FLEXIBLE MANUFACTURING SYSTEM SCHEDULING

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CERTIFICATE

This is to certify that this thesis entitled, "***Flexible Manufacturing System Scheduling***", submitted by Mr. K.S.Badarinarayan for the award of the degree of **DOCTOR OF PHILOSOPHY** is a bonafide work done by him in this department under the supervision of Dr. M.P.Chandrasekharan, Former Director N.I.T, Calicut, and that it has not been submitted anywhere else for a degree.

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K.S.BADARINARAYAN

ABSTRACT

This research work is about scheduling of Automatic Storage and Retrieval System (AS/RS) machines in Flexible Manufacturing System (FMS) environment. The FMS is the contemporary production system that combines the characteristic of batch and flow line production systems. With the Just In Time concepts the average inventory levels are coming down drastically in industries. The management of vehicles for storing and retrieving the material from the storage racks is vital to enhance productivity. Therefore this research is focused on the scheduling of AS/RS machines in FMS environment. The work is carried out in three phases.

Most of the research in AS/RS area employs simulation or heuristics. There is hardly any research carried out in identifying the similarity in requests for the storage and retrieval locations while transporting material. In the first phase, an attempt has been made to develop clusters based on the similarities using the Natural and Ideal seeds. Once clusters are formed, a routing logic is proposed for scheduling the AS/RS machine within and among the clusters, which results in reduction of "frequency-distance" traveled. For evaluation purpose, measures for grouping performance are developed.

The routing logic provides a sequence for scheduling the machine, but the sequence generated should minimize the distance traveled by the machine. In the second phase optimum sequence is obtained using Genetic Algorithm (GA). The Genetic Algorithm is governed by factors such as crossover, mutation and number of generations. Orthogonal Array (OA) experiments have been applied to arrive at the levels for these factors. By setting them at different levels, the effect on the convergence of the solution is investigated.

In the third phase, a simulation model is developed using the ProModel software. Performance of machine with breakdown, different dispatching rules, with multiple machines, and arrival time distribution of requests are investigated, for both the before and after clustering scenario and compared. It has been observed that clustering formation leads to better performance in all the above cases. The research work addresses the transportation management of AS/RS machine in FMS environment and provides the solution in toto, with formation of clusters, generation of sequences and simulation modeling to provide a feasible solution for implementation.

CONTENT SHEET

Scheduling of Automated Storage and Retrieval machine in FMS using cluster analysis approach

Generation of Sequence Using Genetic Algorithm

Reduction of AS/RS machine in storage area by clustering of demand data using Simulation Modeling

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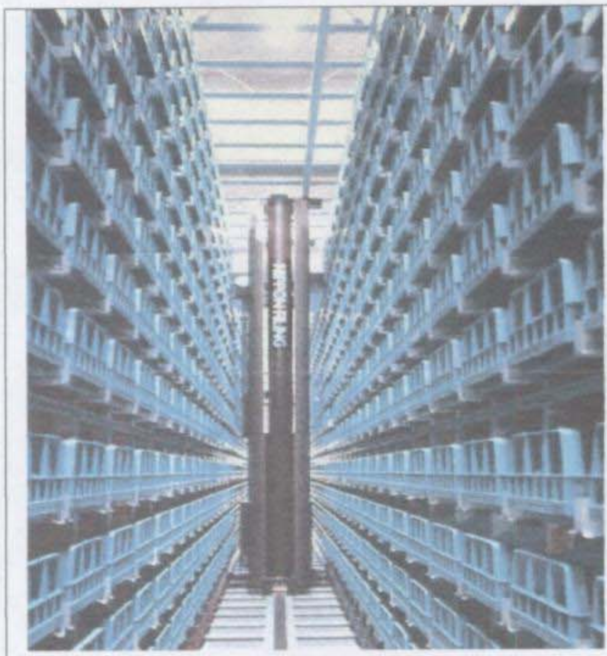

Chapter -1

FLEXIBLE MANUFACTURING SYSTEM SCHEDULING

Beginning……

Chapter - 1

1.0 Introduction

This thesis is concerned with scheduling of Automatic Storage and Retrieval System (AS/RS) machines in Flexible Manufacturing System (FMS) environment. In this chapter, we discuss the context in which the research is undertaken. The Problem of Flexible Manufacturing Systems is highlighted and how scheduling of automatic storage and retrieval machine can provide a solution for transportation management is discussed. Finally an overview of the thesis is provided.

1.1 Context

A Flexible Manufacturing System (FMS) consists of a group of processing stations interconnected by automated material handling devices and storage racks, controlled by an integrated computer system as per Groover [3]. The system is capable of processing different types of parts simultaneously under a NC program control at the different workstations. FMS is considered to fill the gap between high production transfer lines and low production NC machines. For high volume and output rates, transfer lines represent the most efficient method. The limitation of transfer line is that variations in product configuration cannot be readily tolerated; and a substantial redesign of the product may render this mode of production obsolete. On the other hand, stand-alone NC & CNC machines can accommodate changes in part configuration, but the production rates are substantially lower and parts are usually made in batches. In terms of manufacturing efficiency and productivity, a gap exists between the high production transfer line and highly flexible NC machines. The solution to this mid volume production problem is FMS.

In the mid volume range, the advantages of FMS over stand alone NC are that the production of several products can be intermixed, and the production rates are much higher. Instead of batching the products one at a time on a NC machine to meet requirements, the various products can be made simultaneously on the system. The set up time for changeover is minimized with an FMS, so that the economic batch reduces to one at the same time, and the average production rate increases. Intermixing of products on the system permits the output rate of each product to be set at its corresponding demand rate. This reduces the work-in-process and final product inventories that are so typical of batch production methods.

Scheduling is about the allocation of limited resources to tasks over time. It is a decision making process that has to optimize one or more objectives. The scheduling function in an organization or system has to interface with many other functions. These interfaces are of course, system dependent and may differ substantially from one situation to another. In a manufacturing system, orders have to be released and translated into jobs with associated due dates. The jobs often have to be processed by the machines in a work center in a given order or sequence. Jobs may have to wait for processing on machines that are busy, and preemption's may occur when high priority jobs arrive at machines and have to proceed at once. Detailed scheduling of the tasks to be performed in a production system is necessary to maintain efficiency and control of operations. In the current competitive environment, effective sequencing and scheduling has become a necessity for survival in the market. Companies have to meet delivery dates committed to the customers, failure to do so may result in significant loss of goodwill. Hence they have to schedule activities considering optimal utilization of resources. Thus, FMS Scheduling assumes great importance.

With technological changes and shrinking inventories, the management of material handling plays a significant role. Automated Guided Vehicles (AGV), Automatic Storage and Retrieval System (AS/RS) machines play a vital role in transporting materials to workstations. Management of these vehicles to avoid collisions and minimize the distance to be traveled has posed many challenges to all researchers.

1.2 Problem

Certain trends are occurring in manufacturing that will shape the factory of the future. These trends result from management's desire to find new ways to increase productivity from new opportunities afforded by developing technologies. The trends include, shorter product life (cycles) and development of new generations of complex products in less time. The products available to consumers are becoming more individualized and custom engineered. There are more special options and features to meet the particular needs of the customer. This results in smaller lot sizes. The number of products and components made in small batch sizes is expected to represent the majority of future manufacturing activity. Just-in-time production (JIT) is a means of reducing inventory of raw materials and purchased parts. With JIT, a large company that makes an assembled product will require its suppliers to deliver the components needed for the product within a short time interval before the assembly process. The interval may be one day or less, depending on the reliability of the supplier to make deliveries on schedule. Ideally, the components are delivered immediately before they are needed in assembly (i.e., "just in time").

In the management of material handling function two problems have to be tackled, 1) Flexible routings for different parts and 2) Mechanical interfacing of material handling and production systems. The first of these problems involves the capability of the material handling system to deliver different work parts to different work cells in the plant according to the particular routing of the part. The various parts and products will each require its own set of processing operations, and the handling system must be able to provide these flexible routings. This flexibility will be achieved using computer control of the material handling system. Process plan for each part will be stored in the computer and this information can be converted into the corresponding work cell routing.

The second problem area is the difficulty in transferring loads between the material handling systems, production work cells, and storage systems in the plant. However, the problems of operating and controlling the automated manufacturing system become significantly larger as the production capacity of the system increases.

Automated Guided Vehicles (AGV), Automatic Storage and Retrieval System (AS/RS) machines play a vital role in transporting materials to workstations. Management of these vehicles to avoid collisions and minimize the distance to be traveled has posed many challenges to all researchers.

1.3 Solution : Scheduling

There are many possible approaches that can be taken to schedule processing of parts through the system. Different approaches may be applicable in different situations. Since operations are computer controlled, set-ups between consecutive operations are automated and most of operations processed by NC machines, it can be assumed that processing times are nearly deterministic. This implies that the result (performance of a schedule) is predictable, if there are no system disturbances. Therefore, in some situations, a fixed off-line scheduling may be enough, although the problem is hard to deal with analytically. However, actual states of FMS may not be predictable because of part arrivals, Machine states (up or down), tool breakages, rushed jobs and many other system disturbances. Because of such a dynamic and uncertain nature of the system states, off-line scheduling may be impractical for FMSs. In general, FMSs are more sensitive to system disturbances than conventional manufacturing systems because of a tighter synchronization, system integration and inter-dependencies among automated components. Hence, an immediate response to changes in system states is required, and this can be achieved by real-time scheduling. If system states change dynamically, it is necessary to schedule flow of parts based on the actual system states. A system's performance is directly related to the speed at which its control system makes scheduling decisions. Therefore, scheduling decisions and actions have to be made quickly, i.e. they need to be done in real-time. Real-time scheduling means such scheduling actions responding to system state changes in real time.

The scheduling problem discussed in this thesis refers to scheduling in very short span of time, during which the storage and retrieval requests from the total system would be such that most of elements in the Frequency distance matrix will be null, and the randomness of the non-null elements would make it amenable to certain grouping by which the AS/RS can deal with clusters in succession. It is possible to run this process continually so that the problem definition and procedure do not change over time.

1.4 Thesis: An overview

This thesis is concerned with scheduling of AS/RS in FMS environment. The literature survey in chapter 2 reveals that the scheduling is carried out using several approaches such as integer programming, fuzzy logic, artificial intelligence, simulation, etc.

Most of the research work on scheduling of AS/RS is carried out using simulation studies. The dual command cycle consisting of transporting material from location to loading / unloading station and placing empty container back to storage rack is a challenge for researches.

Chapter 3 focuses on identifying the similarity of requests coming from different locations. Clusters are formed using the natural and ideal seed concept. Using the routing logic developed in the research work, the scheduling of machine is carried out in the clusters which results in reduction of distance moved. Measures of efficiency and efficacy are developed for interval level data.

Once the clusters are formed the sequence in which the material containers have to be stored / retrieved by the machine has to be developed and this generation of sequences is carried out using Genetic Algorithm. The methodology of applying genetic algorithm is discussed in the chapter 4. The parameters affecting the evolution process are determined by Orthogonal Array experiment techniques.

Simulation modeling is carried out using ProModel software. The model is developed and the results are analyzed for the before and after cluster formation scenario, with breakdown of machine, different scheduling rules, arrival distribution of jobs and number of machines are discussed in the chapter 5.

Different problem sets are considered in the research, after applying the clustering methodology, Genetic Algorithm and simulation modeling, the results obtained are presented in the chapter 6.

1.5 Summary

This chapter presents the problems associated with scheduling of AS/RS in FMS and how scheduling assumes importance in FMS environment. It also provides an overview of the thesis highlighting its salient features.

Review of Literature

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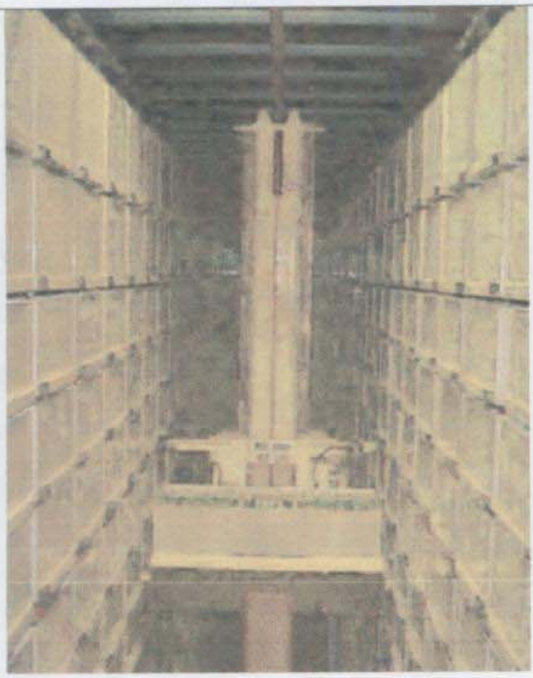
Chapter - 2

Review of Literature

Search begins……..



Chapter – 2

2.0. Literature Survey

In this chapter we attempt to trace the history of scheduling methods and Flexible Manufacturing System scheduling. The research undertaken in the area of material handling, application of genetic algorithm, clustering algorithms to solve FMS problems, simulation of AS/RS, artificial neural network, fuzzy, simulated annealing methods applied to FMS scheduling are explored. The gap and deficiencies in the material handling system scheduling identified in the present work, provide a base for taking off and pursuing research.

Scheduling began to be taken seriously in manufacturing by the beginning of the century. Many years later publications on scheduling started appearing in the operation research literature, such as naval research logistics quarterly. During 1960 a significant amount of work was done on dynamic programming and integer programming formulation of scheduling programs, the research in 1970 focused mainly on the complex hierarchy of scheduling programs. In the 1980, several different directions were pursued in academia and industry with an increasing amount of attention paid to stochastic scheduling problems.
Michael Pinedo [1] classifies the scheduling level with time horizon as shown in the table 2.1.

2.1 Table: Classification of Scheduling Levels

Sl. No		**Examples of problem**	**Horizon**
1	Long-range planning	Plant expansion, plant layout, plant design	2-5 years
2	Middle-range planning	Production smoothing, logistics	1-2 years
3	Short-range planning	Requirements plan, shop bidding, due date setting.	3-6 years
4	Scheduling	Job shop routing, assembly line balancing, process batch sizing.	2-6 years
5	Reactive scheduling/ control	Hot jobs, down machines, late material	1-3 years

The scheduling Environments and the characteristics are provided in the following table 2.2.

2.2 Table: Scheduling Environments

Sl. No	Type	characteristics
1	Classic job shop	Discrete, complex flow, unique jobs, no multi use parts
2	Open job shop	Discrete, complex flow, some repetitive jobs and/or multi use parts
3	Batch shop	Discrete or continuous, less complex, many repetitive and multi use parts, grouping and lotting Important
4	Flow shop	Discrete or continuous, linear flow, jobs all highly similar, grouping and lotting Important
5	Batch/flow shop	First half, large continuous batch process, second half, typical flow shop
6	Manufacturing cell	Discrete, automated grouped version of open job shop or batch shop.
7	Assembly shop	Assembly version of open job shop or batch shop
8	Assembly line	High volume, low variety, transfer line version of assembly shop.
9	Transfer line	Very high volume and low variety linear production facility with automated operations.
10	Flexible transfer line	Modern version of cells and transfer lines intended to bring some of the advantages of high-volume production to job shop items.

The basic theoretical portions are well discussed in Michael Pinedo [1] which provides the theory of scheduling with various algorithms. Thomas Morton [2] provides the Heuristic scheduling systems with applications to production systems and project management. Groover [3] discuss about the features of FMS systems.

2.1 Flexible Manufacturing System Scheduling

The term scheduling rule is used to refer to rules that prioritize jobs in a queue waiting to be serviced. When the process becomes available, a job must be selected from its input queue for immediate set up and processing. Most of the rules reported before 1980 considered scheduling problems in a job shop environment.

A survey in job scheduling by Panwalkar et al [4] reported that more than 100 scheduling rules have been proposed in the literature. They classified the scheduling rules into three categories, simple priority rules, heuristic scheduling rules, and combination rules including concepts from either of the first two categories.

An early study on the scheduling problem in FMS was performed by Stecke et al [5] where a number of scheduling rules were compared in five alternative loading strategies based on a real FMS composed of nine work stations, an inspection station and a common storage area. They found that the shortest processing time divided by the total operation time (SPT /TOT) rule performed the best under all loading strategies. This ratio is no better than the old SPT rule because TOT is a constant in the work referred to.

Blackstone et al [6] reported that the shortest imminent operation rule (SI) is the best priority rule among other rules under several system operation conditions.

Choi et al [7] tested the combination of seven part scheduling rules and four machine center selection rules in FMS. Their study is based on a comparison of several job-shop scheduling rules using a physical simulator. They found that the SPT/WINQ (work in queue) and SLACK/WINQ rule-sets dominated the other major decision rule-sets.

Montazeri et al [8] analyzed the effect of different scheduling rules on the performance of a specific system by using a modular simulator to mimic the operation of a real life FMS. No single scheduling rule was found to be the winner on all performance measures in their study.

Chandra et al [9] developed an intelligent job dispatching strategy for Flexible Manufacturing Systems using an opportunistic reasoning approach rather than a static-scheduling rule. They showed that the intelligent dispatching rule performed better than many common-scheduling rules under the manufacturing environment considered in their study.

O'Keefe et al [10] investigated the interaction between nine scheduling and four next station selection rules in a relatively large dedicated FMS containing 16 workstations with local buffers and nine load/unload stations. The SPT /TOT and WINQ rules performed marginally better than the other rules.

Piplani et al [11] attempted to identify a suitable rule combination for the system performance. A launching rule was used to prescribe the part-type that should be introduced into the system. A scheduling rule was then used to select a part from among the parts waiting for processing at a machine whenever the machine turned idle.

Nayak et al [12] proposed that solution to sub problems of FMS planning problems requires an integrated approach. The mathematical programming approaches, which are often followed, are not suitable for large problems. In their work, they have proposed a three stage approach to solving part type selection, machine loading and part type volume determination problems. In contrast to the usual approach of maximizing the part types in each batch (or minimizing the number of batches),they have attempted to maximize the routing flexibility of the batches. A heuristic has been proposed for the part type selection problem and simple mathematical programs for other two problems. The illustrative examples show that by improving the routing flexibility of the batches the overall system performance has improved.

Newman et al [13] devised a multi-level modeling system for the design of flexible machining installations. The design and management of such systems requires a large number of decisions and choices with regard to production mix, assignment of fixtures and cutting tools. Their work establishes a research prototype for a multi-level approach for the realization of a three-phase design and modeling system for flexible machining facilities.

Guerrero et al [14] present a new approach to the loading problem in Flexible Manufacturing Systems. The loading objective is to balance machine work-loads considering constraints like the number of available tools and on tool magazine capacities. The problem is modeled as a mixed-integer linear program. A classification of different approaches to scheduling is presented in Table 2.3 and 2.4 provide the classification of different approaches.

Table 2.3 Classification of existing approaches by problem type and objective function

Objective function	Loading	Grouping and loading	Batching and loading	Loading and scheduling	Tool allocation & routing
Workload balancing	Berrada and Stecke (1986) Wilson (1992) Kim & Yano (1993), Kirkavak & Dincer (1993) Kim & Yao (1994)	Stecke (1983) Stecke (1986) Stecke & Raman (1994)	Bastos (1988) Shanker & Srinivasulu (1989), Stecke & Kim (1991) Moreno & Ding (1993), Solomon et.al (1995)	Sanker and Tzen (1985) Sawik (1990)	Arbib et.al (1990) Sodji et.al. (1994 a)
Cost optimization	Sarin & Chen (1987) Ram et.al (1990) Kouvelis & Lee (1991) Basnet (1996)		Liang & Dutta (1993)		Liang & Dutta (1990) Sodhi et.al (1994 b)
Part movements minimization	Shaker & Rajamarthandan (1989) Wilson (1989)	Stecke (1983) Stecke (1986)			Arbib et. Al (1990) D'Alfonso & Ventura (1995)
part priorities maximization			Bastos (1988) Hwan 7 Shogan (1989), Liang & Dutta (1993) Srivastava & Chen (1993), Mohammed (1996)		
Tool changeovers minimization	De Werra & Widmer (1990)			Sawik (1990)	
Makespan minimization			Chen & Chung (1996) Liang & Durra (1993)	Greene & Sadowski (1986), Sherali et.al (1990) Chen & Chung (1996)	Chen & Chung (1991) Liang & Dutta (1990)
Total processing time minimization	Chakravarty & Shtub (1984) De Werra & Widmer (1990)				
Part type lateness minimization			Moreno & Ding (1993)	Shanker & Tzen (1985) Greene & Sadowski (1986) Sawik (1990)	
Other	Lashkari et.al (1987) De Werra & Widmer (1990)	Stecke (1983) Stecke (1986)	Shanker & Srinivasulu (1989)	Greene & Sadowski (1986)	Chen & Chung (1991) Atan and Pandit (1996)

Table 2.4 Classification of existing approaches by modeling approach

Nonlinear model	ILP / MILP model	LP model	Network flow model	Heuristic
Stecke (1983) Stecke (1986) Berrada & Stecke (1986) Lashkari et al. (1987) Shanker & Rajamarthandan (1989) Wilson (1992)	Chakravarty & Shtub (1984) Shanker & Tzen (1985) Greene & Sadowski (1986) Sari & Chen (1987) Bastos (1988) Shanker and Srinivasulu (1989) Wilson (1989) Sawik (1990) Liang & Dutta (1990) De Werra & Widmer (1990) Arbib el al. (1990) Sherali el al. (1990) Kouvelis and Lee (1991) Chen and Chung (1993) Srivastava and Chen (1993) Kirkavak and Dincr (1993) Liang and Dutta (1993) Moreno and Ding (1993) Kim and Yano (1994) Sodhi el al. (1994 a) Sodhi el al. (1994 b) D'Alfonso and Ventura (1995) Solomon el al. (1995) Chen and Chung (1996) Basnet (1996) Atan and Pandit (1996) Mohamed (1996)	Bastos (1988) Stecke & Kim (1991) Stecke & Raman (1994) Sodhi et al. (1994 b)	Ram et al. (1990) Hwan & Shogan (1989)	Shanker & Tzen (1985) Shanker & Srinivasulu (1989) Sheralli et al. (1990) Wilson (1992) Moreno & Ding (1993) Kim & Yano (1993) Kirkavak & Dincer (1993) Stecke & Raman (1994) Atan and Pandit (1996) Chen & Chung (1996)

Taeho Park et al [15] suggested a FMS design model with multiple objectives using compromise programming. They present a method for simultaneously determining design and control parameters of an FMS with the multiple performance objectives via full-factorial design of experiments, regression analysis and compromise programming

Jason Rupe et al [16] address the design for reliability of complex systems, such as Flexible Manufacturing Systems (FMS), through mathematical modeling of the machine failure, spares inventory, and repair processes. The unique model allows separation of systems by Machine Part Type (MPT); thus, an extremely complicated FMS can be modeled through many simpler models. They provide a measure of system effectiveness.

Chandra et al [17] work on optimization-based Parts-Machines Matching in Flexible Manufacturing Systems. A new dynamic scheduling strategy, Parts-Machines Matching (PMM), is developed and tested in simulated flexible manufacturing systems. Global and Partial implementation of PMM are presented and compared with other conventional part-flow rules. They are found to achieve better shop performance than conventional rules, in terms of system throughput, robustness against travel time uncertainties and recovery from machine breakdowns.

Jingsong Ma et al [18] discuss the performance evaluation of the Flexible Machining/Assembly Systems (FMS/FAS) of a central server type, and give a comparative consideration of a fixed, dynamic versus an ordered-entry routing rule. First, the steady state equations are given, and the system throughput is obtained. Next, the system configurations of FMS/FAS are numerically discussed on the basis of system throughput. Finally, the superiority of an ordered-entry routing rule is numerically discussed for development of routing theory.

Jie Chen et al [19] suggest adaptive scheduling in random Flexible Manufacturing Systems. In a FMS dynamic scheduling environment, frequent rescheduling to react to disruptions such as machine breakdowns can make the behavior of the system hard to predict, and hence reduce the effectiveness of dynamic scheduling. The effectiveness of the proposed method is compared with other approaches based on various dispatching heuristics such as Apparent Tardiness Cost, Cost over Time, and Bottleneck Dynamics, etc. under different shop load and machine downtime levels.

The scheduling in FMS environment has been addressed by different approaches, there is no single solution available, and the solutions are problem specific. There is a need for a generalised approach for problem solving.

