8 + X75_8 + X43_8 + X22_8 + X61_8 + X40_8
+ X37_8<1
X7_9 + X16_9 + X10_9 + X53_9 + X59_9 + X57_9 + X94_9 + X11_9 + X66_9 + X45_9
+ X31_9 + X70_9 + X44_9 + X84_9 + X51_9 + X52_9 + X87_9 + X36_9 + X73_9 +
X47_9 + X48_9 + X92_9 + X33_9 + X41_9 + X75_9 + X43_9 + X22_9 + X61_9 + X40_9
+ X37_9<1
X7_10 + X16_10 + X10_10 + X53_10 + X59_10 + X57_10 + X94_10 + X11_10 + X66_10
+ X45_10 + X31_10 + X70_10 + X44_10 + X84_10 + X51_10 + X52_10 + X87_10 +
X36_10 + X73_10 + X47_10 + X48_10 + X92_10 + X33_10 + X41_10 + X75_10 +
X43_10 + X22_10 + X61_10 + X40_10 + X37_10<1
X7_11 + X16_11 + X10_11 + X53_11 + X59_11 + X57_11 + X94_11 + X11_11 + X66_11
+ X45_11 + X31_11 + X70_11 + X44_11 + X84_11 + X51_11 + X52_11 + X87_11 +

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X36_11 + X73_11 + X47_11 + X48_11 + X92_11 + X33_11 + X41_11 + X75_11 + X43_11 + X22_11 + X61_11 + X40_11 + X37_11<1
X7_12 + X16_12 + X10_12 + X53_12 + X59_12 + X57_12 + X94_12 + X11_12 + X66_12 + X45_12 + X31_12 + X70_12 + X44_12 + X84_12 + X51_12 + X52_12 + X87_12 + X36_12 + X73_12 + X47_12 + X48_12 + X92_12 + X33_12 + X41_12 + X75_12 + X43_12 + X22_12 + X61_12 + X40_12 + X37_12<1
X7_13 + X16_13 + X10_13 + X53_13 + X59_13 + X57_13 + X94_13 + X11_13 + X66_13 + X45_13 + X31_13 + X70_13 + X44_13 + X84_13 + X51_13 + X52_13 + X87_13 + X36_13 + X73_13 + X47_13 + X48_13 + X92_13 + X33_13 + X41_13 + X75_13 + X43_13 + X22_13 + X61_13 + X40_13 + X37_13<1
X7_14 + X16_14 + X10_14 + X53_14 + X59_14 + X57_14 + X94_14 + X11_14 + X66_14 + X45_14 + X31_14 + X70_14 + X44_14 + X84_14 + X51_14 + X52_14 + X87_14 + X36_14 + X73_14 + X47_14 + X48_14 + X92_14 + X33_14 + X41_14 + X75_14 + X43_14 + X22_14 + X61_14 + X40_14 + X37_14<1
X7_15 + X16_15 + X10_15 + X53_15 + X59_15 + X57_15 + X94_15 + X11_15 + X66_15 + X45_15 + X31_15 + X70_15 + X44_15 + X84_15 + X51_15 + X52_15 + X87_15 + X36_15 + X73_15 + X47_15 + X48_15 + X92_15 + X33_15 + X41_15 + X75_15 + X43_15 + X22_15 + X61_15 + X40_15 + X37_15<1
X7_16 + X16_16 + X10_16 + X53_16 + X59_16 + X57_16 + X94_16 + X11_16 + X66_16 + X45_16 + X31_16 + X70_16 + X44_16 + X84_16 + X51_16 + X52_16 + X87_16 + X36_16 + X73_16 + X47_16 + X48_16 + X92_16 + X33_16 + X41_16 + X75_16 + X43_16 + X22_16 + X61_16 + X40_16 + X37_16<1
X7_17 + X16_17 + X10_17 + X53_17 + X59_17 + X57_17 + X94_17 + X11_17 + X66_17 + X45_17 + X31_17 + X70_17 + X44_17 + X84_17 + X51_17 + X52_17 + X87_17 + X36_17 + X73_17 + X47_17 + X48_17 + X92_17 + X33_17 + X41_17 + X75_17 + X43_17 + X22_17 + X61_17 + X40_17 + X37_17<1
X7_18 + X16_18 + X10_18 + X53_18 + X59_18 + X57_18 + X94_18 + X11_18 + X66_18 + X45_18 + X31_18 + X70_18 + X44_18 + X84_18 + X51_18 + X52_18 + X87_18 + X36_18 + X73_18 + X47_18 + X48_18 + X92_18 + X33_18 + X41_18 + X75_18 + X43_18 + X22_18 + X61_18 + X40_18 + X37_18<1
X7_19 + X16_19 + X10_19 + X53_19 + X59_19 + X57_19 + X94_19 + X11_19 + X66_19 + X45_19 + X31_19 + X70_19 + X44_19 + X84_19 + X51_19 + X52_19 + X87_19 + X36_19 + X73_19 + X47_19 + X48_19 + X92_19 + X33_19 + X41_19 + X75_19 + X43_19 + X22_19 + X61_19 + X40_19 + X37_19<1
X7_20 + X16_20 + X10_20 + X53_20 + X59_20 + X57_20 + X94_20 + X11_20 + X66_20 + X45_20 + X31_20 + X70_20 + X44_20 + X84_20 + X51_20 + X52_20 + X87_20 + X36_20 + X73_20 + X47_20 + X48_20 + X92_20 + X33_20 + X41_20 + X75_20 + X43_20 + X22_20 + X61_20 + X40_20 + X37_20<1
X7_21 + X16_21 + X10_21 + X53_21 + X59_21 + X57_21 + X94_21 + X11_21 + X66_21 + X45_21 + X31_21 + X70_21 + X44_21 + X84_21 + X51_21 + X52_21 + X87_21 + X36_21 + X73_21 + X47_21 + X48_21 + X92_21 + X33_21 + X41_21 + X75_21 + X43_21 + X22_21 + X61_21 + X40_21 + X37_21<1
X7_22 + X16_22 + X10_22 + X53_22 + X59_22 + X57_22 + X94_22 + X11_22 + X66_22 + X45_22 + X31_22 + X70_22 + X44_22 + X84_22 + X51_22 + X52_22 + X87_22 + X36_22 + X73_22 + X47_22 + X48_22 + X92_22 + X33_22 + X41_22 + X75_22 + X43_22 + X22_22 + X61_22 + X40_22 + X37_22<1
X7_23 + X16_23 + X10_23 + X53_23 + X59_23 + X57_23 + X94_23 + X11_23 + X66_23 + X45_23 + X31_23 + X70_23 + X44_23 + X84_23 + X51_23 + X52_23 + X87_23 + X36_23 + X73_23 + X47_23 + X48_23 + X92_23 + X33_23 + X41_23 + X75_23 + X43_23 + X22_23 + X61_23 + X40_23 + X37_23<1