2.2 Material handling in Flexible Manufacturing System.

Material handling is one of the essential components of a flexible manufacturing system (FMS). Among various equipments employed for this purpose, the automated guided vehicle (AGV) is fast becoming a popular choice. An automated guided vehicle system (AGVS) features battery powered, driverless vehicles moving on a guide path layout. It has programming capabilities for path selection and can be reconfigured easily to accommodate changes in production volume, product mix, product routing and equipment interfacing requirements. These flexibilities are essential requirements of a flexible material handling system in an FMS environment.

Several design and operational control issues influence achievement of high performance from an AGVS. These include specifying the type and number of vehicles to be employed, specifying appropriate guide path configuration together with locating load transfer stations, locating vehicle buffering areas and specifying their holding capacities, specifying vehicle dispatching and routing strategies, managing traffic, specifying unit load sizes, specifying central and/or local work-in-process storage capacity, etc. As a consequence of selection of a suitable mix of these design variables and control measures, the system exhibits its operating behavior in the form of loaded and empty vehicle travel, idle wait of vehicles for load transportation assignments, vehicle blocking as a result of path contention, variation in work-in-process storage queues and shop locking phenomenon.

The determination of a unique vehicle route and its time schedule has traditionally been classified under static and dynamic approaches. In a static approach route planning the main criterion is to dispatch a vehicle by assigning it to the flow path route associated with the minimum distance to its destination. The shortest distance between any two nodes in the system is computed and the vehicles are dispatched accordingly. Thus, the single objective function in such models is to minimize the distance traveled by the vehicles. The possibility of track congestion and vehicle blocking in an AGVS using static path planning is very high since the same optimal routes are taken regardless of the traffic congestion status of the tracks. Such a system offers very little flexibility. The traditional method for route planning of AGVS is to determine, in advance, all of the useful paths within the system, and store the information in a central computer until needed.

Egbelu et al [20] have proposed a routing algorithm. The disadvantage of the method is the lack of flexibility, which can, in turn, result in longer vehicle trip times.

Egbelu et al [21] have proposed a heuristic to resolve node conflict in bi-directional traffic flow and suggested that provision of vehicle buffering areas is important in resolving vehicular conflicts in the use of an aisle, featured a more flexible design capable of evaluating system control strategies for a wider range of system configurations.

Haines [22] described a routing algorithm that determined the correct turns an AGV would make solely by knowing its destination node number, its current node number and the alternative candidate nodes numbers. The algorithm is applicable when there exists a path through the system that passes exactly once through each intersection, buffer and processing center, and there are no more than two paths leaving any intersection.

The concept of conflict-free shortest-time AGV routing was first introduced by Broad Bent et al [23].The Imperial College free ranging AGV employed Dijkstra's shortest path algorithm and generated a matrix describing the node occupation times of vehicles. Potential conflicts were detected by comparing the occupation time of the new vehicle for each node with the existing nodes occupation times. Head-on collisions were resolved by finding another shortest path excluding the congested segment, and changing the node occupation times and/or the speeds of the following, vehicles. The bi-directional flows represent highly tedious traffic control problems.

Egbelu et al [24] and Kim et al [25] studied the potentials of bi-directional traffic flow by conducting simulation experiments.

To design optimal flow paths for an AGV system, Gaskins and Tanchoco [26] formulated and solved a zero-one integer-programming problem. The objective was to construct a vehicle routing plan that minimizes the total distance traveled by loaded vehicles to satisfy a given set of transportation requirements.

Blair et al [27] presented a two-phased heuristic algorithm for the near optimal routing of AGVS which sought to organize material moves into tours with the objective of minimizing the maximum tour length (minmax) and thus distributing the workload evenly among vehicles.

Koch [28] described a central, intelligent system director which could dynamically control vehicle dispatching rules and route plans by altering the priorities of unit loads, vehicles and route network segments.

Tanchoco et al [29] developed a LISP-based controller for free- ranging AGV systems. They performed a simulation-based performance evaluation of a job shop, where transportation was critical. It was shown that increasing the number of vehicles improved the throughput of the system up to a point; however, beyond that point, the throughput started to decrease. This decrease was found to be due to vehicle blockage (that is, self- congestion), causing unit loads to spend more time on vehicles traveling to work- stations.

Gaskins et al [30] introduced the vehicle simulator AGVSim2, which was intended to be a development tool for testing the performance of an AGV supervisory controller. Rather than modeling the control logic, AGVSim2 was designed to be linked directly to the supervisory controller software. The simulator models the environment in which the supervisory controller software operates, generating the events to which the controller responds. By altering the environment and other components of the AGV system, the user can test the performance of the supervisory controller software under a variety of conditions. To enhance the evaluation procedure, the simulator is designed to be linked to an animation module that graphically displays the vehicle's location.

Cesarone et al [31] described a research effort in the area of collision avoidance path planning for AGVs or mobile robots. They discussed the general principle of dynamic programming and its modification to fit the AGV routing problem. They tackled the find-path problem, blending the shortest-path and safest-path approaches. Their dynamic programming modification employed a user defined performance index, which could be adjusted to yield a compromise between the shortest and the safest extremes.

The labeling algorithm proposed by Huang et al [32] assigned labels to free time windows defined for each node rather than to physical nodes. The algorithm treated the physical arcs of the original guide path as nodes in the converted network. The journey time on an arc of the original network was converted to the dwell time on the corresponding node of the converted network. The algorithm was applicable to both unidirectional and bi-directional flow networks, and the shortest time route found by the algorithm allowed for both cycles and loops in the final solution.

Fujii et al. [33] presented a routing control algorithm to determine, using a branch-and-bound method, a non-conflicting path for an AGV. The routing problem was regarded as a shortest path finding problem on a network with time windows. The concepts of modified time windows and shifted time windows were introduced to regulate an AGV's traveling schedule. Time windows were placed on arcs as well as nodes so as to constrain the AGV both to start and to arrive at the node or the arc within the specified time window.

Bozer et al [34] proposed a tandem configuration flow path design consisting of non-overlapping, single vehicle closed-loops with additional load transfer stations provided as an interface between adjacent loops. Their work was extended by Lin et al. [35], Lin and Dgen, [36] This formulation was extended by Kaspi et al [37] to apply to the problem of optimal flow path design for unidirectional AGV systems.

Kim et al [38] stated the problem environment for a conflict-free shortest time AGV routing decision as follows. The proposed algorithm was based on Dijkstra's shortest path method. There are several vehicles in the system serving a predefined flow path network, which consists of a set of nodes and a set of arcs. Nodes represent load transfer stations, intersections and other important locations. Arcs can be unidirectional and/or bi-directional. A dispatch command issued to a vehicle includes a pair of source and destination nodes. Assuming the vehicle is currently located at the source node, the problem is then to find a route starting from the source and arriving at the destination as early as possible without disrupting other active travel schedules.

Mahadevan et al [39] developed an analytical model for estimation of number of AGVs.

Much of the research is reported in AGV compared to AS/RS machines. Much of the early work on AS/RS relied primarily on simulation. Hausman et al [40] were among the first to develop analytical and empirical results to aid the analysis of these systems. The authors address the problem of optimal storage assignment and consider two policies: Randomized storage and class based storage. They show that turnover -based storage rules such as class based storage policy results in significant reductions in AS/RS machine travel time.

Bozer et al [41] employ a continuos rack approximation. They derive expressions for expected single and dual command cycle times for rectangular racks, a randomized storage policy, and a variety of I/O point configurations and AS/RS machine dwell point policies.

Min et al. [42] develop an analytical expression for expected dual command travel time using the nearest-neighbour sequencing rule for unit load AS/RS.

Bozer et al [43] devise travel time model for automated storage/retrieval machines. For randomized storage conditions expected travel times are determined for both single and dual command cycles.

Foley et al [44] derive an exact expression for the distribution of the AS/RS machine travel time under the FCFS retrieval policy, in order to determine the throughput for the miniload AS/RS.

Ashayeri et al [45] have presented an exact geometry-based analytical model that can be used to compute the expected cycle time for a storage/retrieval (S/R) machine, executing single commands, dual commands, or both, in a rack structure that has been laid out in a pre-specified storage zones for classes of goods.

Charles J. Malmborg [46] proposes a well-known rule of thumb for evaluating storage rack configurations in automated storage and retrieval systems. The relationship between the system cost estimates with utilization of storage and retrieval machine are established.

Charles J. Malmborg [47] suggests various models in autonomous vehicle storage and retrieval systems. Autonomous vehicle storage and retrieval systems utilize rail-guided vehicles moving in rectilinear paths within and between the aisles of unit load storage racks. Vertical vehicle movement is provided by lifts installed at fixed locations along the periphery. As an alternative to traditional automated storage and retrieval systems, autonomous vehicle systems enable users to match vehicle fleet size and the number of lifts to the level of transactions demand in a storage system. Analytical conceptualizing tools based on the features of autonomous vehicle systems are proposed for modeling expected performance as a function of key attributes including storage capacity, rack configuration and fleet size. The models are demonstrated for a sample problem and compared with analytical conceptualizing tools used for automated storage and retrieval systems.

Robert R. Inman [48] study a mixed model assembly line's efficiency. Since it depends on the sequence of jobs moving down the line, manufacturers spend considerable effort optimizing the sequence of jobs entering the plant. In automotive assembly plants however, repair loops and parallel stations scramble the sequence before it reaches the final assembly stage. Many automotive assembly plants use an automatic and retrieval system to revamp the scrambled sequence before final assembly. The authors derive a relationship between the sequence scrambling information, the variety of model-colour configurations, and the size of the automatic storage and retrieval system needed to reconstruct the initial sequence. The authors enunciate this new ASRS sizing problem actually facing industry, show how to model it, present a solution approach, and demonstrate the approach on actual sequence scrambling data from an automotive assembly plant.

Mahajan et al [49] have suggested a retrieval sequencing scheme aimed at improving the throughput of miniload automated storage/retrieval systems in an order picking environment. They assume that an order comprised of retrieval requests is always available such that dual command cycles are always performed. A nearest-neighbor retrieval sequencing heuristic is presented, an analytical model is developed to predict its performance, and this model is validated using simulation. The heuristic is shown to improve throughput by 5-15% over traditional first-come-first-served retrieval sequencing. The heuristic achieves this improvement by appropriately sequencing retrieval requests within an order and also optimizing retrieval requests among successive orders. An upper bound for throughput under any sequencing rule is established, and under the conditions tested, the heuristic is found to perform within 3-6% of this bound over different order sizes.

Paulo J et al [50] have proposed a sequential modeling approach to operation allocation and materials-handling system selection in a flexible manufacturing system. This work proposes a first approach to the simultaneous consideration of the operation allocation and the materials-handling system selection problems in a flexible manufacturing system.

The research carried out in material handling is towards resolving the conflict in the AGV collisions and developing the optimal routes. The previous research has not been able to address the root cause of the problem. The similarities of the requests for retrieval and storage is not explored by the researchers. We have tried to exploit this opportunity in our research.

2.3 Genetic Algorithm

Most of the GA applications have been in function optimization where attention is paid only to the fittest few individuals. Besides extensive application in unconstrained function optimization, GA's have also been used for many typical combinatorial optimization problems in operations research, such as set covering, set partitioning, weighted graph matching, graph covering, cutting stock, knapsack, generalized assignment, transportation, and the traveling sales- person problem, etc.

Holland [51] introduced genetic algorithms, which, later on, were applied to a wide variety of problems.

Rajasekharan [52] has worked on FMS facility layout problem which involves the positioning of cell within a given area so as to minimize the material flow cost between cells. A mixed integer programming formulation for the FLP is adapted and heuristically solved. Because of the NP-hard nature of the solution space, a genetic algorithm based decomposition strategy is proposed and computationally tested. A comparison of the computational results with the existing methods indicates that the heuristic is a viable alternative for efficiently and effectively generating layout designs for flexible manufacturing systems.

Andrea Rossi [53] addressed the problem of dynamic scheduling of FMS using real time Genetic Algorithm. The ability of the system to generate alternative plans following part-flow changes and unforeseen situations is particularly stressed (dynamic scheduling). Two contrasting objectives represented by the reduction of machine idle-times, dynamic scheduling computation and the reduction of the make span, are taken into account by the proposed system. The key-point is the real-time response obtained by an optimized evolutionary strategy capable of minimizing the number of genetic operations needed to reach the optimal schedule in complex manufacturing systems.

Jordan [54] has introduced the batch sequencing problem (BSP) with item and batch available for the single-machine and two-machine flow-shop case. They proposed a genetic algorithm which solves the BSP through decomposition into a phase I- batching and phase II-scheduling decision. The batch sequencing problem is closely related to the discrete lot sizing and scheduling problem (DLSP). Computational experience shows that the genetic algorithm for solving the BSP favorably compares with procedures for solving the DLSP.

Jain et al [55] studied scheduling of production in Flexible Manufacturing Systems. Genetic algorithm is used by them to obtain an initial schedule. Uncertainties in the production environment and modeling limitations, unforeseen machine breakdowns, increased order priority, rush orders arrival and order cancellations are considered and an algorithm is proposed to improve the efficiency of the flexible manufacturing system.

Tam et al [56] have presented a parallel genetic algorithm approach to the facility layout problem which improves on previous work in terms of schema coding and solution method. Four coarse-grained parallel genetic algorithms for the layout problem are developed and compared based on sound statistical experimental design. Experimental results indicate that the distributed and totally distributed parallel genetic algorithms consistently outperform others, independent of problem size and number of processors. The work also demonstrates the potential of parallel genetic algorithms as a viable tool to tackle hard combinatorial management science problems.

Maimon et al [57] have addressed the problem of scheduling N printed circuit boards (PCBs) on a single machine equipped with an automatic component interchange mechanism. This problem is addressed employing a genetic algorithm to search the space of alternative solutions. To evaluate the performance of the GA, a heuristic solution based on a traveling salesman formulation is described. Extensive experiments were carried out for both approaches based on data extracted from industrial scenes.

Candido et al [58] have worked on a robust procedure to solve job shop scheduling problems with large number of more realistic constraints. The system uses modified schedule generation algorithms to obtain a set of initial solutions. Each initial solution is enhanced by a local improvement procedure. Then a hybrid genetic algorithm, which incorporates a local hill climbing procedure, is applied to the set of local optimum schedules.

Lam et al [59] have worked on a method by considering a scheduling problem encountered in a manufacturing company where the time for designing products (or makespan) needs to be minimized. They develop a genetic algorithm (GA), which is one of combinatorial optimization subjects to many practical constraints. The GA is found to be very effective for solving this intractable problem.

Bhaskara Reddy et al [60] have worked on Computer Aided Process Planning (CAPP) which is an important interface between Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) in Computer Integrated Manufacturing (CIM). They demonstrated the application of genetic algorithms as a global search technique for a quick identification of optimal or near optimal operation sequences in a dynamic planning environment. A novel initialization scheme for representing the genetic code and a new crossover operator are designed to retain the local operation precedence for each form feature. Since sequences can be obtained quickly, this approach can actually be used by the process planner to generate alternative feasible sequences for the prevailing operating environment.

Tiwari et al [61] have studied the machine-loading problem of a flexible manufacturing system which is recognized as one of the most important planning problems. In their research, a Genetic Algorithm (GA) based heuristic is proposed to solve the machine loading problem of a random type FMS. The objective of the loading problems is to minimize the system unbalance and maximize the throughput, satisfying the technological constraints such as availability of machining time, and tool slots. The proposed GA based heuristic determines the part type sequence and the operation-machine allocation that guarantee the optimal solution to the problem, rather than using fixed predetermined part sequencing rules. The efficiency of the proposed heuristic has been tested on ten sample problems and the results obtained have been compared with those of existing methods.

Yeung et al [62] have presented a methodology for the advancement of fault tolerance in cell control when applied to a class of flexible assembly system. The FPP scheme and the genetic algorithm are successfully integrated into a prototype Colour Petri Net (CPN) based cell control system which allows the system to regenerate its control logic and the production schedules whenever system faults occur, and therefore enable it to continue in operation. The successful implementation of this fault recovery cell control system within a demonstrator assembly cell indicates that the framework proposed provides a foundation for the further development and application of advanced cell control.

Marc Gravel et al [63] have presented a genetic algorithm for the solution of an industrial scheduling problem in an Alcan aluminum foundry situated in Quebec. They seek the best processing sequence for *n* orders on *m* parallel machines. There are also a number of structural constraints that distinguish this situation from the classical model. The performance of the solution approach is compared with the results of the scheduling process used by the firm according to three criteria: meeting due dates, number and duration of required set-ups and metal flow.

Zhang et al [64] have developed an algorithm that solves a paper reel layout problem where the available space is divided into equal-size cells. The problem is to find a layout with the minimum transportation cost subject to adjacency and other constraints. A genetic algorithm is used in a two-stage iterative approach to solve the problem. Computational results seem to indicate the efficiency and effectiveness of the proposed solution method.

Patrick et al [65] have proposed a methodology to solve the Just-in-Time (JIT) sequencing problem for multiple product scenarios when set-ups between products are required. Problems of this type are combinatorial, and complete enumeration of all possible solutions is computationally prohibitive. Therefore, Genetic Algorithms are often employed to find desirable, although not necessarily optimal, solutions. This research, through experimentation, shows that Genetic Algorithms provide formidable solutions to the multi-product JIT sequencing problem with set-ups. The results also compare favorably to those found using the search techniques of Tabu search and simulated annealing.

Neeraj Kumar et al [66] have worked on the part type selection and machine loading problems in the production planning of FMSs. They solve these problems by the use of GAs. They exploit the problem's mixed integer programming model to make the GA more meaningful and less computation-intensive. Their GA is able to achieve optimum or near-optimum performance on a variety of objectives. A parametric study of GA factors is also carried out, indicating population size and mutation probability as influential parameters.

Latif Al-Hakim [67] has developed a genetic algorithm for solving job shop scheduling problems. It discusses the difficulties arising from the traditional encoding of the problem and suggests a new encoding scheme. The algorithm considers the conventional genetic operations but with some modification. The computational results, developed for the makespan criterion, show that, for this criterion, the algorithm is reliable and performs relatively well.

Dimopoulos et al [68] have studied the problem of identifying machine cell and corresponding part families in cellular manufacturing. However, the complexity of the problem and the considerable number of issues involved in its solution create the need for increasingly efficient algorithms. They use genetic programming for the solution of a simple version of the problem. The methodology is tested on a number of problems taken from the literature and comparative results are presented.

Ong et al [69] have proposed a method to determine the set-up of a workpiece with a certain orientation and fixturing on a worktable, as well as the number and sequence of set-ups and operations performed in each set-up. They present a concurrent constraint planning methodology and a hybrid genetic algorithm (GA) and simulated annealing (SA) approach for set-up planning, and re-set-up planning in a dynamic workshop environment. The proposed approach and optimization methodology analyses the precedence relationships among features to generate a precedence relationship matrix (PRM). Based on the PRM and inquiry results from a dynamic workshop resource database, the hybrid GA and SA approach, which adopts the feature-based representation, optimizes the set-up plan using six cost indices. The PRM acts as the main constraints for the set-up planning optimization. Case studies show that the hybrid GA and SA approach is able to generate optimal results as well as carry out re-set-up planning on the occurrence of workshop resource changes.

Zhang et al [70] have studied a new kind of warehouse layout problem. Both horizontal and vertical travel costs need to be considered when making a layout. In the problem, unit travel costs are item-dependent and different items can be mixed in a cell. An IP model is proposed, which is shown to be NP- hard. An effective assignment method is presented and genetic algorithm heuristics developed. Extensive computational experiments are conducted to verify the effectiveness of the algorithms.

Rai et al [71] have proposed a solution for the decision-making process for machine-tool selection and operation allocation in a FMS which involves multiple conflicting objectives. Thus, a fuzzy goal-programming model can be effectively applied to the decision problem, with the objectives of minimizing the total cost of machining operation, material handling and set-up. The constraints pertaining to the capacity of machines, tool magazine and tool life are included in the model. A Genetic Algorithm (GA) based approach is adopted to optimize this fuzzy goal-programming model.

Dong Hyun Baek et al [72] have proposed a solution for optimizing dispatching policy in a networked, multi-machine system which is a formidable task for both field experts and operations researchers due to its stochastic and combinatorial nature. It gives an innovative variation of Co-evolutionary Genetic Algorithm (CGA) for acquiring the adaptive scheduling strategies in a complex multi-machine system. The task is to assign each machine an appropriate dispatching rule that is harmonious with the rules used in neighboring machines. An ordinary co-evolutionary algorithm would not be successful due to the high variability (i.e. noisy causality) of system performance and the ripple effects among neighboring populations. The computing time for large enough populations to avoid premature convergence would be prohibitive.

Moon et al [73] have studied the economic lot-scheduling problem (ELSP). Numerous heuristic algorithms have been developed since the problem is NP-hard. It provides a hybrid genetic algorithm based on the time-varying lot sizes approach in the ELSP literature.

Evelyn et al [74] have proposed a solution for the machine-part cell formation (MPCF) problem that addresses the issues surrounding the formation of part families based on the processing requirements of the components, and the identification of machine groups based on their ability to process specific part families.

Genetic algorithm has been applied by researchers to wide variety of problems as discussed above. The application of GA for arriving at a sequence of request for storage and retrieval by AS/RS machine is not researched. Hence an attempt has been made to use the power of GA for arriving at the optimal sequence.

Setting the levels for factors affecting evolution is a challenging task. An attempt has been made in this research to apply orthogonal array experiments by Genichi Taguchi[126] to arrive at the best sequence for retrieval/storage request by setting the levels for crossover, mutation operators and number of generations.

2.4 Cluster Formation

Clustering algorithms have been extensively used in group technology to group machines and parts into cells. The similarity between the parts having common operations is used to form clusters. Several similarity coefficients are available in literature to form clusters.

Carrie [75] identifies the need for a technique which can assess whether a functional or a group cell system of production is most appropriate in a specific case as well as develop the appropriate system. He describes the technique of numerical taxonomy and showed how it may be applied to both group technology and plant layout. A computer program for production flow analysis is presented. The use of numerical taxonomy in developing functional-type layout is also described.

King [76] reviews existing cluster analysis methods and a new approach using rank-order clustering algorithm is described which is particularly relevant to the machine-component group formation. A relaxation and regrouping procedure is developed whereby the basic rank order clustering method may be extended to the case where there are bottleneck machines.

Rajagopalan [77] had used fuzzy clusters and fuzzy cells in group technology. King et al [78] have developed a technique for block diagonalisation of zero – one matrices.

Chandrasekharan et al [79] present an extension of the well-known rank-order clustering algorithm for group technology problems. The ROC method is analyzed and its main drawbacks are identified. The method uses the ROC algorithm in conjunction with a block and slice method for obtaining a set of intersecting machine cells and non-intersecting part families. Then a hierarchical clustering method is applied based on a measure of association among pairs of machine cells. Clustering is terminated when all the surviving cells are non-intersecting or when a single group is formed. In the latter case, the number of cells is determined on the basis of a suitable decision criterion and the bottleneck machines are identified at the appropriate hierarchical level in the clustering process.

Chandrasekharan et al [80] describe the development of a non-heuristic algorithm for solving group technology problems. The problem is first formulated as a bi-partite graph, and then an expression for the upper limit to the number of groups is derived. Using this limit, a non-hierarchical clustering method is adopted for grouping components into families and machines into cells. After diagonally correlating the groups, an ideal-seed method is used to improve the initial grouping. A quantitative criterion called 'Grouping Efficiency' is then developed for comparing alternative solutions. The algorithm and the criterion are demonstrated through an example.

Chandrasekharan et al [81] further deal with the development of an algorithm for concurrent formation of part-families and machine-cells in group technology. The acronym ZODIAC stands for zero-one data: ideal seed algorithm for clustering. The present algorithm is an expanded and improved version of the earlier ideal seed method. The formation of part families and machine-cells has been treated as a problem of block diagonalization of the zero-one matrix. Different methods of choosing seeds have been developed and tested. A new concept called 'relative efficiency' has been developed and used as a stopping rule for the iterations. Block-diagonalization of the machine-component incidence matrix is the first step in the implementation of group technology. Even powerful algorithms will fail to achieve this if the matrix itself is not amenable to block-diagonalization.

Chandrasekharan et al (82) analyze the properties of the matrix and identifies the standard deviation of the pairwise similarities (Jaccard) of the vectors as the major factor that decides the groupability of the data set. Many data sets ranging from the perfectly groupable to the most ill structured ones are analyzed and presented. The groupability curves show the variation of the property against the relevant factors.

Suresh Kumar et al [83] study the grouping efficiency in a cellular production system. Block-diagonalization of binary matrices is a primary step in the design of cellular production systems. Grouping efficiency which is a weighted average of two measures that consider the voids in the diagonal blocks and exceptional elements in the off-diagonal blocks was the only criterion available to measure the goodness of block diagonal forms. They critically analyzed this function and bring out shortcomings, the most severe of them being low discriminating power. A simple and elegant function has been derived in its place. The new function called 'Grouping Efficacy' obviates all the defects of the earlier function while retaining the requisite properties. The mathematical properties of the function have been analyzed and the function values compared with those of grouping efficiency in the case of well-structured and ill-structured data sets.

Badarinarayana [84] has worked on Grouping of Machines and Cells using Cluster Analysis for Interval Level Data.

Mu-Chen Chen [85] proposed configuration of cellular manufacturing systems using association rule induction. A cell-formation approach based on association rule induction is developed to find the effective configurations for cellular manufacturing systems. To gain the benefits of flexibility and efficiency, the manufacturing system is decomposed into several manageable subsystems by categorizing similar parts into part families and machines into cells. A data-mining technique referred to as association rule induction is used herein to find the association rules among machines from the process database. The performance of the proposed approach is compared with several existing techniques. From the computational results, the proposed approach shows its ability to find quality solutions.

The application of cluster analysis has been successfully attempted in group formation of machine cells and part families by the researchers. The similarity between the operations and the common machines used for processing is the key element in cluster formation.

However in transporting material from the storage racks to loading / unloading the movement of AS/RS must be controlled to minimize the distance traveled. The identification of similarities between the request locations is the key element for the clustering. In this research this similarity between the request locations is used to form the clusters. The scheduling of machine within and between the clusters will minimize the distance traveled by the machine.

2.5 Simulation

Many researchers have used the technique of computer simulation to address the problem of dynamic vehicle routing. The main motivation is that using a simulation model provides a system-wide view of the effect of a local change in the AGV system.

McGinnis et al [86] address throughput improvement by retrieval sequencing in conventional unit load automated storage/Retrieval system when several retrieval requests are available and dual command cycles are performed. Taking first-come-first-served as the reference sequencing rule, the potential for improvement is identified. A “nearest-neighbor” sequencing rule is proposed as an alternative, an analytic model for its expected performance is developed, and Monte Carlo simulation is used for evaluation. In addition, a lower bound on dual command cycle times is developed, and the dynamic behavior of two heuristic sequencing rules is discussed.

Kay [87], Kay et al [88] have used the information from the cameras to monitor the work space to detect and track potential obstacles in the immediate vicinity of each AGV and over its intended path; track each AGV along its intended path to bound errors in the vehicle's dead-reckoning sensors; monitor the load aboard each AGV to detect positioning errors; and provide video images of the entire work space so that a human operator can monitor the status of operations throughout the facility. The status of the AGV system is available as input to high-Level transport control functions.

Sabuncuoglu et al [89] have investigated the performances of six machine-scheduling rules and six AGV scheduling rules against the mean flow-time criterion in FMS. Among the machine scheduling rules tested against the mean flow-time criteria, the SPT rule and the SPT * TOT rule appeared to be the best rules with any combination of AGV rules.

Sabuncuoglu et al [90] have further investigated the scheduling of jobs and AGVs in an FMS based on due-date criterion. They found the smallest modified operation due-date (MOD) rule to be the preferable machine priority rule with any AGV scheduling rule.

Kap et al [91] suggest a branch-and-bound procedure for designing flow paths of fixed-path material handling systems. The method may be applied to Automated Monorail Systems (AMS), Automated Guided Vehicle Systems (AGVS), flexible conveyor systems and other fixed-path material handling systems. The authors formulate an economic model which considers the construction cost of each path segment as well as the travel cost. A procedure is developed to determine the configuration of flow path and the direction of each flow path segment. A tight lower bound for the optimal objective function and an efficient search strategy are suggested.

Jeong et al [92] present a real time scheduling methodology which uses simulation and dispatching rules for flexible manufacturing systems. The authors develop a scheduling mechanism in which job dispatching rules vary dynamically based on information from discrete event simulation that is used for evaluating candidate dispatching rules.

Rajotia et al [93] suggested that the required number of AGVs necessary to perform a given level of material handling task in an FMS environment is determined using analytical and simulation modeling. The analytical method involves consideration of load handling time, empty travel time, and waiting and blocking time. Determination of empty vehicle travel is difficult due to the inherent randomness of an FMS. It entails formulation of a mixed integer programme with an objective of minimizing empty trips. The constraints are in the form of upper and lower bounds placed on the total number of empty trips starting from or ending at a load transfer station. The phenomena of vehicle waiting and blocking are also discussed. Simulation methodology is used to validate the initial estimates of fleet size. The proposed model, though under estimates the minimum AGV requirement, yet provides results which are close to the simulation results

Rajotia et al [94] studied a semi-dynamic time window constrained routing strategy in an AGV system. This study addresses the issue of vehicle route planning in an AGV system. The two salient approaches to route planning- static and dynamic are briefly discussed. Dijkstra`s algorithm is applied to find the least congested fastest routes for vehicles. A simulation study of a bidirectional flow path is then reported. The results show that the proposed routing strategy helps in reducing vehicle blocking time and improving the throughput potential of the system.

Rajotia et al [95] developed a heuristic methodology in their work for configuring a mixed (hybrid) uni/bidirectional flow path for an AGV material handling system. The heuristic has been applied to an illustrative FMS and various alternative flow path designs have been obtained. Simulation is then performed with the aim of comparing the productive potentials of the facility when it is operated on either unidirectional, or mixed uni/bidirectional, or all bidirectional flow path design alternatives. The decision related to location and capacity planning of vehicle buffering zones is also addressed.

Sabuncuoglu [96] studied the scheduling rules of FMS using a simulation approach. Several machine and AGV scheduling rules are tested against the mean flow time criterion. They compare the rules under various experimental conditions by using an FMS simulation model. Their objective is to measure sensitivity of the rules to changes in processing time distributions, various levels of breakdown rates, and types of AGV priority schemes.

Seifert et el [97] worked on the evaluation of AGV routing strategies using hierarchical simulation. They present a simulation model that can handle an arbitrary system layout as well as arbitrary numbers of AGVs and pedestrians causing congestion in the system. A case study involving a prototype AGV system operating under the control of a global vision system illustrates the advantages not only of this strategy, but also of global-vision-based control.

Gupta et al [98] suggested a solution which describes a dispatching approach for FMSs where all parts are stored in a central buffer. Machine failures and loading rules have also been shown to have less impact on the proposed dispatching algorithm than the traditional one.

Jim Lee et al [99] worked on dispatching rail-guided vehicles and scheduling jobs in a flexible manufacturing system. They develop and evaluate dispatching strategies of rail-guided vehicles (RGVs) in the load/unload area of a flexible manufacturing system with a bidirectional track. Their focus is on the load/unload area of the system, but the effective combination of RGV dispatching and scheduling rules to prioritize jobs in the buffer storage between the load/unload area and the machine centre is also explored. Five RGV dispatching rules are developed and evaluated along with the common scheduling rules using computer simulation. The scheduling rules may or may not significantly affect the system performance, depending on the characteristics of the job queue. The result on RGV dispatching reveals the need to efficiently dispatch the material handling vehicle despite its simple structure and straight routing.

Narasimhan et al [100] developed a solution for routing AGVs in the presence of interruptions. They analyze, via simulation, re-routing of AGVs that encounter interruptions. A route database is used to obtain quickly previously generated paths and a flexible re-routing strategy is used when an AGV is interrupted. A factorial-designed simulation experiment is conducted in a realistic setting, based on data collected at a large manufacturing facility. Recommendations are made on important practical considerations for routing AGVs in such an environment.

Eric Johnson [101] developed a model for empty vehicle traffic in AGVS design. Empty vehicle traffic plays a critical role in the operating performance of AGVs. They show how empty vehicle traffic strongly influences several important AGVS design problems, such as flow path design and vehicle requirements. They present analytical models to predict empty vehicle travel under two popular vehicle dispatching rules for systems facing stochastic trip demand. They show that using these models estimates of empty vehicle traffic in the AGVS design process can dramatically improve the resulting system performance. They also analyze shop-floor transfer patters and find that empty traffic has a larger impact on systems with discernible trends in job movement.

Byung et al [102] suggested a multi-attribute dispatching rule for AGV systems. A multi-attribute dispatching rule for dispatching of an AGV is developed and evaluated. A neural network approach is used to obtain dynamically adjusting attribute weights based on the current status of the manufacturing system. Simulation analysis of a job shop is used to compare the multi-attribute dispatching rule with dynamically adjusting attribute weights to the same dispatching rule with fixed attribute weights and to several single attribute rules. Results show that the multi-attribute dispatching rule with the ability to adapt attribute weights to job shop operational conditions provides a better balance among the performance measures used in the study.

Fuh-Hwa Liu et al [103] worked on the real-time deadlock-free control strategy for single multi-load AGV on a job shop manufacturing system. An unmanned automated job shop manufacturing system with a single multi-load AGV, which traverses around a single-loop guide path, is considered in this work. The proposed control strategy for a single multi-load vehicle uses global shop real-time information to achieve the objectives: avoid shop deadlocks caused by inappropriate job movement as well as satisfy the system transport requirement. The efficiency of the proposed vehicle control strategy and the other two expanded strategies under various parameter designs are verified by computer simulation.

Farling et al [104] describes the analysis of AGV configurations in FMSs. AGV systems complement the operation of FMS by providing integrated automated material handling that capitalizes on the system's flexibility. Their study uses the simulation methodology to compare the performance of three AGV configurations under a variety of experimental conditions. The results indicate that system size, load/unload time, and machine failure rate factors have significant impacts on the operation of the systems considered.

Kaspi et al [105] devised an optimal Flow Path Layout (FPL) design method as a handy tool for an AGV system planning stage. The problem is analyzed and formulated by linear mixed-integer programming. A procedure based on the branch-and-bound depth-first search technique is proposed to solve the FPL problem. Transportation model is used for calculating the required and optimal flow of empty vehicles

Maria Pia Fanti [106] formulated an event-based controller to avoid deadlock and collisions in zone-control AGVS. They formulate a zone-control scheme to face the problem in real time, based on the knowledge of the AGVS operative conditions.

Bharadwaj et al [107] designed and analyzed an optimal solution for material distribution policies in FMSs using a single AGV. They analyzed the requirements for an optimal schedule and then provide a mathematical framework for an efficient schedule of material delivery by an AGV. With this model, the optimal number of machine centers to be utilized will also be determined.

Simulation has been the most favorable tool for arriving at the solutions for the complex systems for which mathematical model is difficult to apply. The researchers have attempted to simulate the FMS system and have worked on AGV's extensively. However, the study of the simulation of the storage location has not been researched.

In this research work the ProModel software is used to develop a simulation modeling of the storage locations. The effect of grouping the requests into clusters is analyzed with different scenarios such as machine breakdown, different inter arrival distributions, number of machines, different scheduling rules. The average stay in the system and the average time spent in the moves are used as the performance measures.

2.6 Artificial Neural Networks applied to Scheduling.

Wang et al [108] have carried out performance evaluation of tandem and conventional AGV systems using generalized stochastic Petri nets.

Johnston et al [109] suggested a novel concept of continuous suitability functions defined over a continuous time domain to represent soft temporal relationships between activities. All constraints and preferences are automatically translated into the weights of an appropriately designed artificial neural network. Equipped with a novel stochastic neuron update rule, the resulting GDS-network effectively implements a LasVegas-type algorithm to generate good schedules with an unparalleled efficiency

Shiva Kumar Vaithyanathan et al [110] used neural networks for the modeling and solution of problems of optimization, and particularly problems of combinatorics, which continues to grow at a substantial pace. The approach that has been developed and evaluated by them is designed specifically for a certain type of resource constrained scheduling problem- where such problems are subjected to sudden, dynamic changes.

Kate Smith et al [111] proposed a hybrid neural approach to combinatorial optimization. Both the Hopfield neural network and Kohonen's principles of self-organization have been used to solve difficult optimization problems, with varying degrees of success. It is demonstrated that many of the traditional problems associated with each of these approaches can be resolved when they are combined into a hybrid model. After presenting the broad class of 0-1 optimization problems for which this hybrid neural network is suited, details of the algorithm and convergence properties are presented. This hybrid neural approach is applied to solve the sequencing problem in a car manufacturing industry.

Jain et al [112] proposed job- shop scheduling using neural networks. Complete enumeration of all sequences to establish global optimality is not feasible.

Min et al [113] works include application of ANN to multi-objective FMS scheduling. A competitive neural network is applied. A unique feature of the FMS scheduler is that the competitive neural network generates the next decision rules based on the current decision rules, system status and performance measures. A commercial FMS is simulated to prove the effectiveness of the FMS scheduler. The result shows that the FMS scheduler can successfully satisfy multiple objectives.

Chen et al [114] have worked on an action strategy generation for an online scheduling and control system in batch process with neural networks.

Jih-Gau Juang et al [115] worked to devise an intelligent automatic landing system using time delay controller and linearised inverse aircraft model to improve the performance of conventional automatic landing systems. Simulation results show that the controller can act as an experienced pilot and guide the aircraft to a safe landing in severe wind disturbance environments without using the game scheduling technique.

Cakar et al [116] proposed the use of artificial neural networks for design of manufacturing systems and selection of priority rules. Four different priority rules are used: EDD, SPT, CR and FCFS. As a result, four different design alternatives are obtained from trained artificial neural networks. Performance measures of a manufacturing system are given to the artificial neural networks which then gives a design alternative. The design alternatives are evaluated in terms of performance measures and then the best design alternative is selected from four different alternatives.

Monfared et al [117] worked on multi level intelligent scheduling employing the techniques of artificial neural networks. At the first level, a conventional scheduling and control system is considered, and then at the second level, a new fuzzy logic mechanism is developed to enable the conventional system to improve and perceive the changes of system parameters adaptively. A new perturbation mechanism is embedded in the third level to implement online optimization for coping with the more complex structural changes of system dynamics. The final level is composed of ANN's that can learn from experiences provided by the perturbation mechanism. The approach is designed to improve system intelligence gradually to cope with various forms of systems dynamics.

The artificial neural networks is one of the contemporary area which is promising for application in AS/RS transportation.

2.7 Fuzzy, Simulated Annealing, Petri net methods

Yu et al have [118] proposed a fuzzy inference-based scheduling decision for FMS with multiple objectives. The objectives have different and dynamic preference levels. It is inferred that the changes in the production environment may be sensed by environmental variables. The detected changes are input in a fuzzy inference mechanism, which outputs the current preference levels of al objectives. A multiple criteria scheduling decision is then made, using the partitioned combination of the preference levels. An example of application is presented. Simulation results show very good performance for the proposed system.

Yun-Bae Lee et al [119] have developed a new algorithm for an Autonomous Guided Vehicle (AGV) with curved-path and velocity control by applying fuzzy logic. The curved-path and velocity control of an AGV has two significant problems: (1) rotation-angle and deceleration when the AGV follows curved-path; (2) acceleration when the AGV leaves the curved path. In order to solve these problems, they present an algorithm that enables the current AGV speed to reduce properly when it begins the curved path, and to then rapidly recover the original speed. They verify the validity of the algorithm through simulation and show that the AGV reaches its destination without changing speed rapidly on the curved path.

Hong Tau Lee et al [120] have introduced the linguistic values of fuzzy set theory to evaluate each criterion and to represent its relative weight for the schedules of a multi criteria environment. The basic operations for the triangular fuzzy numbers and the calculations for obtaining the ranking of each aggregated linguistic evaluation for the quality of the schedule are explained clearly. According to the complex property of scheduling problems, a heuristic approach of the tabu search are also interpreted here.

Mukhopadhyay et al [121] have considered the problem of FMS machine loading is considered with the objective of minimizing the system imbalance using a simulated annealing (SA) approach. New job sequences are generated with a proposed perturbation scheme named the 'Modified Insertion Scheme' (MIS). These sequences are used in the proposed simulated annealing algorithm to arrive at a near global optimum solution. A new approach for temperature variation in the SA algorithms also suggested in which temperature is assumed to be parabolic. The SA algorithm using the proposed MIS and the assumed temperature variation proved to be giving substantial improvement in system imbalance as against conventional sequences.

Cho [122] has worked on Petri net models for message manipulation and event monitoring in an FMS cell. Suhua [123] has used coloured timed Petri nets for synthesizing AGVS.

Raju et al [124] have conducted an extended-timed Petri net based simulation study of an FMS with one of the aims as determination of the holding capacity of battery charging stations and vehicle parking lots.

Yim et al [125] have used Petri net-based simulation to investigate the effect of different push and pull AGV dispatching rules in FMS. In the push-based AGV dispatching procedure, an idle vehicle first selects a part to move and then determines the destination of the selected part. On the other hand, the pull-based AGV dispatching procedure first selects a workstation (destination) that can receive parts according to the process selection rule specified. No significant difference was found among the rules proposed.

Fuzzy, Simulated annealing, Petri net methods are applied extensively in FMS area. In the area of AS/RS transportation much work can be carried out.

2.7Approach to Research

In view of the deficiencies and research gaps identified in the literature survey, we arrive at a method for scheduling of machines in storage area of FMS layout. The objectives of the work are:

- To group the requests for retrieving and storage of materials using cluster analysis approach.

- To develop an optimal sequence for machine movement with in clusters, using Genetic Algorithm.
- To establish levels for factors affecting evolution using Orthogonal Array technique.
- To develop a simulation model to validate the findings of clustering and GA and conduct a pre and post scenario of clustering.

To sum up, this work presents a powerful method for providing solution in toto to scheduling of AS/RS machine in storage area of FMS environment.

2.9 Summary

We have discussed history and application of scheduling and FMS scheduling using various approaches. The deficiencies in the current methods and need for doing research is established and also the methodology and direction for research have been broadly spelt out.

Scheduling of Automated Storage and Retrieval machine in FMS using cluster analysis approach

K.S.Badarinarayan “Flexible manufacturing system scheduling” Thesis.
Department of Mechanical Engineering, NIT Calicut, University of Calicut,
2007

Chapter - 3

Scheduling of Automated Storage and Retrieval machine in FMS using cluster analysis approach

Chapter – 3

3.0 Introduction

In today's competitive manufacturing environment, Lean six sigma, Just in time, Supply chain management and other host of techniques are employed to minimize waste and the inventory of material is one of the contributing components of waste. Reduced inventories have led to smaller storage systems, which in turn, have created the need for quick access to the material held in storage. Hence, Automated Storage and Retrieval System (AS/RS) machine used in warehousing applications must be managed to provide quick response to service requests for efficient system operation.

In the storage area, the materials are stored in the containers and are placed in racks. When a request for the material is generated, the AS/RS machine retrieves the material and transfer it to the unloading station. The containers are stored back in the location by the machine. The current retrieval points turns out to be the future storage points, the consideration of this dual command cycle in scheduling is a challenge for researchers. To and fro movements of the machine from loading/unloading point to container locations increases the distance traveled.

This work has considered the AS/RS scheduling problem in its totality. In a large system when storage / retrieval requests appear at random. The AS/RS has to move in a given order without considering the total distance traveled. This, apart from reducing the productivity will keep on increasing the backlog as time passes. Therefore it is necessary to work out a near optimal way in which AS/RS can executive the storage / retrieval requests. This work establishes that if the few requests that appear in a short period of time are clustered based on the similarity and request handled based on the cluster membership. The total distance traveled by AS/RS can be considerably reduced. The result presented at the end of the chapter shows that the average savings in an example problem works out to be around 46%.

In the literature survey, it is observed that the researchers have concentrated on AGV movements and they have proposed problem specific solutions. The AS/RS machines movements in storage area has been dealt with mathematical formulations. The similarity in request for storage retrieval location has not been looked into. The concept of cluster analysis was extensively used in group technology area cited in section 2.4. The closeness is measured by the index distance which is the basis for the cluster formation. Lesser the distance more is the similarity. In group technology the formation of part families and machine cells have been applied extensively in the industries as a lean management initiative. In storage locations, the identification of similarity has not been explored by the researchers. Hence in this work we have developed a heuristic using cluster analysis approach for grouping retrieval/storage requests into clusters.

Using FIFO logic, the distance traveled by the machine will be same either with or without clustering. After identification of clusters the visit of machine to different locations has to be rescheduled. Hence a routing logic is proposed for scheduling the machine within and between clusters.

The formation of clusters is not the end of the problem. The grouping has to be evaluated by a measure of performance such as Efficiency, Efficacy developed to compare the performance of the grouping for interval data. Perfect and imperfect clusters are analyzed using a wide set of problems. The results indicate that the performance of the machine will be better with the clustering of requests, and the proposed routing logic.

3.1 Problem Area

The research carried out in AS/RS machine handling have varied and wider objectives. Mathematical approaches have been extensively used to arrive at solutions to the movement of the machine. Dual command cycle has been addressed but the approach is not robust.

The movement of the machine in storage area takes place without any value addition under FIFO queue discipline. Identification of similarity between the locations of storage/retrieval for requests has not been considered and application of cluster analysis techniques is not researched in AS/RS. By identifying the similarities between the request locations, they can be grouped in to clusters. When the movement of the machine is scheduled within the clusters, the distance moved by the AS/RS machine can be minimized. The crux of the problem is identification of the clusters and logic for movement in the cluster. The study focuses on an approach using cluster analysis for group formation and scheduling of machine to minimize frequency distance traveled.

3.2 Cluster Formation

The objective of cluster analysis is "To sort the observations into groups such that the degree of natural association is high among the members of the same group and low among members of different groups." Cluster analysis is not a term for a single integrated technique with well defined rules of utilization. It is an umbrella term for a loose collection of heuristic procedures and diverse methods of applied statistics. The actual search for clusters in real data involves a series of iterative decisions as to which elements of cluster analysis repertory should be utilized. The clustering process involves, choice of data units, variables, what to cluster, homogenizing variables, similarity measures, clustering criteria, algorithms and implementation and number of clusters have to be carried out before we proceed with cluster analysis. In hierarchical clustering a similarity matrix describing the strength of all pairwise relationships among the entities in the data set is constructed. Two most similar entities are clustered. The relationship with other entities with the merged cluster is updated. This process is continued until all the clusters are merged. The major clustering methods are: Single linkage, complete linkage, Average linkage clustering, Centriod method and Error sum of square or variable methods. We reject hierarchical clustering because of its basic defect. Once a pair of elements are clustered it faces the rest of the data with a "fait accompli" and never separates even if an alternate formation gives a better cluster structure. Non hierarchical clustering is more open to better chances of getting meaningful clusters.

Macquen's K-means method is a general algorithm for nonhierarchical clustering of interval and ratio level data. The drawback of choosing the first K vectors of machine – component data matrix has been pointed out in ZODIAC, while handling zero-one data. We have not considered K-means method in our study. With the help of K-seeds a preliminary grouping of component families and machine cells is obtained. Since the K-seeds chosen were arbitrary the clusters formed will not be natural. So in order to improve the situation one vector from each cluster is picked. They are called representative seeds. We have not considered representative seeds in our study.

Before clustering the data units it is necessary to specify the number of seeds or number of clusters that should emerge as a result of clustering. This problem has been eliminated by use of Natural seeds, by which data set would yield as many seeds as there are Natural clusters in system.

3.2.1 Ideal Seeds

Before defining Ideal seeds, it is necessary to conceive a situation called perfect grouping a technique evolved by the author of ZODIAC (Chandrasekharan). The perfect group is one in which all the elements of the diagonal sub matrices are positive numbers and those of the off diagonal sub matrices are zero. We superimpose a 'perfectly grouped' matrix with the same group sizes on the diagonalised matrix. Centroids of each diagonal sub matrix of the diagonalised matrix are then computed.

The Ideal seed representing the i^{th} group.

$$\bar{S}_i = \left|0,0,0.......\left\{\text{centroid of } i^{th}\text{submatrix }\right\}0,0,.....0\right|$$

i^{th} block contains centroid of the data units and all other remaining elements of S_i are zero.

After generating Ideal seeds for column vectors clustering is done using them as seed points. During clustering the centroid of the gaining cluster is updated. During this operation clusters may collapse eliminating unnatural formations of the earlier stage. After rearranging the column vectors resulting matrix is used for generating Ideal seeds for row vectors and the process is repeated. If further collapse takes place the iterations should be repeated until the number clusters in rows and columns are the same. A repetitive application of ideal seeding may be necessary before obtaining the best possible block diagonal form.