X7_24 + X16_24 + X10_24 + X53_24 + X59_24 + X57_24 + X94_24 + X11_24 + X66_24 + X45_24 + X31_24 + X70_24 + X44_24 + X84_24 + X51_24 + X52_24 + X87_24 + X36_24 + X73_24 + X47_24 + X48_24 + X92_24 + X33_24 + X41_24 + X75_24 + X43_24 + X22_24 + X61_24 + X40_24 + X37_24<1
X7_25 + X16_25 + X10_25 + X53_25 + X59_25 + X57_25 + X94_25 + X11_25 + X66_25 + X45_25 + X31_25 + X70_25 + X44_25 + X84_25 + X51_25 + X52_25 + X87_25 +

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X36_25 + X73_25 + X47_25 + X48_25 + X92_25 + X33_25 + X41_25 + X75_25 +
X43_25 + X22_25 + X61_25 + X40_25 + X37_25<1
X7_26 + X16_26 + X10_26 + X53_26 + X59_26 + X57_26 + X94_26 + X11_26 + X66_26
+ X45_26 + X31_26 + X70_26 + X44_26 + X84_26 + X51_26 + X52_26 + X87_26 +
X36_26 + X73_26 + X47_26 + X48_26 + X92_26 + X33_26 + X41_26 + X75_26 +
X43_26 + X22_26 + X61_26 + X40_26 + X37_26<1
X7_27 + X16_27 + X10_27 + X53_27 + X59_27 + X57_27 + X94_27 + X11_27 + X66_27
+ X45_27 + X31_27 + X70_27 + X44_27 + X84_27 + X51_27 + X52_27 + X87_27 +
X36_27 + X73_27 + X47_27 + X48_27 + X92_27 + X33_27 + X41_27 + X75_27 +
X43_27 + X22_27 + X61_27 + X40_27 + X37_27<1
X7_28 + X16_28 + X10_28 + X53_28 + X59_28 + X57_28 + X94_28 + X11_28 + X66_28
+ X45_28 + X31_28 + X70_28 + X44_28 + X84_28 + X51_28 + X52_28 + X87_28 +
X36_28 + X73_28 + X47_28 + X48_28 + X92_28 + X33_28 + X41_28 + X75_28 +
X43_28 + X22_28 + X61_28 + X40_28 + X37_28<1
X7_29 + X16_29 + X10_29 + X53_29 + X59_29 + X57_29 + X94_29 + X11_29 + X66_29
+ X45_29 + X31_29 + X70_29 + X44_29 + X84_29 + X51_29 + X52_29 + X87_29 +
X36_29 + X73_29 + X47_29 + X48_29 + X92_29 + X33_29 + X41_29 + X75_29 +
X43_29 + X22_29 + X61_29 + X40_29 + X37_29<1
X7_30 + X16_30 + X10_30 + X53_30 + X59_30 + X57_30 + X94_30 + X11_30 + X66_30
+ X45_30 + X31_30 + X70_30 + X44_30 + X84_30 + X51_30 + X52_30 + X87_30 +
X36_30 + X73_30 + X47_30 + X48_30 + X92_30 + X33_30 + X41_30 + X75_30 +
X43_30 + X22_30 + X61_30 + X40_30 + X37_30<1

END
```

A.2 LINGO SETS Code for Press pattern 3A

```
MIN 16640X86_1 + 19200X86_2 + 19360X86_3 + 19520X86_4 + 22080X86_5 +
19840X86_6 + 22400X86_7 + 22560X86_8 + 22720X86_9 + 25280X86_10 + 23040X86_11
+ 25600X86_12 + 25760X86_13 + 25920X86_14 + 28480X86_15 + 26240X86_16 +
28800X86_17 + 28960X86_18+29120X86_19 + 31680X86_20 + 29440X86_21 +
32000X86_22 + 32160X86_23 + 32320X86_24 + 34880X86_25 + 32640X86_26 +
35200X86_27 + 35360X86_28+35520X86_29 + 38080X86_30 + 8320X14_1 + 9600X14_2 +
9680X14_3 + 9760X14_4 + 11040X14_5 + 9920X14_6 + 11200X14_7 + 11280X14_8 +
11360X14_9 + 12640X14_10 + 11520X14_11 + 12800X14_12 + 12880X14_13 +
12960X14_14 + 14240X14_16+14400X14_17 + 14480X14_18 + 14560X14_19 +
15840X14_20 + 14720X14_21 + 16000X14_22 + 16080X14_23 + 16160X14_24 +
17440X14_25 + 16320X14_26 + 17600X14_27 + 17680X14_28+17760X14_29 +
19040X14_30 + 8320X58_1 + 9600X58_2 + 9680X58_3 + 9760X58_4 + 11040X58_5 +
9920X58_6 + 11200X58_7 + 11280X58_8 + 11360X58_9 + 12640X58_10 + 11520X58_11
+ 12800X58_12+ 12880X58_13 + 12960X58_14 + 14240X58_15 + 13120X58_16 +
14400X58_17 + 14480X58_18 + 14560X58_19 + 15840X58_20 + 14720X58_21 +
16000X58_22 + 16080X58_23 + 16160X58_24 + 17440X58_25 + 16320X58_26 +
17600X58_27 + 17680X58_28+17760X58_29 + 19040X58_30 + 8320X4_1+9600X4_2 +
9680X4_3 + 9760X4_4 + 11040X4_5 + 9920X4_6 + 11200X4_7 + 11280X4_8 +
11360X4_9+12640X4_10+11520X4_11 + 12800X4_12 + 12880X4_13 + 12960X4_14 +
14240X4_15 + 13120X4_16 + 14400X4_17 + 14480X4_18 + 14560X4_19 + 15840X4_20 +
14720X4_21 + 16000X4_22+16080X4_23+16160X4_24 + 17440X4_25 + 16320X4_26 +
17600X4_27 + 17680X4_28 + 17760X4_29 + 19040X4_30 + 8320X5_1 + 9600X5_2 +
9680X5_3 + 9760X5_4 + 11040X5_5 + 9920X5_6 + 11200X5_7 + 11280X5_8 +
11360X5_9 + 12640X5_10 + 11520X5_11 + 12800X5_12 + 12880X5_13 + 12960X5_14 +
14240X5_15 + 13120X5_16 + 14400X5_17 + 14480X5_18 + 14560X5_19 + 15840X5_20 +
14720X5_21 + 16000X5_22 + 16080X5_23 + 16160X5_24 + 17440X5_25 + 16320X5_26 +
17600X5_27+17680X5_28 + 17760X5_29 + 19040X5_30 + 8320X8_1 + 9600X8_2 +
9680X8_3 + 9760X8_4 + 11040X8_5 + 9920X8_6 + 11200X8_7 + 11280X8_8 +
```