3.2.2 Natural Seeds

Natural cluster seeding has the ability to pick up seeds from prospectively different clusters even though the number and identification of cluster are not known a-priori. Several procedures for selection of seeds for clustering are employed.

Methods such as initial partitioning of data and various kinds of seeds result in a reasonable identification of cluster. "Natural Seeding" was a technique evolved by the author of ZODIAC [82] to elicit the real cluster structure contained in the data. To be consistent with the basic definition of clusters it is necessary to locate seeds from each individual cluster so that they form nuclei for the formation of clusters. If the number of clusters is decided a-priori, it might result either in the rejection of a valid formation or in the merger of distinct clusters. To avoid this, a double- blind method of choice is employed using the statistical properties of that data, so that

(i) Each seed is from a distinct cluster and

(ii) The number of clusters emerges as a result of that choice rather than as a-priori decision.

Such clusters are obviously "natural formations" that exist within the data.

The selection of the natural seeds in zero-one data is easier because all the data units are vertices of an n-dimensional hyper cube or simplex. But picking natural seeds is not an easy task in interval data. It is obvious that two pairs of points belonging to the same cluster will be closer to each other (in terms of the distance function defined) than a pair belonging to two different clusters.

If there are m vectors to be merged then there are [m (m-1)/2] inter point distances. It is possible to define a threshold value such that the inter point distance between points in the same cluster would fall below the threshold value and those in different clusters would fall above it. The threshold value is expected to be a function of the average and standard deviation of the inter point distance.

ie. $X_t = \overline{X} + C * \sigma$

Where X_t = threshold value, $\overline{X}$ = average of inter point distances , C = constant and σ = standard deviation.

The threshold value is adjusted such that the number of seeds in both vector spaces (n-dimensional and m-dimensional) is the same. The r^{th} vector qualifies as the i^{th} seed point ($r >= i$) if its distance from all the $(i - 1)$ seed points (already chosen) fall above the threshold value. Natural seeding proved to be efficient in handling zero-one data, but while handling interval level data ideal seeding is also employed along with natural seeding to improve the cluster formation.

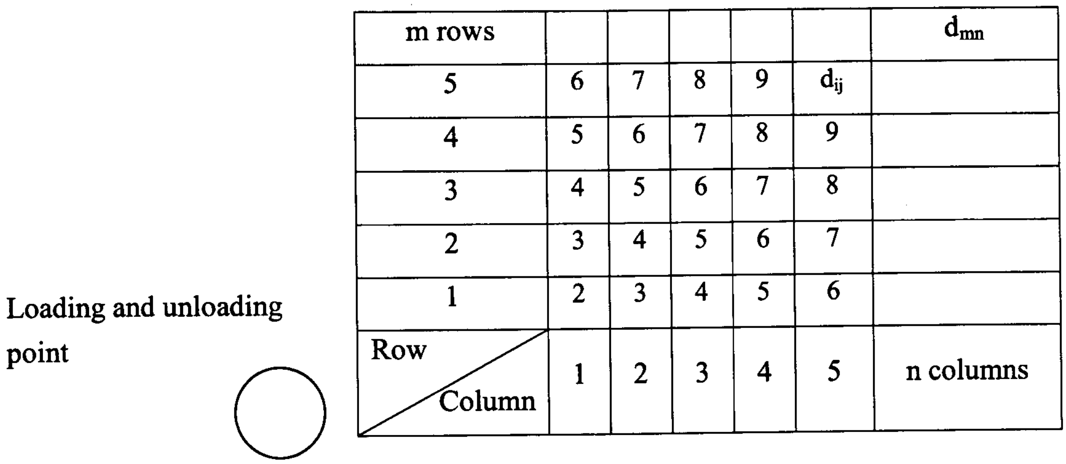
The output of clustering of rows and columns using natural seeds and ideal seeds is shown in Annexure 3.1

3.3 Assumptions:

The following assumptions are made while carrying out the work:

- The storage rack is split into m rows and n columns which houses containers, a schematic diagram is shown in Figure 3.1 and photo in Figure 3.1a.
- The parts are stored in containers placed in the storage racks.
- All containers are of unit size, the distances between adjacent containers are assumed to be unity.
- The AS/RS machine makes tchebychev travel. d_{ij} is the tchebychev distance between the unloading /loading point to the ij^th^ location.

Figure 3.1 – Storage Rack



m rows						d_{mn}
5	6	7	8	9	d_{ij}	
4	5	6	7	8	9	
3	4	5	6	7	8	
2	3	4	5	6	7	
1	2	3	4	5	6	
Row / Column	1	2	3	4	5	n columns

Figure 3.1a – Storage Rack

3.4 Frequency distance matrix

For the purpose of research we have considered a matrix of 25 rows x 25 columns and the frequency of requests made for material from different locations is recorded. The frequency of visits for meeting the request coming from 1st row and 4th column for retrieval of material is 25, A sample frequency matrix is shown in Figure-3.2.

The distance matrix contains the information about the distance to be traveled from the location to loading, unloading point. For meeting the request coming from 1st row and 4th column a distance of 5 units (considering unit distance), has to be traveled by the machine from loading / unloading point to location. The distance matrix for 25 x 25 matrix is shown in figure 3.3.

The frequency for retrieval of material is 25 and the distance to be traveled is 5 units, hence the frequency distance traveled will be 125 units. The frequency matrix is the input to the clustering algorithm.

Figure 3.2 – Frequency matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1				25					26		27														
2	12		7			9	11	13					3						5						
3																				54		55			50
4	13		8			10	12	14					4						6						
5	15		10			12	14	16					6						8						
6				26					27		28														
7										33						24							27		
8		32										10					35								
9															31			47						43	
10										35						26							29		
11				27					28		29														
12		30										20					25								
13				24					25		26														
14					30									34							15				
15				23					24		25														
16					30									35							16				
17															30			46						42	
18	14		9			11	13	15					5						7						
19															32			48						44	
20		31										30					30								
21																				52		53			48
22				28					29		30														
23					40									36							17				
24																				53		54			49
25										34						25							28		

Once the matrix is formed the clusters have to identified. The formation of the clusters takes place only when there is a similarity between the pair of requests.

The data set can be considered as two arrays of vectors row vectors and column vector in an n dimensional and m dimensional space respectively. The similarity between any two rows or columns is measured by the Euclidean distance. Lesser the distance, more the similarity. The distance between each row and the natural seeds formed are computed. Applying the algorithm cited in section 3.6, rows are grouped together as per their similarity and the rows of the original matrix are interchanged as per the cluster membership. The same procedure is applied to columns also and columns are rearranged as per the cluster membership. The resultant matrix after diagonalisation showing the cluster formation for the sample problem is as shown in Figure 3.4. After the cluster formation the requests in each cluster are identified by its unique cluster number. In the present example there are 7 natural clusters. The application of the algorithm may result in formation of perfect and imperfect clusters. It may be noted that the cluster identification could have been done with zero one data just as well. As the work requires the interval level information, we proceed with interval level data from the beginning.

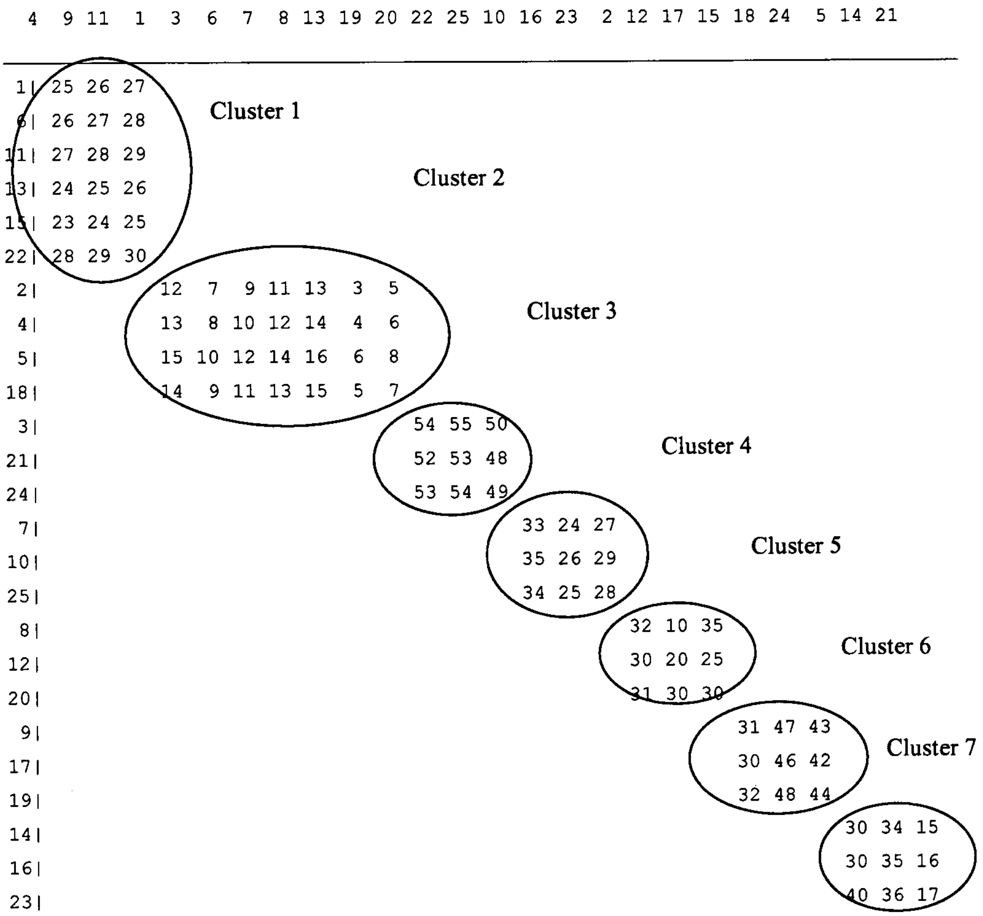
Figure 3.3 Distance matrix

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Row/Column

○ Loading / unloading point

Figure 3.4 - Cluster formation of the frequency matrix



	4	9	11	1	3	6	7	8	13	19	20	22	25	10	16	23	2	12	17	15	18	24	5	14	21
1	25	26	27																						
6	26	27	28																						
11	27	28	29																						
13	24	25	26																						
15	23	24	25																						
22	28	29	30																						
2				12	7	9	11	13	3	5															
4				13	8	10	12	14	4	6															
5				15	10	12	14	16	6	8															
18				14	9	11	13	15	5	7															
3											54	55	50												
21											52	53	48												
24											53	54	49												
7														33	24	27									
10														35	26	29									
25														34	25	28									
8																	32	10	35						
12																	30	20	25						
20																	31	30	30						
9																				31	47	43			
17																				30	46	42			
19																				32	48	44			
14																							30	34	15
16																							30	35	16
23																							40	36	17

3.5 Routing Logic

Before the cluster formation, in the First Come First Serve policy, for retrieval of the parts the machine has to travel from unloading / loading point to location to pick the container and travel back to loading / unloading point. For storing back the container the machine travels from loading / unloading point to the location, deposits the container and comes back to the original loading / unloading position. Thus four movements of machine are required for each request. For example, for retrieving and storing the container from a location 1st row and 4th column, frequency distance traveled will be 125 units and as four movements are required, it will be 125*4 =500 units of distance to be traveled by the machine.

In order to meet all requests the total frequency distance will be =

$$4\times\sum_{i=1}^{m}\sum_{j=1}^{n}A\times d_{ij}\times f_{ij}$$

Where d_{ij} = distance from loading /unloading point to i^{th} row and j^{th} column position, and

$$\left.\begin{array}{l}A=1\\A=0\end{array}\right\}\begin{array}{l}\text{if request is there}\\\text{if there is no request}\end{array}$$

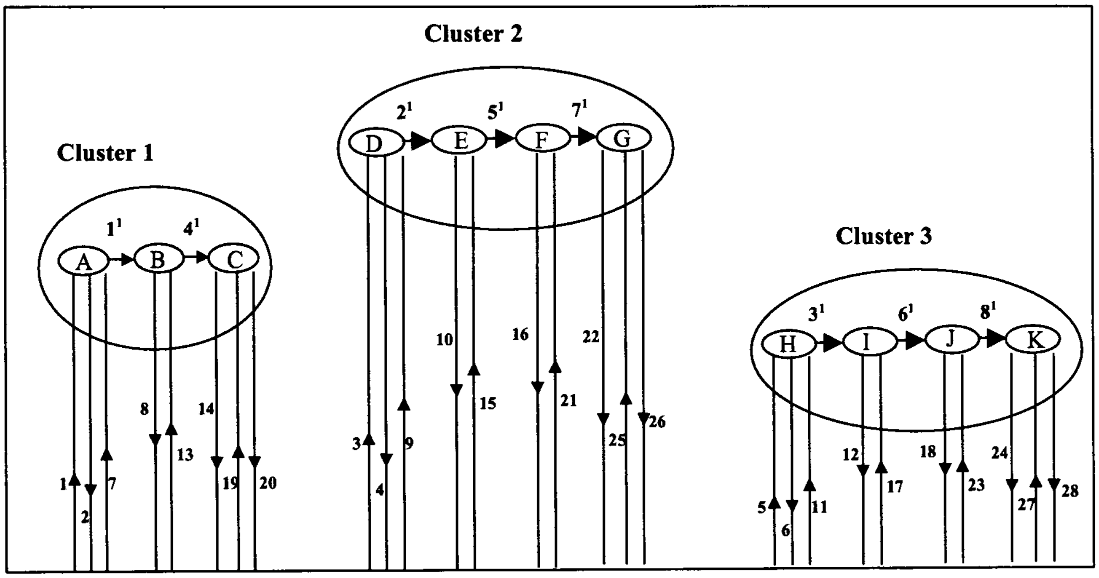
m = number of rows and n = rows of columns.

f_{ij}=frequency of request for material stored in ij^{th} container.

After applying the algorithm the clusters are formed, but it is observed that there will not be any savings in the distance traveled, because the advantage of clustering is not utilized. Hence a routing logic is proposed for the movement of the AS/RS machine in the clusters. In the proposed method while going for retrieval of container in a cluster, the AS/RS machine takes the empty container of previous request of that cluster and stores that container back into that cluster. There is also inter and intra cluster machine movements. This value added machine movement will reduce the movement of the machine from storage location to loading/unloading area. Using this logic a sequence for retrieval of container is developed for scheduling the machine.

To understand the logic, let us consider three clusters as shown in figure 3.5, cluster 1, 2, 3 with 3, 4, 4 requests respectively. Initially machine has to travel three times for first request 'A' from loading/unloading point to location. For the next request 'B' in the cluster it is sufficient for the machine to make only two movements. For the last request 'C' machine has to travel three times from loading and unloading point to last request point. Similar movements are required for meeting the requests from other clusters. The sequence 1-2-3- ...... 28 is the route for machine.1'-2'...8' are the inter container movements.

Figure 3.5 - Routing Logic



The machine takes the empty container of 'A' request while going for retrieval of 'B' request and the machine travels inside cluster to retrieve 'B' as indicated by 1^1 movement, inter location movements made by the machine with in each cluster, will be one less than the number of requests in the cluster. When there are C clusters and N requests, there will be N-C inter location movements within clusters.

The movements made by the machine and the distance traveled in a generalized form will be equal to

$$3 \times \sum_{k=1}^{C} \sum_{p=1}^{2} s_{kp} \times f_{kp} + 2 \sum_{k=1}^{C} \sum_{p=3}^{O_k} s_{kp} \times f_{kp} + (N - C) \times \text{unit distance}$$

Where

C = number of clusters, N=total no of requests. O_k =number of requests in k^{th} cluster.

S_{kp} – is the distance traveled by the machine from the loading and unloading station to the k^{th} cluster and p^{th} request.

3.6 Algorithm

The following algorithm is applied to form clusters and sequence the requests

1. Form the frequency matrix of request for storage and retrieval
2. Generate natural seeds for rows.
3. Cluster rows using Euclidean distance as similarity measure.
4. Rearrange rows as per the sequence obtained above.
5. Generate natural seeds for columns.
6. Cluster columns using Euclidean distance as similarity measure.
7. Rearrange columns as per the sequence obtained above.
8. If the number of clusters is same for row and column go to step 10
9. Adjust the value of Constant and go to step 1.
10. Generate ideal seeds using the diagonalized matrix for rows.
11. Repeat steps 3 and 4 and cluster the rows.
12. Generate ideal seeds using the diagonalized matrix for columns.
13. Repeat steps 6 and 7 and cluster the columns.
14. Repeat the above steps until the grouping take place, and performance measure is maximum.
15. Sequence the movement of the machine in each cluster as per logic.
16. Determine the distance moved before and after and compute efficiency, efficacy, and savings.

A program in C is written to execute the algorithm given above. Several data sets are fed and the results obtained are consolidated in table 3.1& 3.2.The details regarding the input and output matrix and distance traveled, not traveled inside and outside the clusters are given in Annexure 3.3 for different sets of data.

Table 3.1

Data set	Number of requests	Number of clusters	TOT_D_MAT	DTIC	DNTIC	DTOC	DNTOC	Distance After	Distance Before	% Savings
1	92	7	64398	58549	162	5849	13819	150316	257592	41.6
2	209	3	141698	131333	529	10365	10410	306333	566792	46
3	91	7	64829	64829	0	0	14055	139896	259316	46.1
4	149	4	92561	88083	509	4478	12085	199254	370244	46.2
5	111	6	57724	57215	0	509	13495	122716	230896	46.9
6	105	6	64178	63578	239	600	13440	135262	256712	47.3
7	109	6	69328	69328	0	0	13541	145153	277312	47.7
8	128	5	85127	82919	233	2208	12650	178115	340508	47.7
9	115	6	64047	64047	0	0	13460	133420	256188	47.9
10	133	5	90521	90521	0	0	12762	184972	362084	48.9
11	162	4	101489	101489	0	0	12291	207226	405956	49
12	213	3	148712	148712	0	0	10836	299510	594848	49.6

3.7 Performance Measure

To validate the logic proposed, it is essential to compare the grouping performance and link it with productivity of material handling machine. Chandrashekaran et al [82] have defined a grouping efficiency for zero-one incidence matrix. Grouping efficiency is defined as the weighted average of two functions. Suresh Kumar et al [83] have introduced the concept of grouping efficacy that avoids many of the deficiencies of the grouping efficiency. However all these indices are formulated by considering zero-one data, and the interval data is not taken into consideration. In reality distance traveled, time spent at the workstation, frequency of visits is to be considered while grouping the requests into cluster. The present work attempts at developing a measure for grouping of requests i.e for interval level data.

3.7.1 Terminology:

TOT_D_MAT = Total Frequency Distance traveled inside and outside the clusters
DTIC = Frequency Distance traveled inside the clusters
DNTIC = Distance not traveled inside the clusters
DTOC = Frequency Distance traveled outside the clusters
DNTOC = Distance not traveled outside the clusters
C = Number of clusters
η = Grouping efficiency
τ = Grouping efficacy

3.7.2 Grouping Efficiency, Efficacy:

Grouping efficiency of Chandrashekaran for binary data is given by

$$\eta = q * \eta_1 + (1 - q) * \eta_2$$

$$\eta_1 = \frac{\text{number of ones in the diagonal blocks}}{\text{total number of elements in the diagonal blocks}}$$

$$\eta_2 = \frac{\text{number of zero's in the off diagonal blocks}}{\text{total number of elemets in the off diagonal blocks}}$$

$$\textit{and} \qquad 0 \le q \le 1$$

it is modified to derive an efficiency function for interval level data.

$$\eta_1 = \frac{DTIC}{[DTIC + DNTIC]}$$

$$\eta_2 = \frac{DNTOC}{[DTOC + DNTOC]}$$

$$and \qquad 0 \le q \le 1$$

$$\eta = q * \eta_1 + (1 - q) * \eta_2$$

The function has properties of non negativity and zero to one range. The Figure 3.6 and 3.7 show the effect of distance traveled inside and outside the cluster on efficiency. The corresponding data is shown in Annexure – 3.2

Table 3.2

Data set	Number of requests	η	τ
1	92	0.8499	0.9068
2	209	0.7485	0.9234
3	91	1	1
4	149	0.8619	0.9464
5	111	0.9818	0.9911
6	105	0.9767	0.9869
7	109	1	1
8	128	0.9242	0.9714
9	115	1	1
10	133	1	1
11	162	1	1
12	213	1	1

Figure 3.6 – Effect of distance traveled inside and outside clusters on efficiency

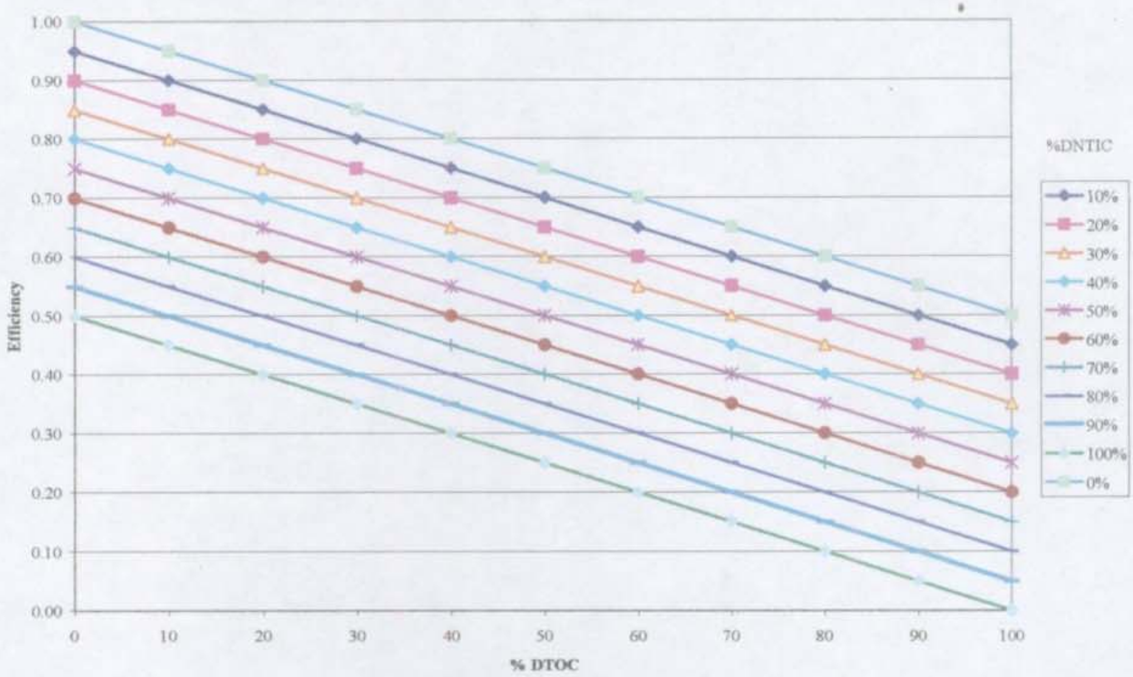
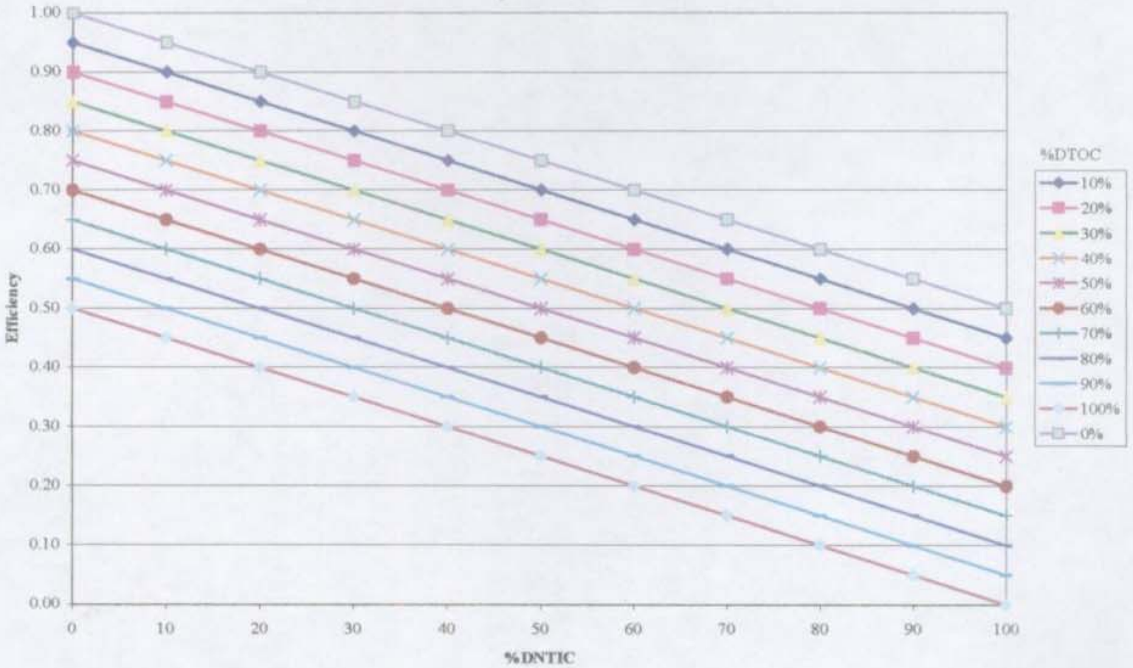


Figure 3.7 – Effect of distance traveled inside and outside clusters on efficiency



Suresh Kumar has introduced the concept of grouping efficacy that avoids many of the deficiencies of grouping efficiency. Grouping efficacy is defined as

Efficacy $\tau = \frac{[1-\psi]}{[1+\phi]}$

$$where \quad \psi = \frac{\text{number of exceptional elemets}}{\text{total number of operations}}$$

$$\phi = \frac{\text{number of voids in the diagonal blocks}}{\text{total number of operations}}$$

it is modified to derive an efficacy function for interval level data.

$$\tau = \frac{[1-\psi]}{[1+\phi]}$$

$$where \quad \psi = \frac{\text{DTOC}}{TOT\_D\_MAT}$$

$$\phi = \frac{\text{DNTIC}}{\text{TOT\_D\_MAT}}$$

$$0 \leq \phi \leq 1, \ 0 \leq \psi \leq 1, \ 0 \leq \tau \leq 1$$

The function has properties of non negativity and zero to one range.