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11360X8_9+12640X4_10 + 11520X8_11 + 12800X8_12 + 12880X8_13 + 12960X8_14 + 14240X8_15 + 13120X8_16 + 14400X8_17+14480X8_18+14560X8_19 + 15840X8_20+14720X8_21 + 16000X8_22 + 16080X8_23 + 16160X8_24 + 17440X8_25 + 16320X8_26 + 17600X8_27+17680X8_28+17760X8_29 + 19040X8_30 + 8320X93_1 + 9600X93_2 + 9680X93_3 + 9760X93_4 + 11040X93_5 + 9920X93_6 + 11200X93_7 + 11280X93_8 + 11360X93_9 + 12640X93_10 + 11520X93_11 + 12800X93_12 + 12880X93_13 + 12960X93_14 + 14240X93_15 + 13120X93_16 + 14400X93_17 + 14480X93_18 + 14560X93_19 + 15840X93_20+14720X93_21 + 16000X93_22 + 16080X93_23 + 16160X93_24 + 17440X93_25 + 16320X93_26 + 17600X93_27 + 17680X93_28 + 17760X93_29+19040X93_30+8320X32_1 + 9600X32_2 + 9680X32_3 + 9760X32_4 + 11040X32_5 + 9920X32_6 + 11200X32_7 + 11280X32_8 + 11360X32_9+12640X32_10 + 11520X32_11 + 12800X32_12 + 12880X32_13 + 12960X32_14 + 14240X32_15 + 13120X32_16 + 14400X32_17+14480X32_18+14560X32_19 + 15840X32_20+14720X32_21 + 16000X32_22 + 16080X32_23 + 16160X32_24 + 17440X32_25 + 16320X32_26 + 17600X32_27 + 17680X32_28 + 17760X32_29+19040X32_30 + 8320X6_1+9600X6_2 + 9680X6_3 + 9760X6_4 + 11040X6_5 + 9920X6_6 + 11200X6_7 + 11280X6_8 + 11360X6_9+12640X6_10 + 11520X6_11 + 12800X6_12 + 12880X6_13 + 12960X6_14 + 14240X6_15 + 13120X6_16 + 14400X6_17+14480X6_18+14560X6_19 + 15840X6_20+14720X6_21 + 16000X6_22 + 16080X6_23 + 16160X6_24 + 17440X6_25 + 16320X6_26 + 17600X6_27+17680X6_28+17760X6_29 + 19040X6_30+8320X85_1 + 9600X85_2 + 9680X85_3 + 9760X85_4 + 11040X85_5 + 9920X85_6 + 11200X85_7 + 11280X85_8 + 11360X85_9+12640X85_10 + 11520X85_11 + 12800X85_12 + 12880X85_13 + 12960X85_14 + 14240X85_15 + 13120X85_16 + 14400X85_17+14480X85_18+14560X85_19 + 15840X85_20 + 14720X85_21 + 16000X85_22 + 16080X85_23 + 16160X85_24 + 17440X85_25 + 16320X85_26 + 17600X85_27+17680X85_28+17760X85_29 + 19040X85_30+8320X9_1+9600X9_2 + 9680X9_3 + 9760X9_4 + 11040X9_5 + 9920X9_6 + 11200X9_7 + 11280X9_8 + 11360X9_9+12640X9_10 + 11520X9_11 + 12800X9_12 + 12880X9_13 + 12960X9_14 + 14240X9_15 + 13120X9_16 + 14400X9_17+14480X9_18+14560X9_19 + 15840X9_20+14720X9_21 + 16000X9_22+16080X9_23 + 16160X9_24 + 17440X9_25 + 16320X9_26 + 17600X9_27 + 17680X9_28 + 17760X9_29 + 19040X9_30 + 8320X38_1 + 9600X38_2 + 9680X38_3 + 9760X38_4 + 11040X38_5 + 9920X38_6 + 11200X38_7 + 11280X38_8 + 11360X38_9+12640X38_10 + 11520X38_11 + 12800X38_12 + 12880X38_13 + 12960X38_14 + 14240X38_15 + 13120X38_16 + 14400X38_17+14480X38_18+14560X38_19 + 15840X38_20+14720X38_21 + 16000X38_22 + 16080X38_23 + 16160X38_24 + 17440X38_25 + 16320X38_26 + 17600X38_27+17680X38_28+17760X38_29 + 19040X38_30+8320X46_1+9600X46_2 + 9680X46_3 + 9760X46_4 + 11040X46_5 + 9920X46_6 + 11200X46_7 + 11280X46_8 + 11360X46_9+12640X46_10 + 11520X46_11 + 12800X46_12 + 12880X46_13 + 12960X46_14 + 14240X46_15 + 13120X46_16 + 14400X46_17+14480X46_18+14560X46_19 + 15840X46_20+14720X46_21 + 16000X46_22 + 16080X46_23 + 16160X46_24 + 17440X46_25 + 16320X46_26 + 17600X46_27+17680X46_28+17760X46_29+19040X46_30+8320X67_1 + 9600X67_2 + 9680X67_3 + 9760X67_4 + 11040X67_5 + 9920X67_6 + 11200X67_7 + 11280X67_8 + 11360X67_9+12640X67_10 + 11520X67_11 + 12800X67_12 + 12880X67_13 + 12960X67_14 + 14240X67_15 + 13120X67_16 + 14400X67_17+14480X67_18+14560X67_19 + 15840X67_20+14720X67_21 + 16000X67_22 + 16080X67_23 + 16160X67_24 + 17440X67_25 + 16320X67_26 + 17600X67_27+17680X67_28+17760X67_29 + 19040X67_30 + 8320X12_1+9600X12_2 + 9680X12_3 + 9760X12_4 + 11040X12_5 + 9920X12_6 + 11200X12_7 + 11280X12_8 + 11360X12_9+12640X12_10 + 11520X12_11 + 12800X12_12 + 12880X12_13 + 12960X12_14 + 14240X12_15 + 13120X12_16 + 14400X12_17+14480X12_18+14560X12_19 + 15840X12_20+14720X12_21 + 16000X12_22 + 16080X12_23 + 16160X12_24 + 17440X12_25 + 16320X12_26 + 17600X12_27+17680X12_28+17760X12_29 + 19040X12_30+8320X82_1 + 9600X82_2 + 9680X82_3 + 9760X82_4 + 11040X82_5 + 9920X82_6 + 11200X82_7 + 11280X82_8 + 11360X82_9+12640X82_10 + 11520X82_11 + 12800X82_12 + 12880X82_13 +