τ= 0 implies that ψ = 1 thus zero efficacy is that point when all the DTIC is zero. τ=1 implies that ψ=0, ϕ=0. This condition corresponding to perfect grouping described in ZODIAC.

As the efficacy function is not symmetric with reference to ψ and ϕ. The influence of exceptions and voids are not identical. It is clearly shown in figure 3.8 and 3.9, which show the effect of distance traveled inside and outside the cluster on efficacy. The corresponding data are shown in annexure 3.2.

Figure 3.8 – Effect of distance traveled inside and outside clusters on efficacy

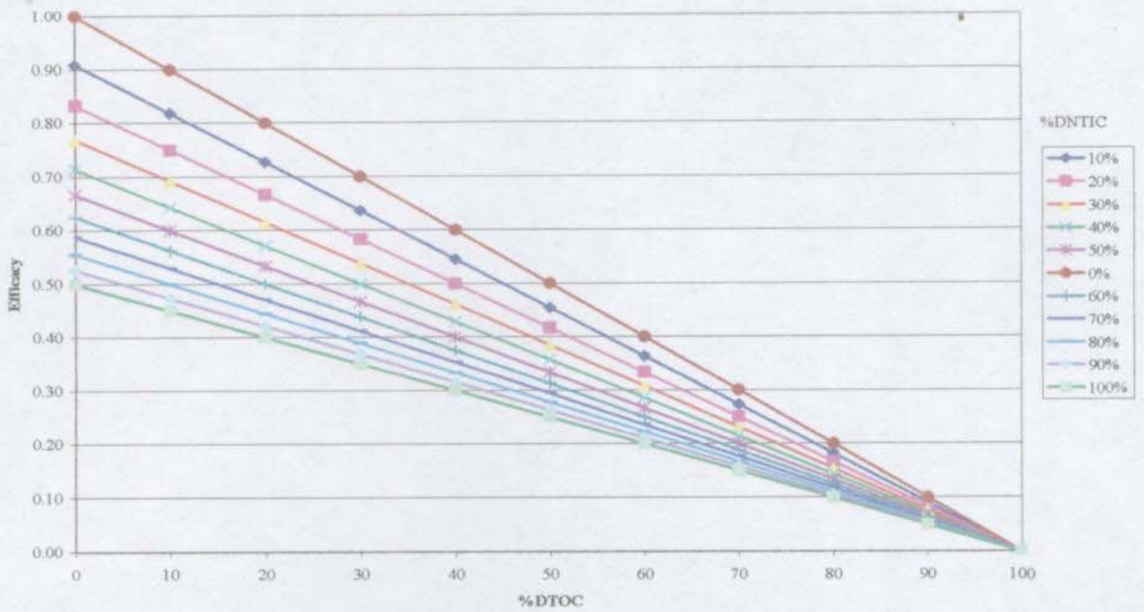
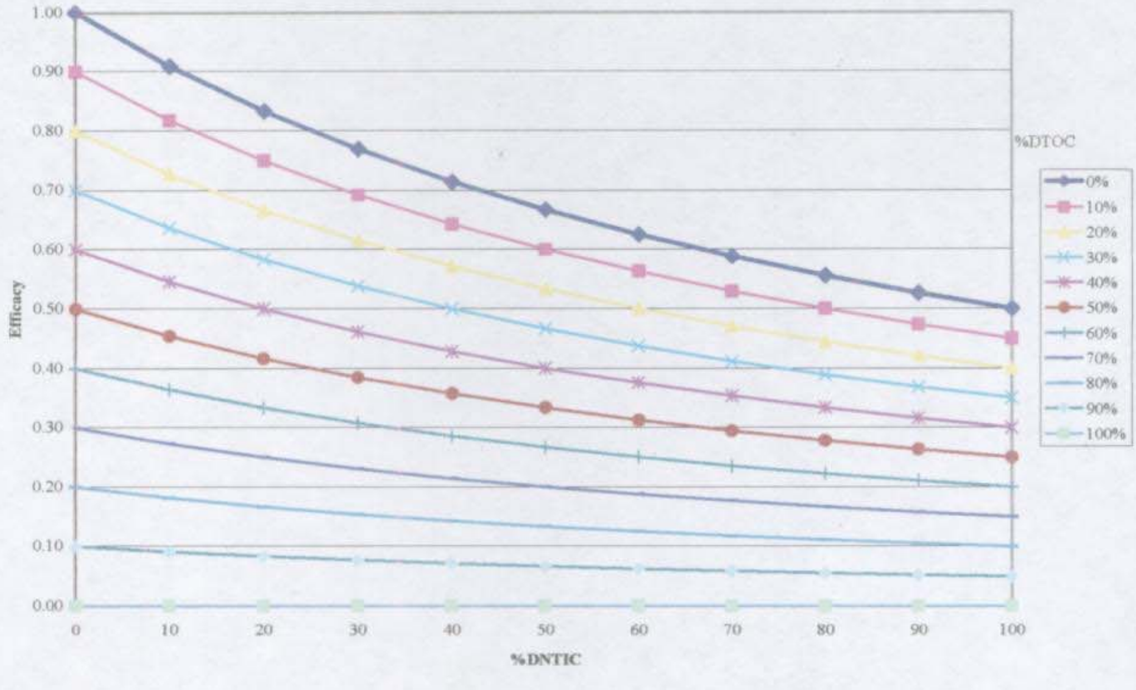


Figure 3.9 – Effect of distance traveled inside and outside clusters on efficacy

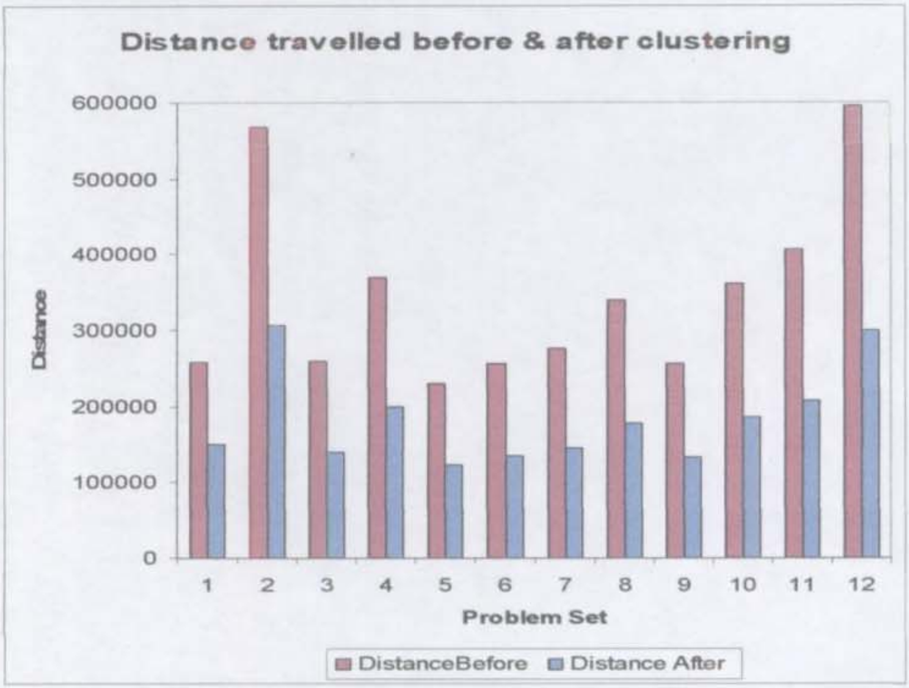


3.8 Savings and Conclusion

The work considers the scheduling problem, involved in moving an AS/RS in a system with many storage and retrieval positions. As a queue discipline FIFO or any other physical criterion will lead to an enormous distance traveled by the AS/RS. It was felt that the short term scheduling could be achieved better by employing a suitable algorithm. It was perceived that grouping the requests together into clusters and dealing with clusters separately could reduce the total distance traveled. This hypothesis was justified by a considerable reduction in the distance traveled.

The graph of frequency distance traveled before and after for different data sets are shown in Figure 3.10.

Figure 3.10 – Distance traveled before and after clustering

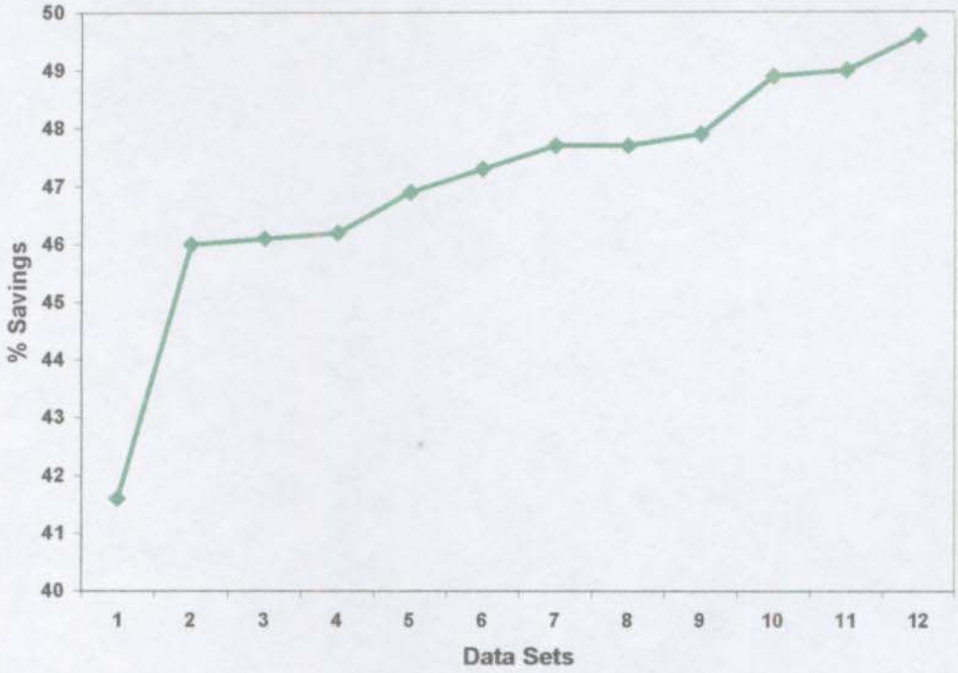


As per the proposed routing logic the requests are arranged in a sequence in clusters. The distances moved before and after cluster formation are computed. The input and output data of the different data sets considered in the work are presented in annexure 3.3

The savings are calculated by the following formula and results are shown in Figure 3.11.

$$\%\text{Distance\_savings} = \frac{\text{Distance\_before} - \text{Distance\_after}}{\text{Distance\_before}}$$

Figure 3.11 – Percentage savings for different data sets



A performance measure for handling interval level data is developed. It is not necessary that one will be getting always Perfect clusters; there will be formation of imperfect clusters also. The Figure 3.6 to 3.9 indicate the effect of distance traveled outside cluster and distance not traveled inside cluster on efficiency and efficacy.

A common data set is considered for analysis. The application of cluster analysis on this data set and results obtained are provided in annexure 3.1. There is a savings of 46% in frequency distance traveled.

Generation of Sequence Using Genetic Algorithm

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2007

Chapter -4

Generation of Sequence Using Genetic Algorithm

Chapter – 4

4.0 Introduction

The requests are grouped into clusters as described in chapter 3.0.The proposed routing logic results in minimization of frequency distance traveled from loading/unloading point to ijth container. There is need to consider the movement of AS/RS machine with in the cluster also. The sequence of machine should be such that it minimizes the distance traveled with in clusters. An attempt has been made to rearrange the requests using genetic algorithms to arrive at the best sequence. Setting of factor levels for factors affecting evolution is important as they influence fitness function. An orthogonal array technique is employed to fix the levels for the factors affecting the generation of population.

4.1 Problem Area

The application of genetic algorithm to develop sequences for AS / RS movement has not been addressed by researchers.

To understand the importance a sequence, let us take a small example, consider the schematic view of an 8 x 8 storage rack area Figure 4.1, for the retrieval of material from the shaded cells, if machine follows the sequence 1-7-5-4-6-3-2, the inter container distance travelled will be 38 units of distance as shown in figure 4.2. For sequences 6-1-5-7-2-4-3, and 1-2-3-4-5-6-7 the distance travelled are 45, 16 as shown in figure 4.3, 4.4 respectively. Therefore the sequence in which the materials are retrieved from the rack is important for minimizing the distance travelled by the AS/RS machine. Hence there is a need to develop a sequence, which minimizes the distance travelled with in clusters.

The solution to the problem is an optimal sequence by which the distance moved by the AS/RS will be minimum. In this chapter a GA method is attempted to arrive at the optimal sequence starting from a set of random sequences. The total distance travelled for every sequence can be computed and used as a fitness value of that particular solution. Applying GA and using the concepts of reproduction, crossover, mutation the final solution evolves in a natural biological process.

The level fixation for these factors is critical in arriving at best sequences. The application of orthogonal array experiments to establish these levels is also not explored by researchers. Hence, the problem for our study is to generate a sequence that minimises the distance travelled with in cluster.

8								**7 (8,8)**
7								
6						**5 (6,6)**		**6 (6,8)**
5								
4				**4 (4,4)**				
3								
2					**3 (2,5)**			
1	**1 (1,1)**		**2 (1,3)**					
	1	2	3	4	5	6	7	8

Figure 4.1 : Storage rack of size 8x8

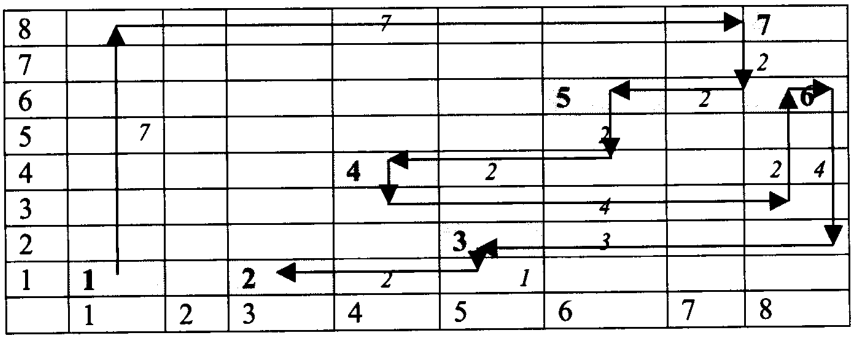


Figure 4.2 : Sequence 1 – 7 – 5 – 4 – 6 – 3 – 2 ,

Inter container distance : 38 (7+7+2+2+2+2+4+2+4+3+1+2)

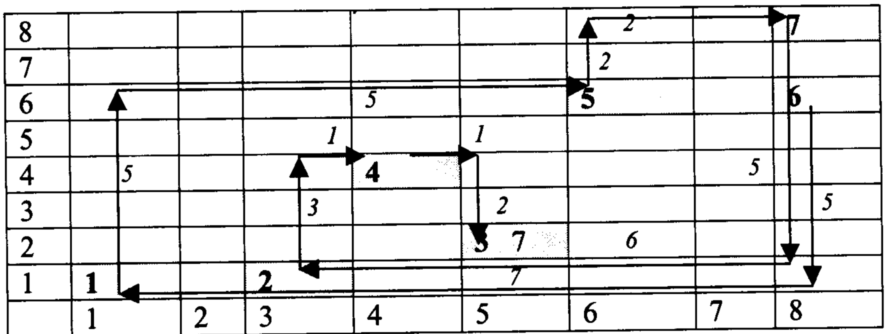


Figure 4.3 -Sequence : 6 – 1 – 5 – 7 – 2 – 4 – 3,

Inter container distance: 45 (5+7+5+5+2+2+5+7+3+1+1+2)

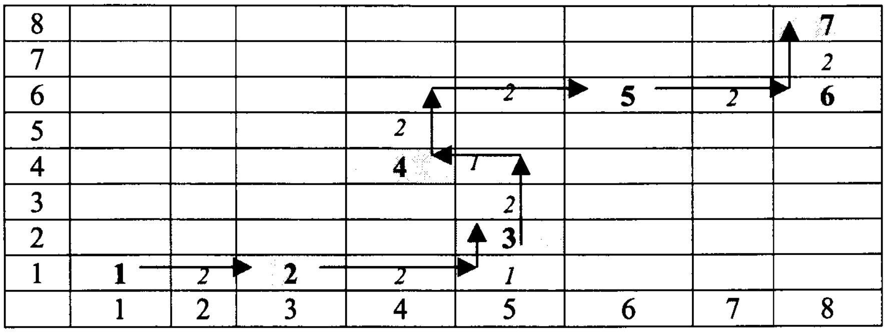


Figure 4.4 -Sequence : 1 – 2 – 3 – 4 – 5 – 6 – 7 ,

Inter container Distance : 16 (2+2+1+2+1+2+2+2+2)

4.2 Genetic Algorithm (GA)

Genetic Algorithms are not function optimizers. The foundation of GA is concerned with improving the overall population fitness rather than that of just a set individual. Although GA has found its application in many areas, to consider it as a solution provider, design of GA process is crucial. Design includes the selection of development of fitness function and determination of parameters such as crossover, mutation, number of generations.

Genetic algorithms are robust search algorithms-Goldberg [128]. They are superior to calculus based, enumerative and random search methods. They randomly generate a population of solutions and search among this population to select the best solution among them. The solution set selected in the beginning of the search is termed as parent solutions. Two “parents” are selected based on a fitness function. A site for selection of crossover is determined and crossover is carried out with a probability, then the exchange of information takes place between two “parents” to generate a new “child”. The child will inherit some characteristics from either parent. This process of crossover results in transfer of qualities from parents to children. The child solutions so generated are decoded and evaluated. If the child solution is better than the worst among the parent population, the child solution replaces the worst element in parent population. The genetic algorithms also allow infrequent mutations. The characteristics of solutions are randomly changed with a probability. The process is continued until some termination criteria are satisfied. Genetic algorithms provide the solution to problems based on the “survival of the fittest” criteria. The Genetic Algorithm with an objective of minimization of distance generates the sequences of the jobs to be retrieved and stored. The best sequences are selected by evaluating the fitness function. Movement of the machine takes place as per the best sequence obtained.

4.2.1 GA parameters:

Selection of parameters for carrying out genetic algorithm is vital. Grefenstette [127] discussed the importance of using the appropriate values for these parameters.

Crossover between two parents takes place to produce a new child. The process of crossover depends upon the type of crossover operator. The probability associated with crossover determines the possibility of crossover taking place during the generation process. If the generated random number is less than the crossover probability, crossover takes place. It is observed that considering the crossover operator alone will not improve fitness function. The functional value ceases to improve over the generations. At this point mutation works wonders and improves the objective function drastically. Further crossover will help in increasing the offsprings in the population. Among this elite population the fittest offspring is selected for future generation

There are different types of crossover operators discussed by researchers, in the current work the effect of Simple Crossover, Cycle Crossover and Partially Matched Crossover are investigated.

In our work the population size is taken as twice the length of the chromosome.

Simple Crossover:

Consider the parent sequences A and B, if the crossover takes place at the sixth position, the elements of A and B after position six are exchanged as shown below to yield children A' and B'

A = 9 8 4 5 6 7 | 1 3 2 10
B = 8 7 1 2 3 10 | 9 5 4 6

A' = 1 8 2 3 10 7 | 9 5 4 6
B' = 8 7 4 5 6 9 | 1 3 2 10

Cycle Crossover:

Gold Berg[128] explains the cycle crossover operator as follows with an example; consider C and D as the parents, we start from the left ,select the 1st element of C ie 9. So the child C' will have the 1st element as 9.The 1st position in the D is 1 ,therefore the C' will have 1 in the 4th position, corresponding to position 1 in C ,D string has number 4.Therefore C' will have 4 and so on. The process will continue until the 1st cycle, then the remaining are filled from the rest of the string.

C = 9 8 2 1 7 4 5 10 6 3

D = 1 2 3 4 5 6 7 8 9 10

C' = 9 - - - - - - - - -

C' = 9 - - 1 - - - - - -

C' = 9 - - 1 - 4 - - 6 –

C' = 9 2 3 1 5 4 7 8 6 10

D' = 1 8 2 4 7 6 5 10 9 3

Partially Matched Crossover (PMX) :

Consider the parent sequence A and B, two crossing sites are picked uniformly at random along the strings. These two points define a matching section that is used to effect a cross through position -by-position exchange operations. The child solution A' B' are shown below.

A = 9 8 4 | 5 6 7 | 1 3 2 10

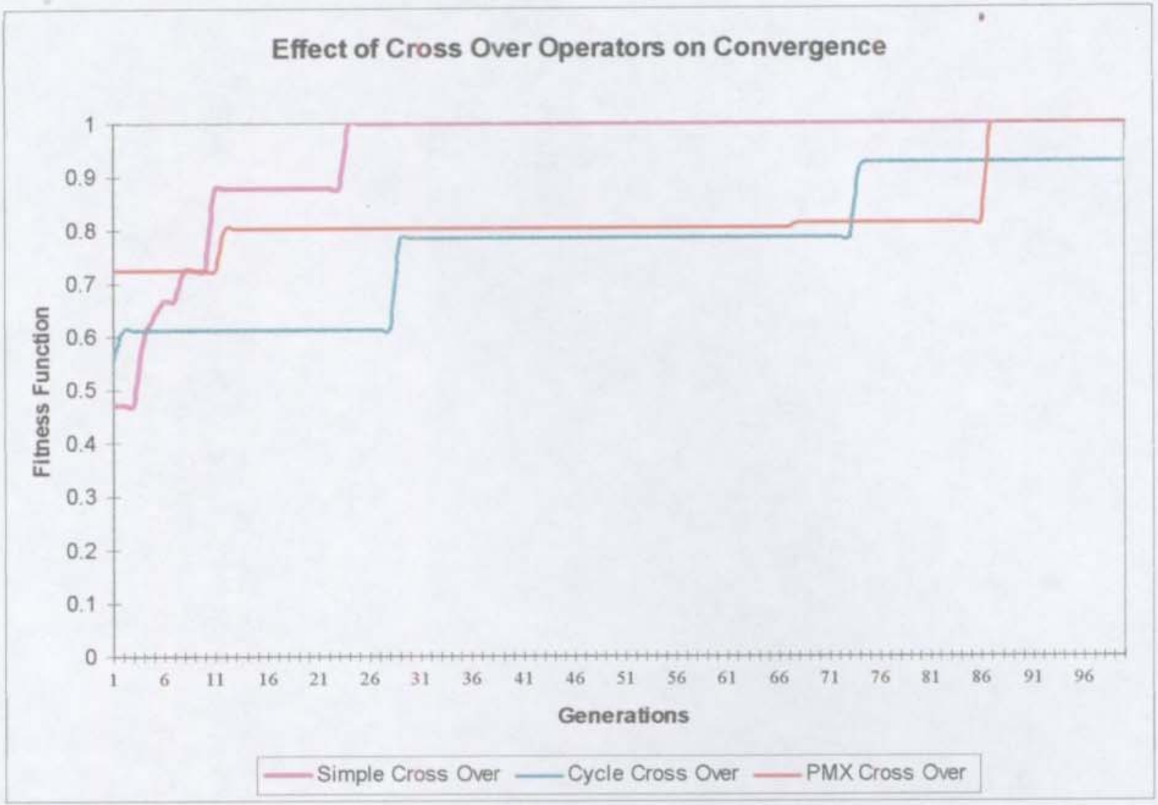
B = 8 7 1 | 2 3 10 | 9 5 4 6

A' = 9 8 4 | 2 3 10 | 1 6 5 7

B' = 8 10 1| 5 6 7 | 9 2 4 3

There are different types of crossover operators in use. We have chosen the most important operators in our study. The effect of different crossover operators on fitness function are considered and shown in the Figure 4.5.The corresponding values are provided in annexure 4.1. It is found that irrespective of type of crossover solution converges. For the results shown below, simple crossover has shown good results. The optimum level of setting the probability of crossover is investigated through OA technique.

Figure 4.5 – Effect of Crossover Operators on Convergence



Mutation happens accidentally during the course of evolution. Mutation plays an important role in enhancing the value of fitness function. Sometimes there is deterioration in the fitness value too. There are different mutation operators reported in literature. The probability associated with mutation determines the possibility of mutation taking place during the generation process. If the generated random number is less than the mutation probability mutation takes place. When the fitness value ceases to improve over the generations, mutation works wonders and improves the fitness function drastically. In the present work simple exchange, multiple exchanges and multiple insertion are considered.

Simple exchange:

Consider the sequence A= 6 5 7 2 3 4 **1**

If mutation takes place at position seven, the number one is exchanged with two and the position gets exchanged. Then new sequence will be 6 5 7 **1** 3 4 **2**

Multiple exchange:

Consider the sequence A= **6** 5 7 **2** 3 4 1

If mutation takes place at multiple position at 1 ,4 position, then the sequence after mutation will be A=**7** 5 **6 1** 3 4 **2**

Multiple insertions:

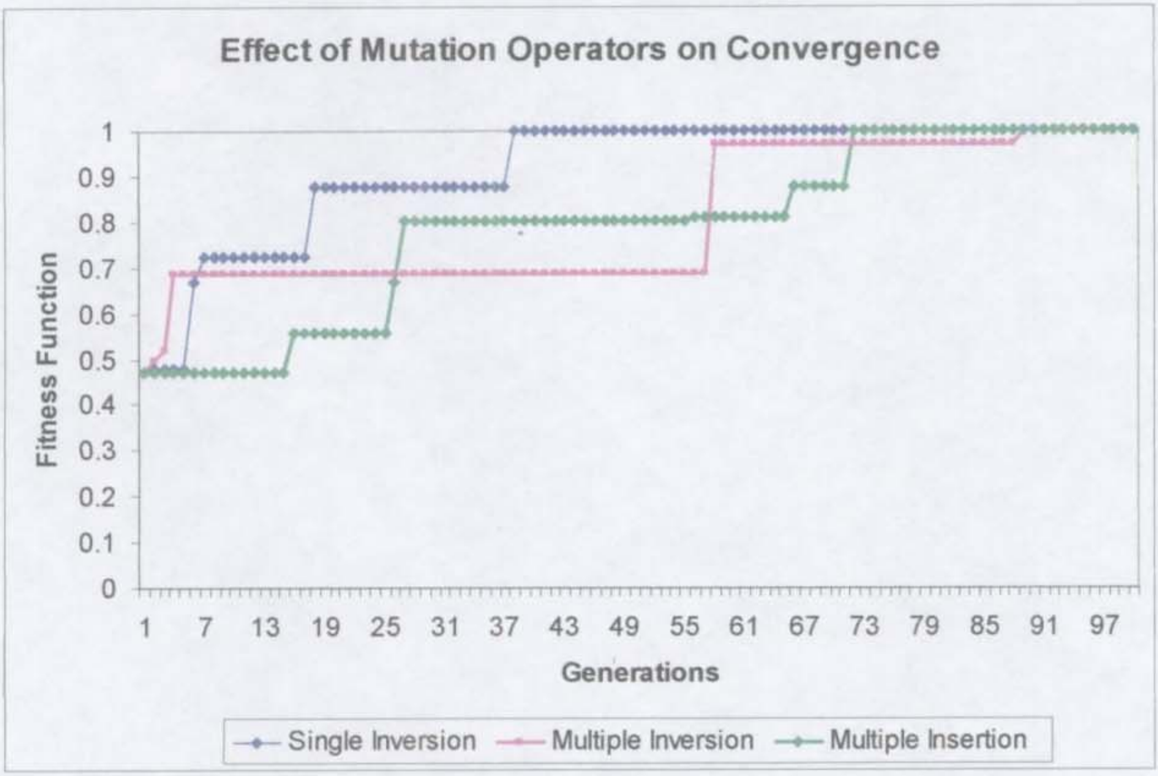
Consider the sequence A= 6 5 7 2 3 4 1

If multiple insertion takes place at position 1 ,4,7

Then A=**1** 5 2 **4** 3 6 **7**

The effect of different mutation operators on fitness function is analyzed and shown in Figure 4.6. The corresponding values are provided in annexure 4.2.

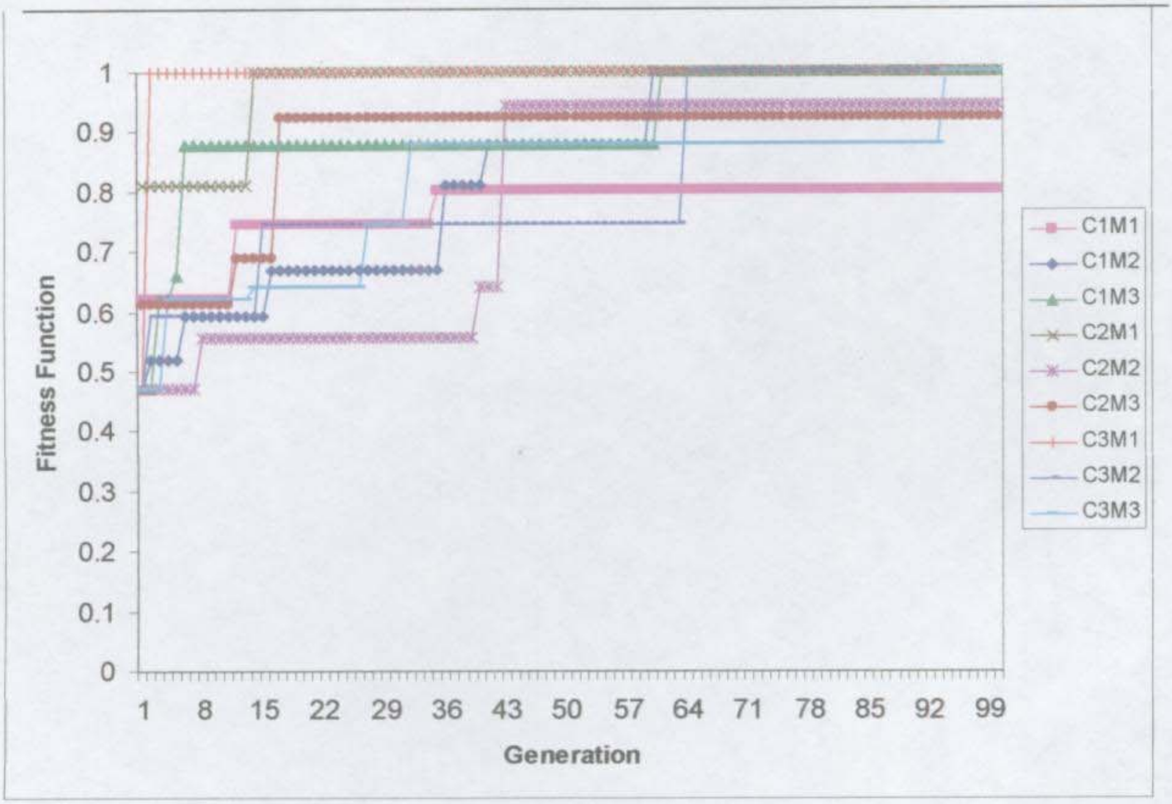
Figure 4.6– Effect of Mutation Operators on Convergence



It is found that irrespective of type of mutation operator solution converges. For the results shown below, simple exchange has shown good results. The optimum level of setting the probability of mutation is investigated through OA technique

A combination of crossover and mutation is also considered; as we have considered three types of crossover operators and three types of mutation operators we will have nine possible combinations. The effect on fitness function is analyzed, and shown in Figure 4.7. The corresponding values are provided in annexure 4.3. It is found that irrespective of combination of operator solution converges. For the results shown below, PMX crossover and simple exchange has shown good results. The optimum level of setting the probability of parameters crossover and mutation is investigated through OA technique.

Figure 4.7 – Combination of Crossover and Mutation on Convergence



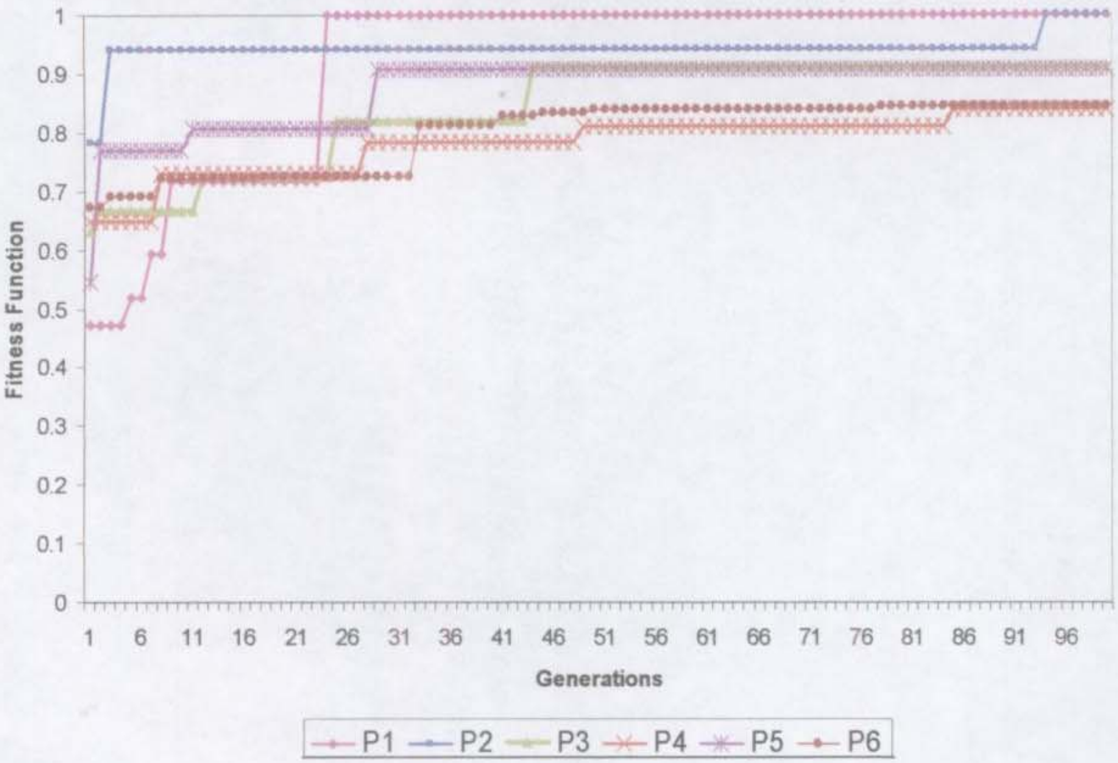
The number of generations required for improvement in the fitness value during the evolution process is very important. Larger the number of generations, higher is the time required for convergence. Too less number of generations lead to unnatural formation of the population. For the natural formation of population the number of generations required will also depend upon the crossover and mutation probabilities. The optimum level of setting the number of generations is investigated through OA technique.

In order to carry out the investigation the following 6 data sets shown in Table 4.1 are formulated with different number of jobs. A program in C was written to develop the software to implement the genetic algorithm. The convergence of the function for the different data sets considered is shown in the Figure 4.8. The corresponding values are provided in annexure 4.4 .As the number of jobs increase the number of generations required for convergence increases.

Table 1 – Data set with maximum and minimum Distance

Data set	No. of Job	Max. distance	Min. distance
1	6	154	48
2	7	181	40
3	8	197	47
4	9	194	46
5	10	264	48
6	11	326	48

Figure 4.8 – Convergence of Different Datasets



4.2.2 Fitness Function

In order to evaluate the sequence it is essential to develop the fitness function and evaluate the function to determine whether the genetic algorithm improves the fitness function.

The minimum ($DIST_{min}$) that has to be travelled will be:

= (number of rows-1)+(number of columns-1),

for example in a 25 row X 25 column matrix the minimum distance that can be travelled (25-1)+(25-1)=48

The maximum ($DIST_{max}$) is computed as follows:

In our case the number of rows is equal to number of columns(n). There will be maximum of [n*(n-1)/2] inter container distances. The distances are arranged in a ascending manner and the first [number of requests – 1] distances are summed up to arrive at ($DIST_{max}$).

The maximum ($DIST_{max}$) and the minimum ($DIST_{min}$) distance that the machine has to travel for the given problem is provided in table 4.1.

The distance travelled by the machine for the given sequence ($DIST_{Seq}$) is estimated for the sequence. For the generated sequences the fitness value is estimated using the formula.

$$f = \frac{DIST_{\max} - DIST_{seq}}{DIST_{\max} - DIST_{\min}}$$

Using GA several sequences are generated and the sequence which results in minimum distance travelled is selected. If the $DIST_{Seq}$ is equal to $DIST_{min}$ then the ratio turns out to be one. Thus the fitness function is so defined that its value increases as the distance travelled decreases. While the objective of maximizing the fitness value results in minimizing the distance travelled. The sequences with the higher values of the function are retained and reproduced as offsprings for the future generation.

4.2.3 Steps in Genetic Algorithm:

Steps followed in the genetic algorithm are:

1. Select the problem out of the case problems considered for research.
2. Select the experiment from the set of 27 experiments. Selection of the experiment will automatically set the levels for crossover, mutation probabilities and number of generations.
3. Generate the initial population and determine the size. The population size will be twice the length of the sequence/chromosome.
4. Calculate the fitness value for each member of the initial population.
5. Select a pair of members that can be used for reproduction using selection criteria i.e, largest fitness value.
6. Apply the genetic operators such as crossover and mutation. Generate offsprings, evaluate, select offsprings with max value, and replace the parents with new off spring to form a new population.
7. If the number of generations is equal to the maximum, then stop.

4.3 Orthogonal Array (OA) experiments

Performing a series of experiments requires making measurements to decide what to do next, such as the identification and extent to which each parameter to be varied. Such series of experiments are often prompt to fail due to negative results that hinder further experimentation. Experiments which are terminated before reaching any logical conclusion are not meaningful.

Taguchi [126] of Nippon Telecom Company has developed a method of OA experiments which gives much reduced "variance" for experiments with optimal setting for control parameters. OA provides a set of balanced and minimum number of experiments to reach the near optimal results.

A statically planned and designed experiment is one in which the controllable parameter / investigation parameter is altered according to a scientifically derived pattern to ensure whether the analysis is compatible with objectives. It is characterized by several concepts such as multi factor manipulation, error quantification, and experimentation and real circumstances, quantification of interactions and plan to see approach.

Orthogonal array experimental design is the task of developing the set of treatment combinations for the conduct of experiment in such a fashion that the level combinations of different factors for different experiments are all orthogonal to one another. An experiment designed in such a fashion will guarantee interpretations of the effect of each of the factors or interactions independent of one another.

Michalewicz [129] mentioned that determination of parameters is an art rather than science.

For the purpose of investigation, three main factors namely crossover, mutation probabilities, and number of generations are selected. Interaction among crossover probability, mutation probability, and number of generation is also investigated. Selecting the level for the factors has an effect on prediction of the objective value for an intermediate setting. The levels can be set at two, three, four or five. For linear response, two levels are sufficient. For non linear response we can select more than three levels for the factors.

The factors, which affect the process, are identified and short-listed. The levels at which these factors are to be set are also determined based on the relationship with the objective function. The degree of freedom for factor is one less than number of levels, which is the number of independent comparisons that one can make while carrying out the experiments. The interaction between the factors is also important as it will have significant effect on the outcome of the process. Table 4.2 shows the factors, levels, degrees of freedom and interactions considered for the study. The total degree of the freedom is the summation of the degrees of freedom of the main factors and interaction factors.

Table 4.2 – Total degrees of freedom

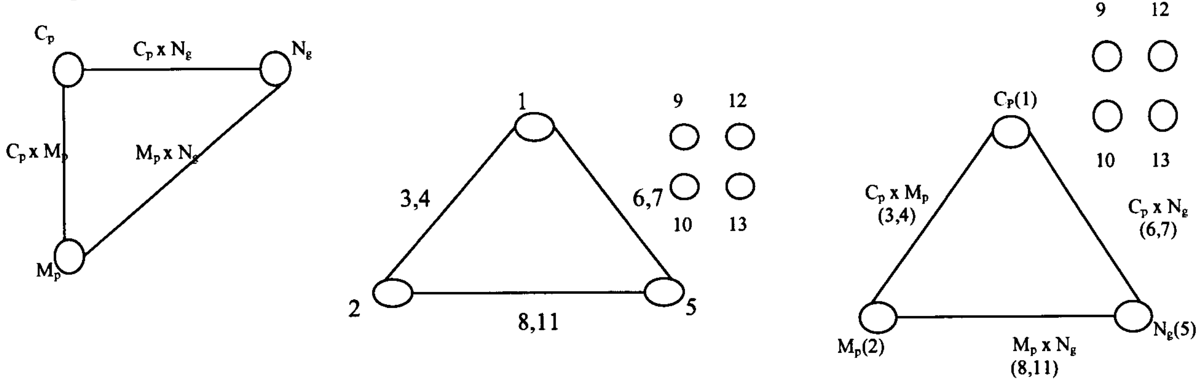
Sl. No.	Main Factor	Levels			D.O.F
		1	2	3	
1.	Crossover Probability (Cp)	0.5	0.7	0.9	2
2.	Mutation Probability (Mp)	0.05	0.1	0.15	2
3.	Number of Generation (Ng)	50	75	100	2
	Interaction				
4.	Crossover Probability x Mutation probability (Cp x Mp)	-	-	-	4
5.	Crossover Probability x Number of generation (Cp x Ng)	-	-	-	4
6.	Mutation Probability x Number of generation (Mp x Ng)	-	-	-	4
Total Degrees of Freedom (DOF)					**18**

As per the design of experiments, the minimum number of experiments that have to be performed will be total degree of freedom plus one; Hence a minimum of nineteen experiments have to be conducted. The series selected for research is $L_{27}\,3^{13}$ as the factors are all at 3 levels.

The Required Linear Graph (RLG) is the graphical representation of the main factors and their interaction. Circles represent main factors and the line connecting the two circles indicate interaction between the two factors. For the Required Linear Graph, a matching Standard Linear Graph (SLG) from series $L_{27}\,3^{13}$, is selected from Taguchi (1986). A Modified Linear Graph (MLG) is the super imposed graph of Required Linear Graph on Standard Linear Graph. Modified Linear Graph provides the column numbers to the factors and their interactions.

The RLG, SLG and MLG for the current experiment is shown in Figure 4.9. Thus for cross over probability, mutation probability, number of generations columns 1, 2& 5 are assigned. For interaction Cp x Mp, Cp x Ng, Mp x Ng columns (3,4), (6,7), (8,11) are assigned. The remaining columns are allotted for errors.

Figure 4.9 – Required, Standard and Modified Linear Graph



Required Linear Graph (RLG)

Standard Linear Graph (SLG)

Modified Linear Graph (MLG)

The columns from the standard tables corresponding to Cp, Ng, Mp, Cp x Mp, Cp x Ng, Mp x Ng are drawn and inserted in OA Layout Table 4.3. The remaining columns are attributed to the error. For the conduct of the experimentation only the main factors and the columns are selected. The level numbers 1, 2 & 3 are replaced by the corresponding factor levels. This will help easy monitoring of the conduct of experiments. The physical layout drawn for the work is shown in table 4.4.

Table 4.3 – Orthogonal Array Layout

Expt. No.	C_P	M_P	N_g	C_P x M_p		C_P x N_g		M_P x N_g		Error			
	1	**2**	**5**	**3**	**4**	**6**	**7**	**8**	**11**	**10**	**12**	**13**	**9**
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	2	1	1	2	2	2	2	2	2	2	2
3	1	1	3	1	1	3	3	3	3	3	3	3	3
4	1	2	1	2	2	1	1	2	3	2	3	3	2
5	1	2	2	2	2	2	2	3	1	3	1	1	3
6	1	2	3	2	2	3	3	1	2	1	2	2	1
7	1	3	1	3	3	1	1	3	2	3	2	2	3
8	1	3	2	3	3	2	2	1	3	1	3	3	1
9	1	3	3	3	3	3	3	2	1	2	1	1	2
10	2	1	1	2	3	2	3	1	1	3	2	3	2
11	2	1	2	2	3	3	1	2	2	1	3	1	3
12	2	1	3	2	3	1	2	3	3	2	1	2	1
13	2	2	1	3	1	2	3	2	3	1	1	2	3
14	2	2	2	3	1	3	1	3	1	2	2	3	1
15	2	2	3	3	1	1	2	1	2	3	3	1	2
16	2	3	1	1	2	2	3	3	2	2	3	1	1

17	2	3	2	1	2	3	1	1	3	3	1	2	2
18	2	3	3	1	2	1	2	2	1	1	2	3	3
19	3	1	1	3	2	3	2	1	1	2	3	2	3
20	3	1	2	3	2	1	3	2	2	3	1	3	1
21	3	1	3	3	2	2	1	3	3	1	2	1	2
22	3	2	1	1	3	3	2	2	3	3	2	1	1
23	3	2	2	1	3	1	3	3	1	1	3	2	2
24	3	2	3	1	3	2	1	1	2	2	1	3	3
25	3	3	1	2	1	3	2	3	2	1	1	3	2
26	3	3	2	2	1	1	3	1	3	2	2	1	3
27	3	3	3	2	1	2	1	2	1	3	3	2	1

Table 4.4 - Physical layout

Expt. No.	C_P	M_P	N_g
1	0.5	0.05	50
2	0.5	0.05	75
3	0.5	0.05	100
4	0.5	0.1	50
5	0.5	0.1	75
6	0.5	0.1	100
7	0.5	0.15	50
8	0.5	0.15	75
9	0.5	0.15	100
10	0.7	0.05	50
11	0.7	0.05	75
12	0.7	0.05	100
13	0.7	0.1	50
14	0.7	0.1	75
15	0.7	0.1	100
16	0.7	0.15	50
17	0.7	0.15	75
18	0.7	0.15	100
19	0.9	0.05	50
20	0.9	0.05	75
21	0.9	0.05	100
22	0.9	0.1	50
23	0.9	0.1	75
24	0.9	0.1	100
25	0.9	0.15	50
26	0.9	0.15	75
27	0.9	0.15	100

Once the physical layout is ready, experiments are run as per the settings in the physical layout. Since the random numbers are used for determining the probability of crossover, mutation and selection of parents, the response will vary every time, when the programme is executed. A sample output of GA is provided in annexure 4.6. The experiments are run several times to arrive at an average value for each of the 27 experiments for all the problems. Analysis of variance is carried out on the collected data to find out the significant factors, which contribute to the minimization of the distance travelled. The responses for the significance factors are shown in Figure 4.10. The corresponding values are provided in annexure 4.5. The totals for the main factor and Interaction are shown in Table 4.5. Using these totals an ANOVA is carried out shown in Table 4.6.The analysis indicates that the factor crossover and the number of generations are significant and also the interaction between the mutation and number of generations is also significant at 0.25 significance level. Hence these factors play an important role in affecting the fitness function they need attention and proper setting. The level setting for probability of crossover at 0.9, number of generations at 100, probability of mutation at 0.1 is recommended.