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12960X82_14 + 14240X82_15 + 13120X82_16 + 14400X82_17+14480X82_18+14560X82_19 + 15840X82_20+14720X82_21 + 16000X82_22 + 16080X82_23 + 16160X82_24 + 17440X82_25 + 16320X82_26 + 17600X82_27+17680X82_28+17760X82_29 + 19040X82_30+4992X15_1+5760X15_2 + 5808X15_3 + 5856X15_4 + 6624X15_5 + 5952X15_6 + 6720X15_7 + 6768X15_8 + 6816X15_9+7584X15_10 + 6912X15_11 + 7680X15_12 + 7728X15_13 + 7776X15_14 + 8544X15_15 + 7872X15_16 + 8640X15_17+8688X15_18+8736X15_19 + 9504X15_20+8832X15_21 + 9600X15_22 + 9648X15_23 + 9696X15_24 + 10464X15_25 + 9792X15_26 + 10560X15_27+10608X15_28+10656X15_29 + 11424X15_30 + 4992X81_1 + 5760X81_2 + 5808X81_3 + 5856X81_4 + 6624X81_5 + 5952X81_6 + 6720X81_7 + 6768X81_8 + 6816X81_9+7584X81_10 + 6912X81_11 + 7680X81_12 + 7728X81_13 + 7776X81_14 + 8544X81_15 + 7872X81_16 + 8640X81_17+8688X81_18+8736X81_19 + 9504X81_20+8832X81_21 + 9600X81_22 + 9648X81_23 + 9696X81_24 + 10464X81_25 + 9792X81_26 + 10560X81_27+10608X81_28+10656X81_29 + 11424X81_30+4992X76_1+5760X76_2 + 5808X76_3 + 5856X76_4 + 6624X76_5 + 5952X76_6 + 6720X76_7 + 6768X76_8 + 6816X76_9+7584X76_10 + 6912X76_11 + 7680X76_12 + 7728X76_13 + 7776X76_14 + 8544X76_15 + 7872X76_16 + 8640X76_17+8688X76_18+8736X76_19 + 9504X76_20+8832X76_21 + 9600X76_22 + 9648X76_23 + 9696X76_24 + 10464X76_25 + 9792X76_26 + 10560X76_27+10608X76_28+10656X76_29 + 11424X76_30+4992X17_1 + 5760X17_2 + 5808X17_3 + 5856X17_4 + 6624X17_5 + 5952X17_6 + 6720X17_7 + 6768X17_8 + 6816X17_9+7584X17_10 + 6912X17_11 + 7680X17_12 + 7728X17_13 + 7776X17_14 + 8544X17_15 + 7872X17_16 + 8640X17_17+8688X17_18+8736X17_19 + 9504X17_20+8832X17_21 + 9600X17_22 + 9648X17_23 + 9696X17_24 + 10464X17_25 + 9792X17_26 + 10560X17_27+10608X17_28+10656X17_29 + 11424X17_30 + 4992X13_1+5760X13_2 + 5808X13_3 + 5856X13_4 + 6624X13_5 + 5952X13_6 + 6720X13_7 + 6768X13_8 + 6816X13_9+7584X13_10 + 6912X13_11 + 7680X13_12 + 7728X13_13 + 7776X13_14 + 8544X13_15 + 7872X13_16 + 8640X13_17+8688X13_18+8736X13_19 + 9504X13_20+8832X13_21 + 9600X13_22 + 9648X13_23 + 9696X13_24 + 10464X13_25 + 9792X13_26 + 10560X13_27+10608X13_28+10656X13_29 + 11424X13_30+4992X95_1 + 5760X95_2 + 5808X95_3 + 5856X95_4 + 6624X95_5 + 5952X95_6 + 6720X95_7 + 6768X95_8 + 6816X95_9+7584X95_10 + 6912X95_11 + 7680X95_12 + 7728X95_13 + 7776X95_14 + 8544X95_15 + 7872X95_16 + 8640X95_17+8688X95_18+8736X95_19 + 9504X95_21 + 9600X95_22 + 9648X95_23 + 9696X95_24 + 10464X95_25 + 9792X95_26 + 10560X95_27+10608X95_28+10656X95_29 + 11424X95_30+4992X74_1+5760X74_2 + 5808X74_3 + 5856X74_4 + 6624X74_5 + 5952X74_6 + 6720X74_7 + 6768X74_8 + 6816X74_9+7584X74_10 + 6912X74_11 + 7680X74_12 + 7728X74_13 + 7776X74_14 + 8544X74_15 + 7872X74_16 + 8640X74_17+8688X74_18+8736X74_19 + 9504X74_20+8832X74_21 + 9600X74_22 + 9648X74_23 + 9696X74_24 + 10464X74_25 + 9792X74_26 + 10560X74_27+10608X74_28+10656X74_29 + 11424X74_30 + 4992X34_1 + 5760X34_2 + 5808X34_3 + 5856X34_4 + 6624X34_5 + 5952X34_6 + 6720X34_7 + 6768X34_8 + 6816X34_9+7584X34_10 + 6912X34_11 + 7680X34_12 + 7728X34_13 + 7776X34_14 + 8544X34_15 + 7872X34_16 + 8640X34_17+8688X34_18+8736X34_19 + 9504X34_20+8832X34_21 + 9600X34_22 + 9648X34_23 + 9696X34_24 + 10464X34_25 + 9792X34_26 + 10560X34_27+10608X34_28+10656X34_29 + 11424X34_30+4992X42_1+5760X42_2 + 5808X42_3 + 5856X42_4 + 6624X42_5 + 5952X42_6 + 6720X42_7 + 6768X42_8 + 6816X42_9+7584X42_10 + 6912X42_11 + 7680X42_12 + 7728X42_13 + 7776X42_14 + 8544X42_15 + 7872X42_16 + 8640X42_17+8688X42_18+8736X42_19 + 9504X42_20+8832X42_21 + 9600X42_22 + 9648X42_23 + 9696X42_24 + 10464X42_25 + 9792X42_26 + 10560X42_27+10608X42_28+10656X42_29 + 11424X42_30+3328X35_1 + 3840X35_2 + 3872X35_3 + 3904X35_4 + 4416X35_5 + 3968X35_6 + 4480X35_7 + 4512X35_8 + 4544X35_9+5056X35_10 + 4608X35_11 + 5120X35_12 + 5152X35_13 + 5184X35_14 + 5696X35_15 + 5248X35_16 + 5760X35_17+5792X35_18+5824X35_19 + 6336X35_20+5888X35_21 + 6400X35_22 + 6432X35_23 + 6464X35_24 + 6976X35_25 +

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6528X35_26 + 7040X35_27+7072X35_28+7104X35_29 + 7616X35_30 +
3328X50_1+3840X50_2 + 3872X50_3 + 3904X50_4 + 4416X50_5 + 3968X50_6 +
4480X50_7 + 4512X50_8 + 4544X50_9+5056X50_10 + 4608X50_11 + 5120X50_12 +
5152X50_13 + 5184X50_14 + 5696X50_15 + 5248X50_16 +
5760X50_17+5792X50_18+5824X50_19 + 6336X50_20+5888X50_21 + 6400X50_22 +
6432X50_23 + 6464X50_24 + 6976X50_25 + 6528X50_26 +
7040X50_27+7072X50_28+7104X50_29 + 7616X50_30+3328X30_1 + 3840X30_2 +
3872X30_3 + 3904X30_4 + 4416X30_5 + 3968X30_6 + 4480X30_7 + 4512X30_8 +
4544X30_9+5056X30_10 + 4608X30_11 + 5120X30_12 + 5152X30_13 + 5184X30_14 +
5696X30_15 + 5248X30_16 + 5760X30_17+5792X30_18+5824X30_19 +
6336X30_20+5888X30_21 + 6400X30_22 + 6432X30_23 + 6464X30_24 + 6976X30_25 +
6528X30_26 + 7040X30_27+7072X30_28+7104X30_29 +
7616X30_30+2496X23_1+2880X23_2 + 2904X23_3 + 2928X23_4 + 3312X23_5 +
2976X23_6 + 3360X23_7 + 3384X23_8 + 3408X23_9+3792X23_10 + 3456X23_11 +
3840X23_12 + 3864X23_13 + 3888X23_14 + 4272X23_15 + 3936X23_16 +
4320X23_17+4344X23_18+4368X23_19 + 4752X23_20+4416X23_21 + 4800X23_22 +
4824X23_23 + 4848X23_24 + 5232X23_25 + 4896X23_26 +
5280X23_27+5304X23_28+5328X23_29 + 5712X23_30 + 2496X69_1 + 2880X69_2 +
2904X69_3 + 2928X69_4 + 3312X69_5 + 2976X69_6 + 3360X69_7 + 3384X69_8 +
3408X69_9+3792X69_10 + 3456X69_11 + 3840X69_12 + 3864X69_13 + 3888X69_14 +
4272X69_15 + 3936X69_16 + 4320X69_17+4344X69_18+4368X69_19 +
4752X69_20+4416X69_21 + 4800X69_22 + 4824X69_23 + 4848X69_24 + 5232X69_25 +
4896X69_26 + 5280X69_27+5304X69_28+5328X69_29 + 5712X69_30

SUBJECT TO
X86_1 + X86_2 + X86_3+X86_4 + X86_5 + X86_6+X86_7 + X86_8 + X86_9+X86_10 +
X86_11 + X86_12+X86_13 + X86_14 + X86_15+X86_16 + X86_17 + X86_18+X86_19 +
X86_20 + X86_21+X86_22 + X86_23 + X86_24+X86_25 + X86_26 + X86_27+X86_28 +
X86_29 + X86_30 = 1
X14_1 + X14_2 + X14_3+X14_4 + X14_5 + X14_6+X14_7 + X14_8 + X14_9+X14_10 +
X14_11 + X14_12+X14_13 + X14_14 + X14_15+X14_16 + X14_17 + X14_18+X14_19 +
X14_20 + X14_21+X14_22 + X14_23 + X14_24+X14_25 + X14_26 + X14_27+X14_28 +
X14_29 + X14_30 = 1
X58_1 + X58_2 + X58_3+X58_4 + X58_5 + X58_6+X58_7 + X58_8 + X58_9+X58_10 +
X58_11 + X58_12+X58_13 + X58_14 + X58_15+X58_16 + X58_17 + X58_18+X58_19 +
X58_20+X58_21+X58_22 + X58_23 + X58_24+X58_25 + X58_26 + X58_27+X58_28 +
X58_29 + X58_30=1
X4_1 + X4_2 + X4_3+X4_4 + X4_5 + X4_6+X4_7 + X4_8 + X4_9+X4_10 + X4_11 +
X4_12+X4_13 + X4_14 + X4_15+X4_16 + X4_17 + X4_18+X4_19 + X4_20 + X4_21+X4_22
+ X4_23 + X4_24+X4_25 + X4_26 + X4_27+X4_28 + X4_29 + X4_30=1
X5_1 + X5_2 + X5_3+X5_4 + X5_5 + X5_6+X5_7 + X5_8 + X5_9+X5_10 + X5_11 +
X5_12+X5_13 + X5_14 + X5_15+X5_16 + X5_17 + X5_18+X5_19 + X5_20+X5_21 + X5_22
+ X5_23+X5_24 + X5_25 + X5_26+X5_27 + X5_28 + X5_29+X5_30=1
X8_1 + X8_2 + X8_3+X8_4 + X8_5 + X8_6+X8_7 + X8_8 + X8_9+X8_10 + X8_11 +
X8_12+X8_13 + X8_14 + X8_15+X8_16 + X8_17 + X8_18+X8_19 + X8_20 + X8_21 +
X8_22+X8_23 + X8_24 + X8_25+X8_26 + X8_27 + X8_28+X8_29 + X8_30=1
X93_1 + X93_2 + X93_3+X93_4 + X93_5 + X93_6+X93_7 + X93_8 + X93_9+X93_10 +
X93_11 + X93_12+X93_13 + X93_14 + X93_15+X93_16 + X93_17 + X93_18+X93_19 +
X93_20 + X93_21 + X93_22+X93_23 + X93_24 + X93_25+X93_26 + X93_27 +
X93_28+X93_29 + X93_30=1
X32_1 + X32_2 + X32_3+X32_4 + X32_5 + X32_6+X32_7 + X32_8 + X32_9+X32_10 +
X32_11 + X32_12+X32_13 + X32_14 + X32_15+X32_16 + X32_17 + X32_18+X32_19 +
X32_20 + X32_21+X32_22 + X32_23 + X32_24+X32_25 + X32_26 + X32_27+X32_28 +
X32_29 + X32_30=1

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X6_1 + X6_2 + X6_3+X6_4 + X6_5 + X6_6+X6_7 + X6_8 + X6_9+X6_10 + X6_11 + X6_12+X6_13 + X6_14 + X6_15+X6_16 + X6_17 + X6_18+X6_19 + X6_20 + X6_21+X6_22 + X6_23 + X6_24+X6_25 + X6_26 + X6_27+X6_28 + X6_29 + X6_30=1
X85_1 + X85_2 + X85_3+X85_4 + X85_5 + X85_6+X85_7 + X85_8 + X85_9+X85_10 + X85_11 + X85_12+X85_13 + X85_14 + X85_15+X85_16 + X85_17 + X85_18+X85_19 + X85_20 + X85_21+X85_22 + X85_23 + X85_24+X85_25 + X85_26 + X85_27+X85_28 + X85_29 + X85_30=1
X9_1 + X9_2 + X9_3+X9_4 + X9_5 + X9_6+X9_7 + X9_8 + X9_9+X9_10 + X9_11 + X9_12+X9_13 + X9_14 + X9_15+X9_16 + X9_17 + X9_18+X9_19 + X9_20 + X9_21 + X9_22+X9_23 + X9_24 + X9_25+X9_26 + X9_27 + X9_28+X9_29 + X9_30=1
X38_1 + X38_2 + X38_3+X38_4 + X38_5 + X38_6+X38_7 + X38_8 + X38_9+X38_10 + X38_11 + X38_12+X38_13 + X38_14 + X38_15+X38_16 + X38_17 + X38_18+X38_19 + X38_20 + X38_21+X38_22 + X38_23 + X38_24+X38_25 + X38_26 + X38_27+X38_28 + X38_29 + X38_30=1