Table 4.5 – Total Response for Main factor and Interaction

Main factor

	Factor Totals		
	1	2	3
Cp	35.5324	36.506	36.714
Mp	35.9873	36.429	36.337
Ng	35.7704	36.063	36.919

Interaction Cp x Mp

CpxMp		Mp		
		1	2	3
	1	11.829	11.704	11.999
Cp	2	12.178	12.235	12.094
	3	11.98	12.49	12.244

MpxNg		Ng		
		1	2	3
	1	12.018	11.518	12.452
Mp	2	11.971	12.32	12.138
	3	11.782	12.225	12.329

CpxNg		Ng		
		1	2	3
	1	11.565	11.829	12.138
Cp	2	12.046	12.273	12.188
	3	12.159	11.961	12.593

Figure 4.10 a – Average Responses -Mutation

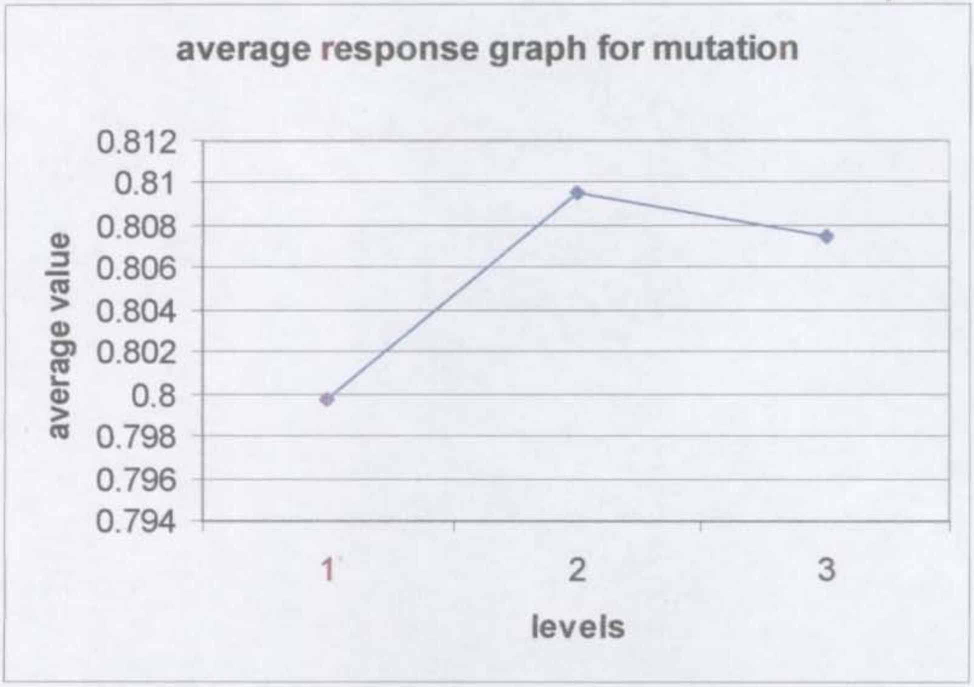


Figure 4.10 b – Average Responses generation

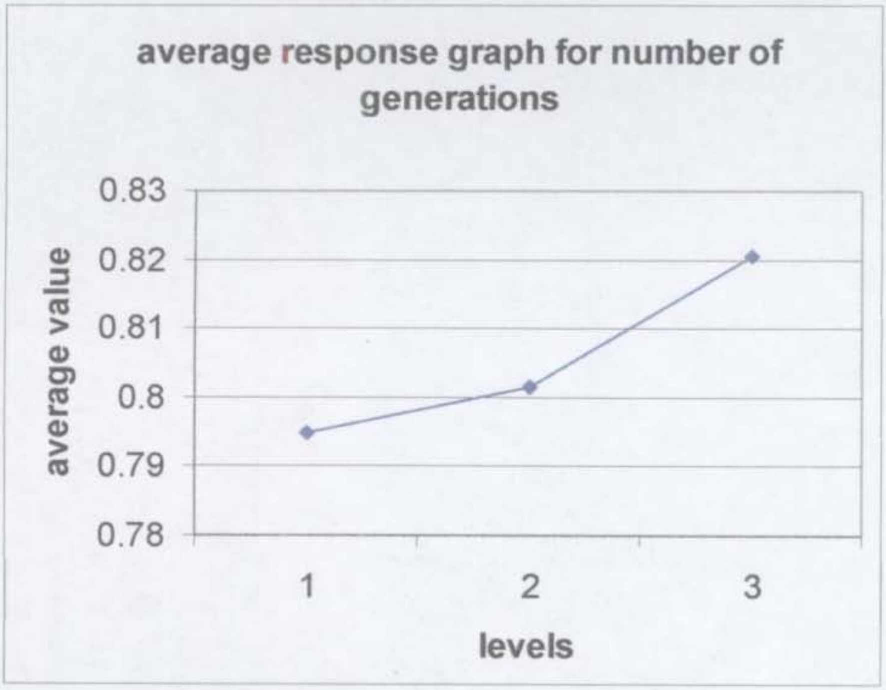
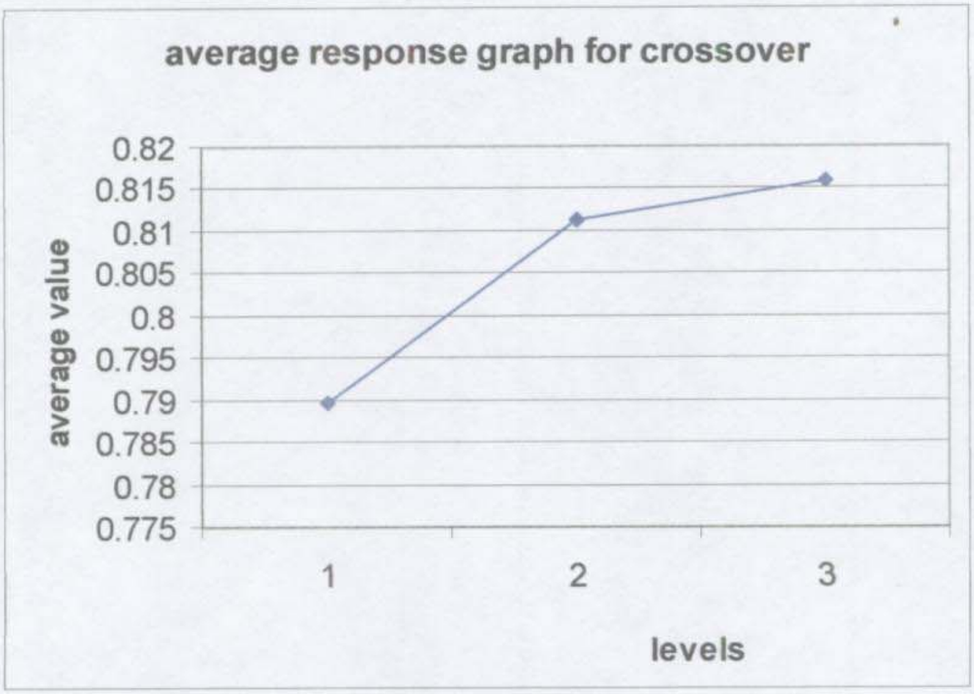


Figure 4.10 c– Average Responses -crossover



4.4 Savings and Conclusion

Generation of sequence for scheduling of AS/RS machine is carried out using genetic algorithm to arrive at the best sequence of the request for storage and retrieval with an objective of minimization of distance.

During the work, it was observed that the convergence of the solution was influenced by factors such as crossover, mutation operators, number of generations and the length of the sequence. The crossover operator alone cannot improve the solution. Mutation results in the avoidance of similar sequences. The effect of crossover operator, mutation operator and a combination of the two operators on convergence of the solution was also investigated. The study on the effect of the GA parameters on the convergence of the solutions for different length of sequence confirmed that the convergence of the solution is influenced by the length of the sequence. During the evolution process it was observed that the final sequence generated gets reversed in some cases without any change in the total distance traveled. It is observed that there is a significant savings in the distance traveled. Table 4.7 provides the initial sequences and final best sequence with distance traveled for all the datasets considered in this work.

A common dataset is considered for analysis. The application of genetic algorithm on this dataset and results obtained are provided in annexure 4.7. There is a savings in the distance traveled.

This work also explored a scientific approach to fix the levels of significant factors influencing the genetic evolution. Orthogonal Array experimentation technique was employed to determine the effect of GA parameters on convergence of solution. A L_{27} 3^{13} design is used for the conduction of experiments. The factors mutation and number of generations and the interaction between these two turned out to be significant in the analysis of variance The level setting for probability of crossover at 0.9, number of generations at 100, probability of mutation at 0.1 is recommended.

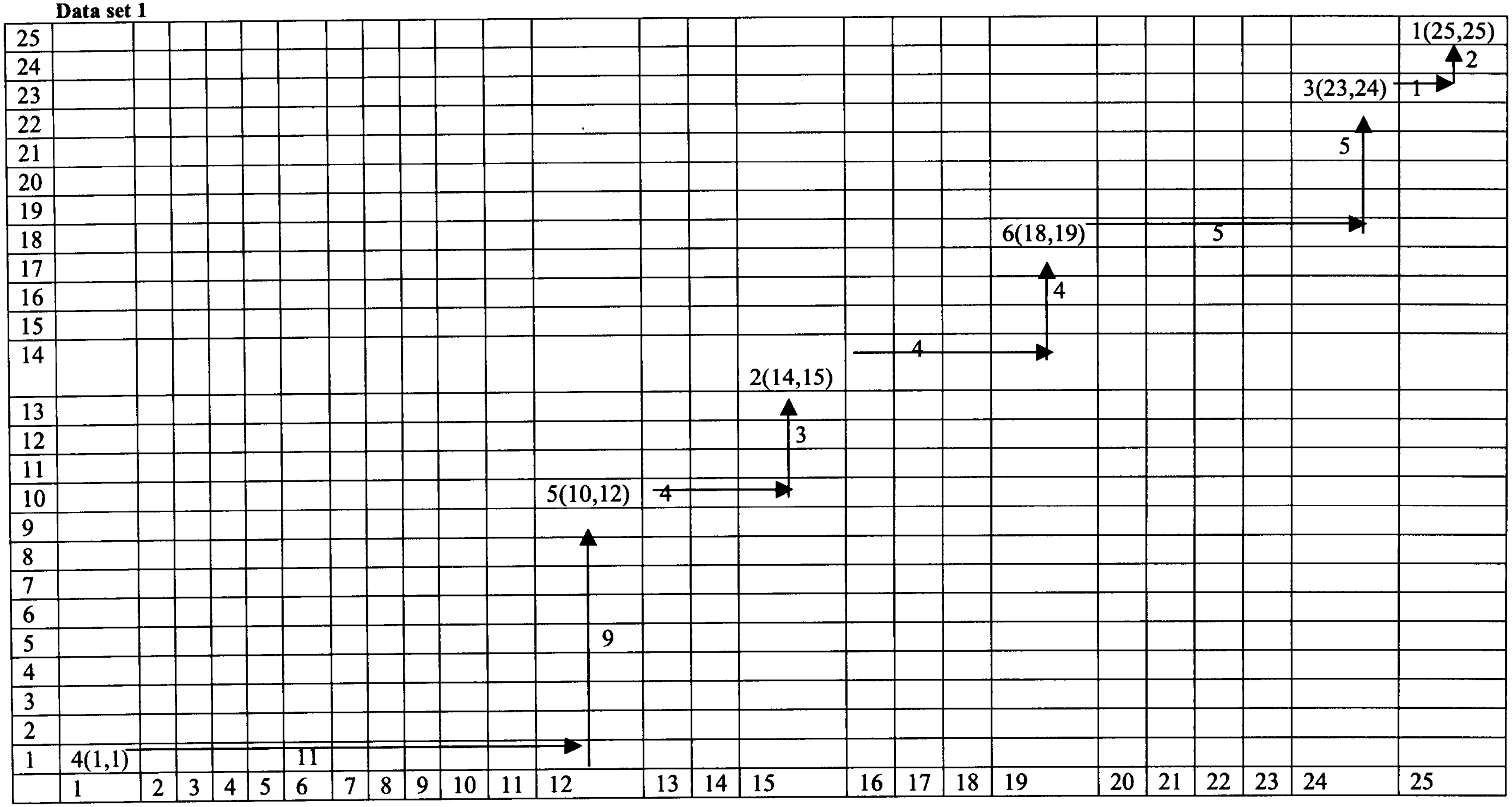
Table 4.6 - Analysis of Variance

Factor	DF	SS	MS	Fcal
Cross over Probability- Cp	2	0.01768236	0.00884118	1.7779505*
Mutation Probability -Mp	2	0.00240863	0.00120431	0.2421862
No. of Generations -Ng	2	0.0158449	0.00792245	1.5931945*
CpxMp	4	0.0098393	0.00245983	0.4946678
CpxNg	4	0.01081962	0.0027049	0.5439529
MpxNg	4	0.02861816	0.00715454	1.4387691*
Error due to replicate	4	0.01822439	0.0045561	
Error	112	0.55694033	0.00497268	
Total	134	0.6603777		

Table 4.7 – Data set with distance moved before and after.

Data set 1						
Job	Row	Column	Initial Population sequence	Distance Moved Before	Final sequence (fitness value)	Distance Moved After
1	25	25	1 2 3 4 5 6	119	4 5 2 6 3 1 (1.0) or 1 3 6 2 5 4	48
2	14	15	2 5 3 1 4 6	118		
3	23	24	4 1 2 6 3 5	112		
4	1	1	5 3 2 6 4 1	134		
5	10	12	1 4 3 5 6 2	141		
6	18	19	2 5 3 1 4 6	118		
			6 2 3 4 5 1	119		
			5 2 3 4 1 6	131		
			2 1 3 4 5 6	104		
			1 2 3 4 5 6	119		
			1 2 4 3 5 6	133		
			1 4 3 5 6 2	141		

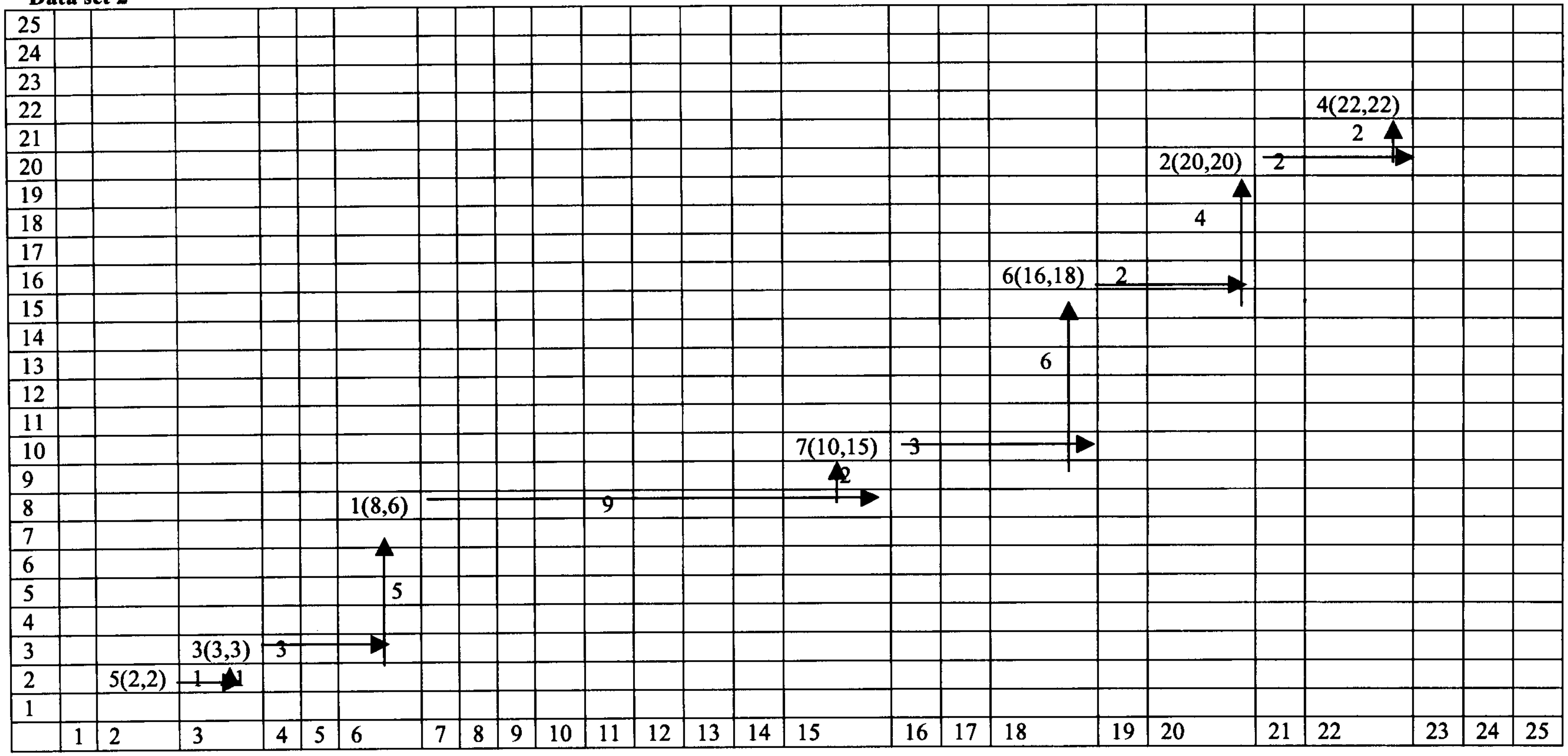
Data set 1



Route: 4 – 5 – 2 – 6 – 3 – 1 or 1 – 3 – 6 – 2 – 5 – 4
Distance: 48

Data set 2						
Job	Row	Column	Initial Population sequence	Distance Moved Before	Final sequence (fitness value)	Distance Moved After
1	8	6	5 3 7 1 4 2 6	72	5 3 1 7 6 2 4 (1.0)	40
2	20	20	5 2 3 7 4 6 1	138		
3	3	3	3 4 7 5 2 1 6	160		
4	22	22	4 5 1 6 7 2 3	128		
5	2	2	1 2 3 4 5 6 7	177		
6	16	18	5 3 7 1 4 2 6	72		
7	10	15	5 2 3 7 4 6 1	138		
			3 4 7 5 2 1 6	160		
			4 5 1 6 7 2 3	128		
			1 2 3 4 5 6 7	177		
			5 3 7 1 4 2 6	72		
			5 2 3 7 4 6 1	138		
			3 4 7 5 2 1 6	160		
			4 5 1 6 7 2 3	128		

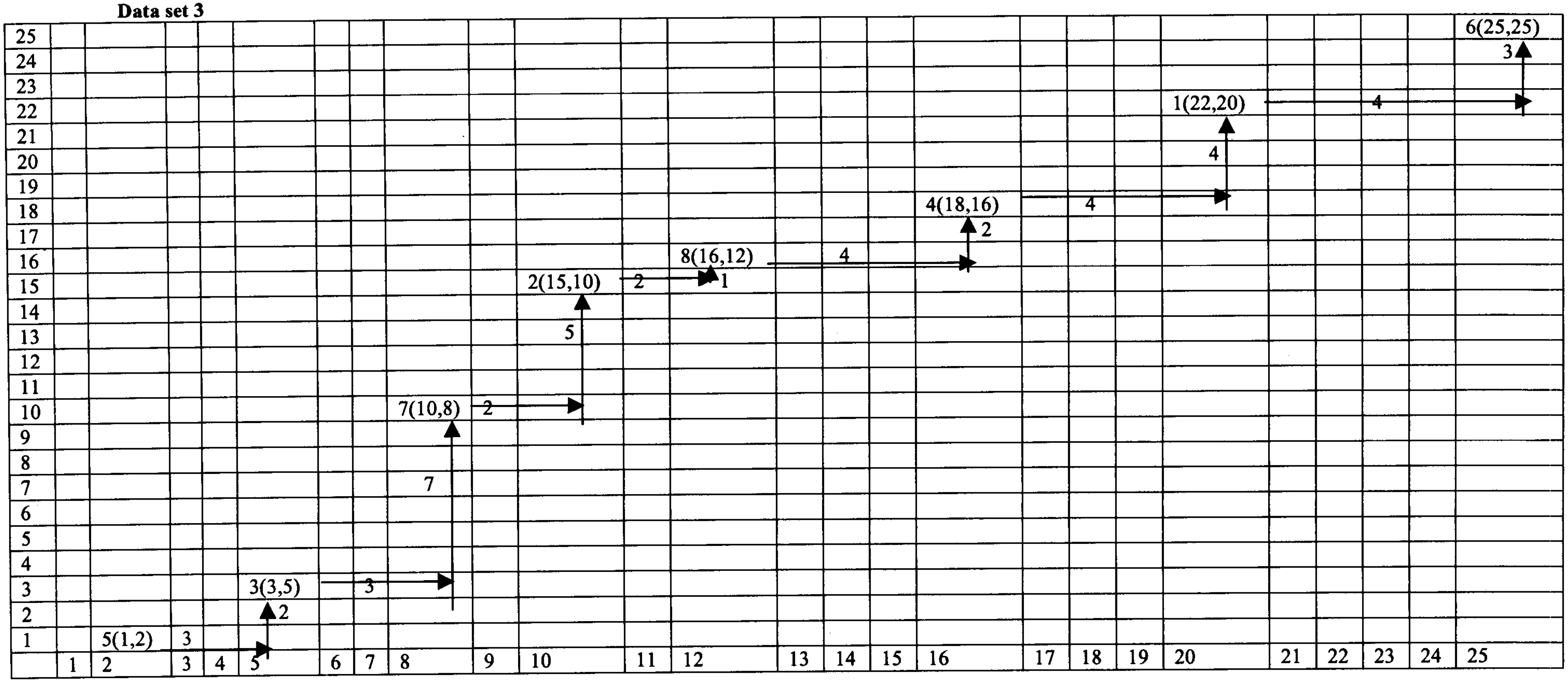
Data set 2



Route: 5 – 3 – 1 – 7 – 6 – 2 – 4
Distance: 40

Data set 3						
Job	Row	Column	Initial Population sequence	Distance Moved Before	Final sequence (fitness value)	Distance Moved After
1	22	20	4 2 6 1 7 3 5 8	106	5 3 7 2 8 4 1 6 (1.0) or 6 1 4 8 2 7 3 5	47
2	15	10	3 5 2 7 6 4 8 1	102		
3	3	5	2 1 7 4 5 6 3 8	197		
4	18	16	2 7 5 1 3 4 6 8	159		
5	1	2	1 2 3 4 5 6 7 8	180		
6	25	25	4 2 6 1 7 3 5 8	106		
7	10	8	3 5 2 7 6 4 8 1	102		
8	16	12	2 1 7 4 5 6 3 8	197		
			2 7 5 1 3 4 6 8	159		
			3 5 2 7 6 4 8 1	102		
			2 1 7 4 5 6 3 8	197		
			2 7 5 1 3 4 6 8	159		
			3 5 2 7 6 4 8 1	102		
			2 1 7 4 5 6 3 8	197		
			2 7 5 1 3 4 6 8	159		
			3 5 2 7 6 4 8 1	102		