X46_1 + X46_2 + X46_3+X46_4 + X46_5 + X46_6+X46_7 + X46_8 + X46_9+X46_10 + X46_11 + X46_12+X46_13 + X46_14 + X46_15+X46_16 + X46_17 + X46_18+X46_19 + X46_20 + X46_21 + X46_22+X46_23 + X46_24 + X46_25+X46_26 + X46_27 + X46_28+X46_29 + X46_30=1
X67_1 + X67_2 + X67_3+X67_4 + X67_5 + X67_6+X67_7 + X67_8 + X67_9+X67_10 + X67_11 + X67_12+X67_13 + X67_14 + X67_15+X67_16 + X67_17 + X67_18+X67_19 + X67_20 + X67_21 + X67_22+X67_23 + X67_24 + X67_25+X67_26 + X67_27 + X67_28+X67_29 + X67_30=1
X12_1 + X12_2 + X12_3+X12_4 + X12_5 + X12_6+X12_7 + X12_8 + X12_9+X12_10 + X12_11 + X12_12+X12_13 + X12_14 + X12_15+X12_16 + X12_17 + X12_18+X12_19 + X12_20 + X12_21 + X12_22+X12_23 + X12_24 + X12_25+X12_26 + X12_27 + X12_28+X12_29 + X12_30=1
X82_1 + X82_2 + X82_3+X82_4 + X82_5 + X82_6+X82_7 + X82_8 + X82_9+X82_10 + X82_11 + X82_12+X82_13 + X82_14 + X82_15+X82_16 + X82_17 + X82_18+X82_19 + X82_20+X82_21 + X82_22 + X82_23+X82_24 + X82_25 + X82_26+X82_27 + X82_28 + X82_29+X82_30=1
X15_1 + X15_2 + X15_3+X15_4 + X15_5 + X15_6+X15_7 + X15_8 + X15_9+X15_10 + X15_11 + X15_12+X15_13 + X15_14 + X15_15+X15_16 + X15_17 + X15_18+X15_19 + X15_20+X15_21 + X15_22 + X15_23+X15_24 + X15_25 + X15_26+X15_27 + X15_28 + X15_29+X15_30=1
X81_1 + X81_2 + X81_3+X81_4 + X81_5 + X81_6+X81_7 + X81_8 + X81_9+X81_10 + X81_11 + X81_12+X81_13 + X81_14 + X81_15+X81_16 + X81_17 + X81_18+X81_19 + X81_20 + X81_21+X81_22 + X81_23 + X81_24+X81_25 + X81_26 + X81_27+X81_28 + X81_29 + X81_30=1
X76_1 + X76_2 + X76_3+X76_4 + X76_5 + X76_6+X76_7 + X76_8 + X76_9+X76_10 + X76_11 + X76_12+X76_13 + X76_14 + X76_15+X76_16 + X76_17 + X76_18+X76_19 + X76_20 + X76_21+X76_22 + X76_23 + X76_24+X76_25 + X76_26 + X76_27+X76_28 + X76_29 + X76_30=1
X17_1 + X17_2 + X17_3+X17_4 + X17_5 + X17_6+X17_7 + X17_8 + X17_9+X17_10 + X17_11 + X17_12+X17_13 + X17_14 + X17_15+X17_16 + X17_17 + X17_18+X17_19 + X17_20 + X17_21 + X17_22+X17_23 + X17_24 + X17_25+X17_26 + X17_27 + X17_28+X17_29 + X17_30=1
X13_1 + X13_2 + X13_3+X13_4 + X13_5 + X13_6+X13_7 + X13_8 + X13_9+X13_10 + X13_11 + X13_12+X13_13 + X13_14 + X13_15+X13_16 + X13_17 + X13_18+X13_19 + X13_20 + X13_21 + X13_22+X13_23 + X13_24 + X13_25+X13_26 + X13_27 + X13_28+X13_29 + X13_30=1
X95_1 + X95_2 + X95_3+X95_4 + X95_5 + X95_6+X95_7 + X95_8 + X95_9+X95_10 + X95_11 + X95_12+X95_13 + X95_14 + X95_15+X95_16 + X95_17 + X95_18+X95_19 + X95_20 + X95_21 + X95_22+X95_23 + X95_24 + X95_25+X95_26 + X95_27 + X95_28+X95_29 + X95_30=1
X74_1 + X74_2 + X74_3+X74_4 + X74_5 + X74_6+X74_7 + X74_8 + X74_9+X74_10 + X74_11 + X74_12+X74_13 + X74_14 + X74_15+X74_16 + X74_17 + X74_18+X74_19 +

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X74_20 + X74_21 + X74_22+X74_23 + X74_24 + X74_25+X74_26 + X74_27 +
X74_28+X74_29 + X74_30=1
X34_1 + X34_2 + X34_3+X34_4 + X34_5 + X34_6+X34_7 + X34_8 + X34_9+X34_10 +
X34_11 + X34_12+X34_13 + X34_14 + X34_15+X34_16 + X34_17 + X34_18+X34_19 +
X34_20 + X34_21 + X34_22+X34_23 + X34_24 + X34_25+X34_26 + X34_27 +
X34_28+X34_29 + X34_30=1
X42_1 + X42_2 + X42_3+X42_4 + X42_5 + X42_6+X42_7 + X42_8 + X42_9+X42_10 +
X42_11 + X42_12+X42_13 + X42_14 + X42_15+X42_16 + X42_17 + X42_18+X42_19 +
X42_20 + X42_21 + X42_22+X42_23 + X42_24 + X42_25+X42_26 + X42_27 +
X42_28+X42_29 + X42_30=1
X35_1 + X35_2 + X35_3+X35_4 + X35_5 + X35_6+X35_7 + X35_8 + X35_9+X35_10 +
X35_11 + X35_12+X35_13 + X35_14 + X35_15+X35_16 + X35_17 + X35_18+X35_19 +
X35_20 + X35_21 + X35_22+X35_23 + X35_24 + X35_25+X35_26 + X35_27 +
X35_28+X35_29 + X35_30=1
X50_1 + X50_2 + X50_3+X50_4 + X50_5 + X50_6+X50_7 + X50_8 + X50_9+X50_10 +
X50_11 + X50_12+X50_13 + X50_14 + X50_15+X50_16 + X50_17 + X50_18+X50_19 +
X50_20 + X50_21 + X50_22+X50_23 + X50_24 + X50_25+X50_26 + X50_27 +
X50_28+X50_29 + X50_30=1
X30_1 + X30_2 + X30_3+X30_4 + X30_5 + X30_6+X30_7 + X30_8 + X30_9+X30_10 +
X30_11 + X30_12+X30_13 + X30_14 + X30_15+X30_16 + X30_17 + X30_18+X30_19 +
X30_20 + X30_21 + X30_22+X30_23 + X30_24 + X30_25+X30_26 + X30_27 +
X30_28+X30_29 + X30_30=1
X23_1 + X23_2 + X23_3+X23_4 + X23_5 + X23_6+X23_7 + X23_8 + X23_9+X23_10 +
X23_11 + X23_12+X23_13 + X23_14 + X23_15+X23_16 + X23_17 + X23_18+X23_19 +
X23_20 + X23_21 + X23_22+X23_23 + X23_24 + X23_25+X23_26 + X23_27 +
X23_28+X23_29 + X23_30=1
X69_1 + X69_2 + X69_3+X69_4 + X69_5 + X69_6+X69_7 + X69_8 + X69_9+X69_10 +
X69_11 + X69_12+X69_13 + X69_14 + X69_15+X69_16 + X69_17 + X69_18+X69_19 +
X69_20 + X69_21 + X69_22+X69_23 + X69_24 + X69_25+X69_26 + X69_27 +
X69_28+X69_29 + X69_30=1

X86_1 + X14_1 + X58_1 + X4_1 + X5_1 + X8_1 + X93_1 + X32_1 + X6_1 + X85_1 +
X9_1 + X38_1 + X46_1 + X67_1 + X12_1 + X82_1 + X15_1 + X81_1 + X76_1 + X17_1
+ X13_1 + X95_1 + X74_1 + X34_1 + X42_1 + X35_1 + X50_1 + X30_1 + X23_1 +
X69_1<1
X86_2 + X14_2 + X58_2 + X4_2 + X5_2 + X8_2 + X93_2 + X32_2 + X6_2 + X85_2 +
X9_2 + X38_2 + X46_2 + X67_2 + X12_2 + X82_2 + X15_2 + X81_2 + X76_2 +
X17_2+X13_2 + X95_2 + X74_2 + X34_2 + X42_2 + X35_2 + X50_2 + X30_2 + X23_2 +
X69_2<1
X86_3 + X14_3 + X58_3 + X4_3 + X5_3 + X8_3 + X93_3 + X32_3 + X6_3 + X85_3 +
X9_3 + X38_3 + X46_3 + X67_3 + X12_3 + X82_3 + X15_3 + X81_3 + X76_3 +
X17_3+X13_3 + X95_3 + X74_3 + X34_3 + X42_3 + X35_3 + X50_3 + X30_3 + X23_3 +
X69_3<1
X86_4 + X14_4 + X58_4 + X4_4 + X5_4 + X8_4 + X93_4 + X32_4 + X6_4 + X85_4 +
X9_4 + X38_4 + X46_4 + X67_4 + X12_4 + X82_4 + X15_4 + X81_4 + X76_4 + X17_4
+ X13_4 + X95_4 + X74_4 + X34_4 + X42_4 + X35_4 + X50_4 + X30_4 + X23_4 +
X69_4<1
X86_5 + X14_5 + X58_5 + X4_5 + X5_5 + X8_5 + X93_5 + X32_5 + X6_5 + X85_5 +
X9_5 + X38_5 + X46_5 + X67_5 + X12_5 + X82_5 + X15_5 + X81_5 + X76_5 + X17_5
+ X13_5 + X95_5 + X74_5 + X34_5 + X42_5 + X35_5 + X50_5 + X30_5 + X23_5 +
X69_5<1
X86_6 + X14_6 + X58_6 + X4_6 + X5_6 + X8_6 + X93_6 + X32_6 + X6_6 + X85_6 +
X9_6 + X38_6 + X46_6 + X67_6 + X12_6 + X82_6 + X15_6 + X81_6 + X76_6 + X17_6
+ X13_6 + X95_6 + X74_6 + X34_6 + X42_6 + X35_6 + X50_6 + X30_6 + X23_6 +
X69_6<1

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X86_7 + X14_7 + X58_7 + X4_7 + X5_7 + X8_7 + X93_7 + X32_7 + X6_7 + X85_7 + X9_7 + X38_7 + X46_7 + X67_7 + X12_7 + X82_7 + X15_7 + X81_7 + X76_7 + X17_7 + X13_7 + X95_7 + X74_7 + X34_7 + X42_7 + X35_7 + X50_7 + X30_7 + X23_7 + X69_7<1

X86_8 + X14_8 + X58_8 + X4_8 + X5_8 + X8_8 + X93_8 + X32_8 + X6_8 + X85_8 + X9_8 + X38_8 + X46_8 + X67_8 + X12_8 + X82_8 + X15_8 + X81_8 + X76_8 + X17_8 + X13_8 + X95_8 + X74_8 + X34_8 + X42_8 + X35_8 + X50_8 + X30_8 + X23_8 + X69_8<1

X86_9 + X14_9 + X58_9 + X4_9 + X5_9 + X8_9 + X93_9 + X32_9 + X6_9 + X85_9 + X9_9 + X38_9 + X46_9 + X67_9 + X12_9 + X82_9 + X15_9 + X81_9 + X76_9 + X17_9 + X13_9 + X95_9 + X74_9 + X34_9 + X42_9 + X35_9 + X50_9 + X30_9 + X23_9 + X69_9<1

X86_10 + X14_10 + X58_10 + X4_10 + X5_10 + X8_10 + X93_10 + X32_10 + X6_10 + X85_10 + X9_10 + X38_10 + X46_10 + X67_10 + X12_10 + X82_10 + X15_10 + X81_10 + X76_10 + X17_10 + X13_10 + X95_10 + X74_10 + X34_10 + X42_10 + X35_10 + X50_10 + X30_10 + X23_10 + X69_10<1

X86_11 + X14_11 + X58_11 + X4_11 + X5_11 + X8_11 + X93_11 + X32_11 + X6_11 + X85_11 + X9_11 + X38_11 + X46_11 + X67_11 + X12_11 + X82_11 + X15_11 + X81_11 + X76_11 + X17_11 + X13_11 + X95_11 + X74_11 + X34_11 + X42_11 + X35_11 + X50_11 + X30_11 + X23_11 + X69_11<1

X86_12 + X14_12 + X58_12 + X4_12 + X5_12 + X8_12 + X93_12 + X32_12 + X6_12 + X85_12 + X9_12 + X38_12 + X46_12 + X67_12 + X12_12 + X82_12 + X15_12 + X81_12 + X76_12 + X17_12 + X13_12 + X95_12 + X74_12 + X34_12 + X42_12 + X35_12 + X50_12 + X30_12 + X23_12 + X69_12<1

X86_13 + X14_13 + X58_13 + X4_13 + X5_13 + X8_13 + X93_13 + X32_13 + X6_13 + X85_13 + X9_13 + X38_13 + X46_13 + X67_13 + X12_13 + X82_13 + X15_13 + X81_13 + X76_13 + X17_13 + X13_13 + X95_13 + X74_13 + X34_13 + X42_13 + X35_13 + X50_13 + X30_13 + X23_13 + X69_13<1

X86_14 + X14_14 + X58_14 + X4_14 + X5_14 + X8_14 + X93_14 + X32_14 + X6_14 + X85_14 + X9_14 + X38_14 + X46_14 + X67_14 + X12_14 + X82_14 + X15_14 + X81_14 + X76_14 + X17_14 + X13_14 + X95_14 + X74_14 + X34_14 + X42_14 + X35_14 + X50_14 + X30_14 + X23_14 + X69_14<1

X86_15 + X14_15 + X58_15 + X4_15 + X5_15 + X8_15 + X93_15 + X32_15 + X6_15 + X85_15 + X9_15 + X38_15 + X46_15 + X67_15 + X12_15 + X82_15 + X15_15 + X81_15 + X76_15 + X17_15 + X13_15 + X95_15 + X74_15 + X34_15 + X42_15 + X35_15 + X50_15 + X30_15 + X23_15 + X69_15<1

X86_16 + X14_16 + X58_16 + X4_16 + X5_16 + X8_16 + X93_16 + X32_16 + X6_16 + X85_16 + X9_16 + X38_16 + X46_16 + X67_16 + X12_16 + X82_16 + X15_16 + X81_16 + X76_16 + X17_16 + X13_16 + X95_16 + X74_16 + X34_16 + X42_16 + X35_16 + X50_16 + X30_16 + X23_16 + X69_16<1

X86_17 + X14_17 + X58_17 + X4_17 + X5_17 + X8_17 + X93_17 + X32_17 + X6_17 + X85_17 + X9_17 + X38_17 + X46_17 + X67_17 + X12_17 + X82_17 + X15_17 + X81_17 + X76_17 + X17_17 + X13_17 + X95_17 + X74_17 + X34_17 + X42_17 + X35_17 + X50_17 + X30_17 + X23_17 + X69_17<1

X86_18 + X14_18 + X58_18 + X4_18 + X5_18 + X8_18 + X93_18 + X32_18 + X6_18 + X85_18 + X9_18 + X38_18 + X46_18 + X67_18 + X12_18 + X82_18 + X15_18 + X81_18 + X76_18 + X17_18 + X13_18 + X95_18 + X74_18 + X34_18 + X42_18 + X35_18 + X50_18 + X30_18 + X23_18 + X69_18<1

X86_19 + X14_19 + X58_19 + X4_19 + X5_19 + X8_19 + X93_19 + X32_19 + X6_19 + X85_19 + X9_19 + X38_19 + X46_19 + X67_19 + X12_19 + X82_19 + X15_19 + X81_19 + X76_19 + X17_19 + X13_19 + X95_19 + X74_19 + X34_19 + X42_19 + X35_19 + X50_19 + X30_19 + X23_19 + X69_19<1

X86_20 + X14_20 + X58_20 + X4_20 + X5_20 + X8_20 + X93_20 + X32_20 + X6_20 + X85_20 + X9_20 + X38_20 + X46_20 + X67_20 + X12_20 + X82_20 + X15_20 + X81_20 + X76_20 + X17_20 + X13_20 + X95_20 + X74_20 + X34_20 + X42_20 + X35_20 + X50_20 + X30_20 + X23_20 + X69_20<1

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X86_21 + X14_21 + X58_21 + X4_21 + X5_21 + X8_21 + X93_21 + X32_21 + X6_21 +
X85_21 + X9_21 + X38_21 + X46_21 + X67_21 + X12_21 + X82_21 + X15_21 + X81_21
+ X76_21 + X17_21 + X13_21 + X95_21 + X74_21 + X34_21 + X42_21 + X35_21 +
X50_21 + X30_21 + X23_21 + X69_21<1
X86_22 + X14_22 + X58_22 + X4_22 + X5_22 + X8_22 + X93_22 + X32_22 + X6_22 +
X85_22 + X9_22 + X38_22 + X46_22 + X67_22 + X12_22 + X82_22 + X15_22 + X81_22
+ X76_22 + X17_22 + X13_22 + X95_22 + X74_22 + X34_22 + X42_22 + X35_22 +
X50_22 + X30_22 + X23_22 + X69_22<1
X86_23 + X14_23 + X58_23 + X4_23 + X5_23 + X8_23 + X93_23 + X32_23 + X6_23 +
X85_23 + X9_23 + X38_23 + X46_23 + X67_23 + X12_23 + X82_23 + X15_23 + X81_23
+ X76_23 + X17_23 + X13_23 + X95_23 + X74_23 + X34_23 + X42_23 + X35_23 +
X50_23 + X30_23 + X23_23 + X69_23<1
X86_24 + X14_24 + X58_24 + X4_24 + X5_24 + X8_24 + X93_24 + X32_24 + X6_24 +
X85_24 + X9_24 + X38_24 + X46_24 + X67_24 + X12_24 + X82_24 + X15_24 + X81_24
+ X76_24 + X17_24 + X13_24 + X95_24 + X74_24 + X34_24 + X42_24 + X35_24 +
X50_24 + X30_24 + X23_24 + X69_24<1
X86_25 + X14_25 + X58_25 + X4_25 + X5_25 + X8_25 + X93_25 + X32_25 + X6_25 +
X85_25 + X9_25 + X38_25 + X46_25 + X67_25 + X12_25 + X82_25 + X15_25 + X81_25
+ X76_25 + X17_25 + X13_25 + X95_25 + X74_25 + X34_25 + X42_25 + X35_25 +
X50_25 + X30_25 + X23_25 + X69_25<1
X86_26 + X14_26 + X58_26 + X4_26 + X5_26 + X8_26 + X93_26 + X32_26 + X6_26 +
X85_26 + X9_26 + X38_26 + X46_26 + X67_26 + X12_26 + X82_26 + X15_26 + X81_26
+ X76_26 + X17_26 + X13_26 + X95_26 + X74_26 + X34_26 + X42_26 + X35_26 +
X50_26 + X30_26 + X23_26 + X69_26<1
X86_27 + X14_27 + X58_27 + X4_27 + X5_27 + X8_27 + X93_27 + X32_27 + X6_27 +
X85_27 + X9_27 + X38_27 + X46_27 + X67_27 + X12_27 + X82_27 + X15_27 + X81_27
+ X76_27 + X17_27 + X13_27 + X95_27 + X74_27 + X34_27 + X42_27 + X35_27 +
X50_27 + X30_27 + X23_27 + X69_27<1
X86_28 + X14_28 + X58_28 + X4_28 + X5_28 + X8_28 + X93_28 + X32_28 + X6_28 +
X85_28 + X9_28 + X38_28 + X46_28 + X67_28 + X12_28 + X82_28 + X15_28 + X81_28
+ X76_28 + X17_28 + X13_28 + X95_28 + X74_28 + X34_28 + X42_28 + X35_28 +
X50_28 + X30_28 + X23_28 + X69_28<1
X86_29 + X14_29 + X58_29 + X4_29 + X5_29 + X8_29 + X93_29 + X32_29 + X6_29 +
X85_29 + X9_29 + X38_29 + X46_29 + X67_29 + X12_29 + X82_29 + X15_29 + X81_29
+ X76_29 + X17_29 + X13_29 + X95_29 + X74_29 + X34_29 + X42_29 + X35_29 +
X50_29 + X30_29 + X23_29 + X69_29<1
X86_30 + X14_30 + X58_30 + X4_30 + X5_30 + X8_30 + X93_30 + X32_30 + X6_30 +
X85_30 + X9_30 + X38_30 + X46_30 + X67_30 + X12_30 + X82_30 + X15_30 + X81_30
+ X76_30 + X17_30 + X13_30 + X95_30 + X74_30 + X34_30 + X42_30 + X35_30 +
X50_30 + X30_30 + X23_30 + X69_30<1

END
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VITA

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