Data set 3

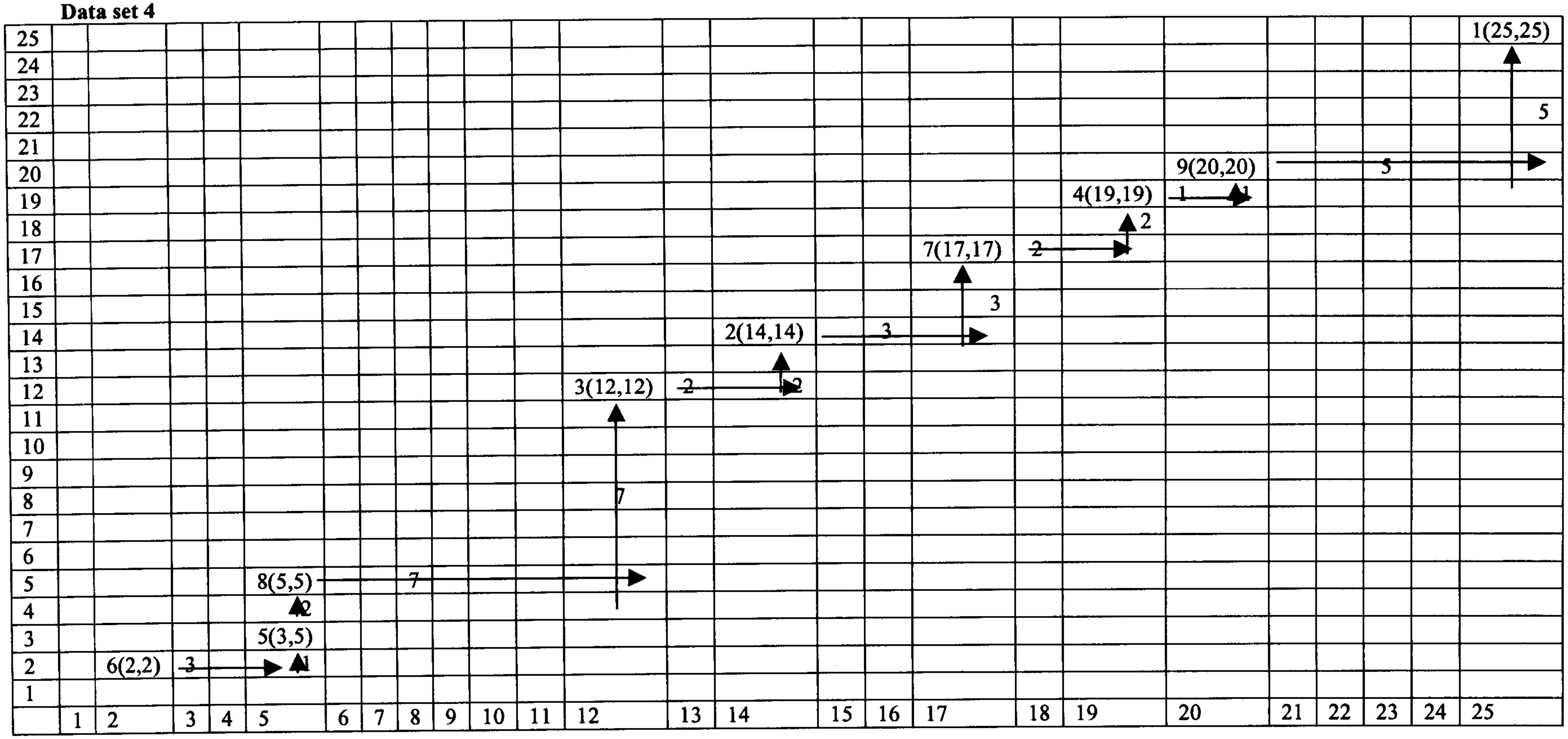


Route: 5 – 3 – 7 – 2 – 8 – 4 – 1 – 6
Distance: 47

Data set 4

Job	Row	Column	Initial Population sequence	Distance Moved Before	Final sequence (fitness value)	Distance Moved After
1	25	25	1 2 3 4 5 6 7 8 9	158	1 9 4 7 2 3 8 5 6 (1.0)	46
2	14	14	1 2 3 6 4 5 8 7 9	142		
3	12	12	2 4 6 1 3 9 7 8 5	164		
4	19	19	5 3 2 1 9 8 4 6 7	174		
5	3	5	2 4 6 1 3 9 7 8 5	164		
6	2	2	1 2 3 4 5 6 7 8 9	158		
7	17	17	1 2 3 6 4 5 8 7 9	142		
8	5	5	2 4 6 1 3 9 7 8 5	164		
9	20	20	1 2 3 4 5 6 7 8 9	158		
			1 2 3 4 5 6 7 8 9	158		
			1 2 3 6 4 5 8 7 9	142		
			2 4 6 1 3 9 7 8 5	164		
			5 3 2 1 9 8 4 6 7	174		
			1 2 3 4 5 6 7 8 9	158		
			1 2 3 6 4 5 8 7 9	142		
			2 4 6 1 3 9 7 8 5	164		
			5 3 2 1 9 8 4 6 7	174		
			1 2 3 6 4 5 8 7 9	142		

Data set 4

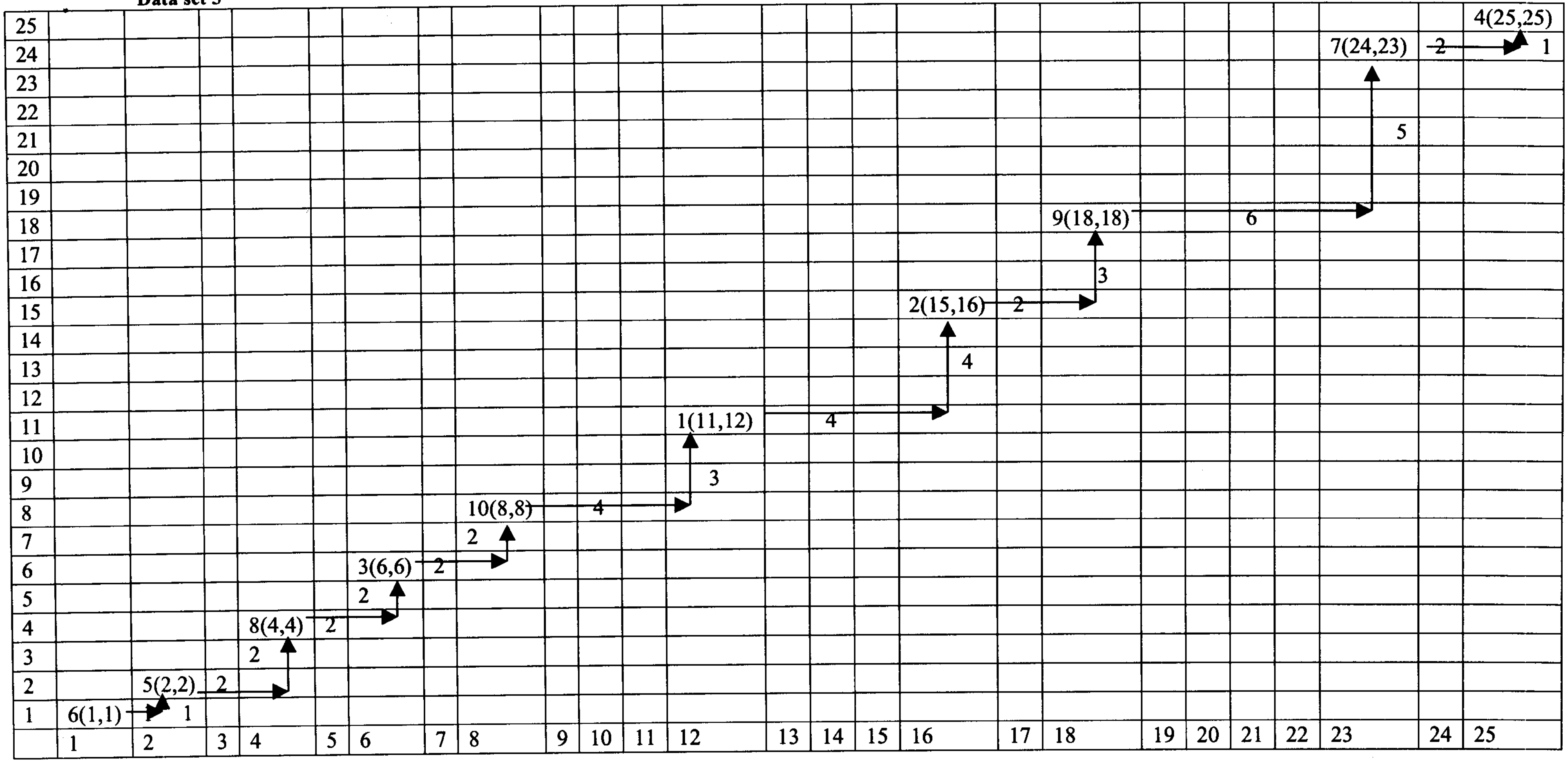


Route: 6 – 5 – 8 – 3 – 2 – 7 – 4 – 9 – 1
Distance: 46

Data set 5

Job	Row	Column	Initial Population sequence	Distance Moved Before	Final sequence (fitness value)	Distance Moved After
1	11	12	110 2 9 3 8 4 7 5 6	145	4 7 2 9 1 10 3 8 5 6 (0.94)	48
2	15	16	5 2 7 9 110 8 3 4 6	172		
3	6	6	4 8 9 7 5 610 1 3 2	177		
4	25	25	6 5 7 9 1 3 410 8 2	183		
5	2	2	1 2 3 4 5 6 7 8 910	245		
6	1	1	110 2 9 3 8 4 7 5 6	145		
7	24	23	5 2 7 9 110 8 3 4 6	172		
8	4	4	4 8 9 7 5 610 1 3 2	177		
9	18	18	6 5 7 9 1 3 410 8 2	183		
10	8	8	1 2 3 4 5 6 7 8 910	245		
			110 2 9 3 8 4 7 5 6	145		
			5 2 7 9 110 8 3 4 6	172		
			4 8 9 7 5 610 1 3 2	177		
			6 5 7 9 1 3 410 8 2	183		
			1 2 3 4 5 6 7 8 910	245		
			110 2 9 3 8 4 7 5 6	145		
			5 2 7 9 110 8 3 4 6	172		
			4 8 9 7 5 610 1 3 2	177		
			6 5 7 9 1 3 410 8 2	183		
			1 2 3 4 5 6 7 8 910	245		

Data set 5

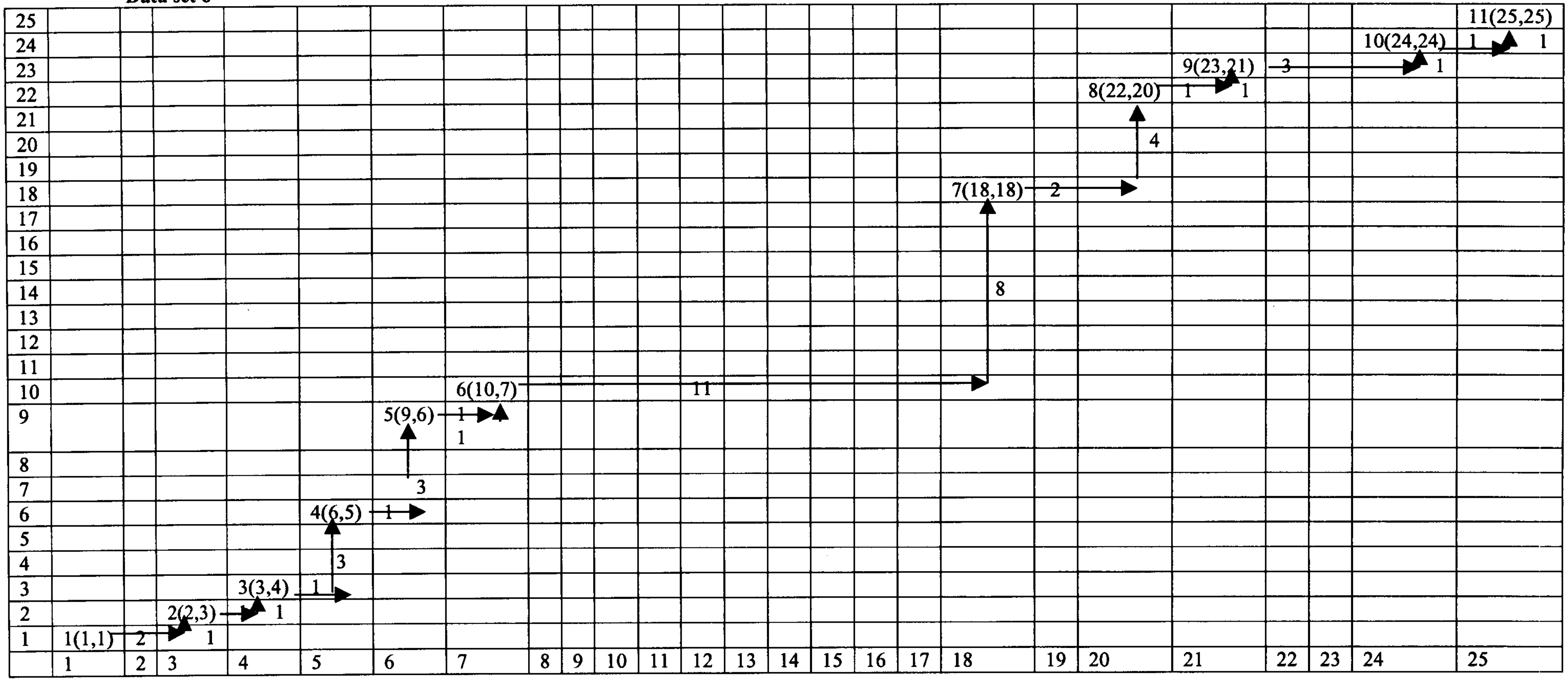


Route: 6 – 5 – 8 – 3 – 10 – 1 – 2 – 9 – 7 – 4
Distance: 48

Data set 6

Job	Row	Column	Initial Population sequence	Distance Moved Before	Final sequence (fitness value)	Distance Moved After
1	1	1	1 6 210 3 9 4 8 5 711	274	1 2 3 4 5 6 7 8 9 10 11 (1.0)	48
2	2	3	2 1 4 9 6 7 8 510 311	241		
3	3	4	9 4 1 6 3 8 710 5 211	208		
4	6	5	8 1 6 2 4 91110 7 3 5	163		
5	9	6	2 3 5 8 91110 1 6 4 7	139		
6	10	7	1 6 210 3 9 4 8 5 711	274		
7	18	18	2 1 4 9 6 7 8 510 311	241		
8	22	20	9 4 1 6 3 8 710 5 211	208		
9	23	21	8 1 6 2 4 91110 7 3 5	163		
10	24	24	2 3 5 8 91110 1 6 4 7	139		
11	25	25	1 6 210 3 9 4 8 5 711	274		
			2 1 4 9 6 7 8 510 311	241		
			9 4 1 6 3 8 710 5 211	208		
			8 1 6 2 4 91110 7 3 5	163		
			2 3 5 8 91110 1 6 4 7	139		
			1 6 210 3 9 4 8 5 711	274		
			2 1 4 9 6 7 8 510 311	241		
			9 4 1 6 3 8 710 5 211	208		
			8 1 6 2 4 91110 7 3 5	163		
			2 3 5 8 91110 1 6 4 7	139		
			2 3 5 8 91110 1 6 4 7	139		
			1 6 210 3 9 4 8 5 711	274		

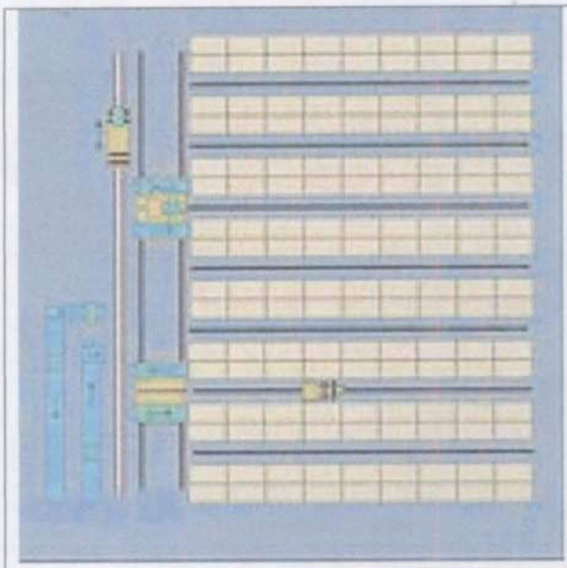
Data set 6



Route: 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10 – 11
Distance: 48

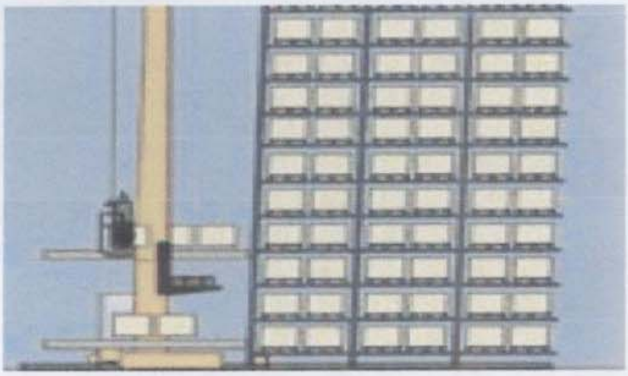
Reduction of AS/RS machine in storage area by clustering of demand data using Simulation Modeling

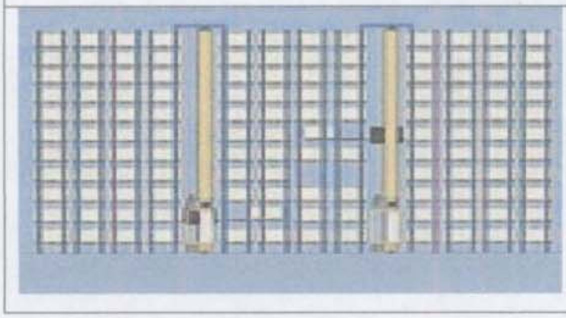
K.S.Badarinarayan “Flexible manufacturing system scheduling” Thesis. Department of Mechanical Engineering, NIT Calicut, University of Calicut, 2007

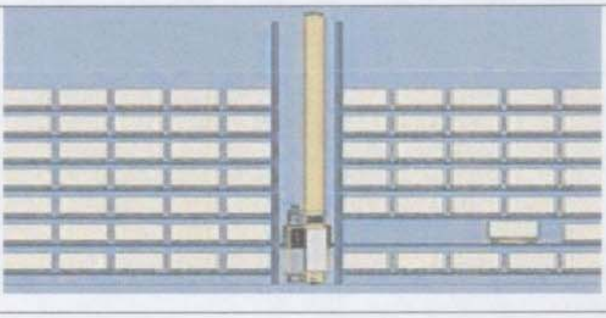


Chapter - 5

Reduction of AS/RS machine in storage area by clustering of demand data using Simulation Modeling







Chapter – 5

5.0 Introduction:

The request for retrieval and storage are clustered using the cluster analysis approach discussed in chapter 3.0. The sequence for the movement of the machine within the clusters is arrived at using genetic algorithm discussed in chapter 4.0. The validation of the assumptions is essential. Hence simulation approach is used in this work to consolidate the findings of the research.

Simulation is the representation of a real life system by another system, which depicts the important characteristics of the real system and allows experimentation on it. In other words simulation is an imitation of the reality. Though the formal use of the simulation technique is not very old, simulation has long been used by the researchers, analysts, designers and other professionals in the physical and non-physical experimentation's and investigations. Simulation is very useful for experiments with the internal interactions of a complex system or of a subsystem within a complex system. Simulation can be employed to experiment with new designs and policies, before implementing them. Simulation can be used to verify the results obtained by analytical methods and to reinforce the analytical techniques. Simulation is very useful in determining the influence of changes in input variables on the output of the system.

Simulation helps in suggesting modifications in the system under investigation for its optimal performance. Different steps employed in simulation are Problem formulation, Model construction, Data collection, Model programming, Validation, Simulation run and analysis, Documentation, and Implementation.

5.1 Problem area

The shortcomings of the research connected with simulation of AS/RS machine handling are;

- Effect of cluster formation in handling material requests is not addressed by simulation
- More work is reported with AGV on shop floor, than AS/RS in storage area.

- Different scenarios like breakdown, arrival time distribution for jobs, dispatching rules, number of machines, are not explored with storage material handling machine.

In order to address the above cited problems the following objectives are formulated.

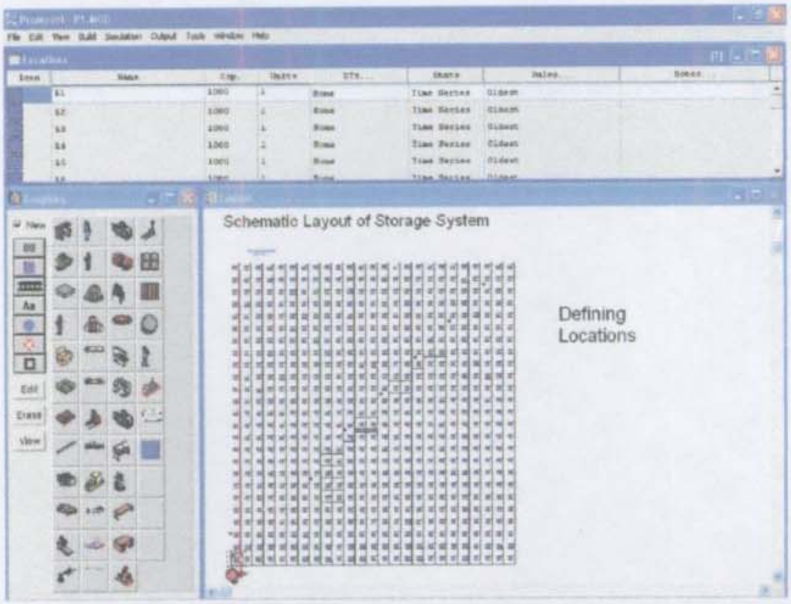
- To develop simulation model using ProModel software to study the performance of the system before and after clustering.
- To study the influence of Downtime, Number of machines, Different arrival time distributions and Different scheduling rules on performance of the system.
- To schedule the movement of AS/RS within and between the clusters for improving productivity.

5.2 ProModel Simulation software

ProModel is powerful, windows based simulation tool for simulation & analyzing production systems of all types and sizes. It provides the perfect combination of ease-of-use and complete flexibility and power of modeling nearly any situation, and its realistic animation capabilities makes simulation come to life. The simulation software is user friendly. Models are created by completing the necessary modules selected from build menu. Each module consists of various edit tables and dialogue boxes used to supply model information. The logic builder in ProModel provides a quick and powerful way to create and insert valid statements and expressions in logic windows or fields. The software has the ability to merge two or more models into one larger model. Completed models are run using the simulation menu. Model data is automatically checked for consistency and completeness before each simulation begins. During model execution we may trace the activity of events to see exactly what's happening in the model. The output generator gathers statistics on each location, entity, resource, path network and variables in the system. The default level of statistics is at summary level, although detailed history plots can be gathered on utilization, queue fluctuations.

The locations are defined in the storage area for storing the raw material. This is the area where operation is performed and value addition takes place. The storage locations and the loading and unloading area are created using the build location module. The screen shot of the same is shown in figure 5.1.

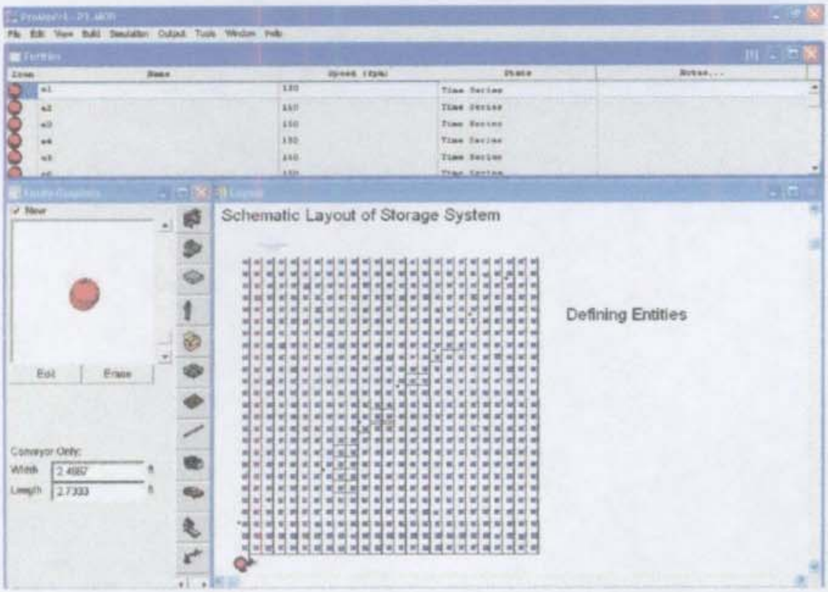
Figure 5.1 - Screen shot of Defining Location



Icon	Name	Cap.	Units	DTs...	Stats	Rules...	Notes...
	L1	1000	1	None	Time Series	Oldest	
	L2	1000	1	None	Time Series	Oldest	
	L3	1000	1	None	Time Series	Oldest	
	L4	1000	1	None	Time Series	Oldest	
	L5	1000	1	None	Time Series	Oldest	

The Entities are nothing but the raw material stored, for each location an entity is defined. Different entities are defined for different locations. The screen shot of the same is shown in figure 5.2.

Figure 5.2 - Screen shot of Defining Entities

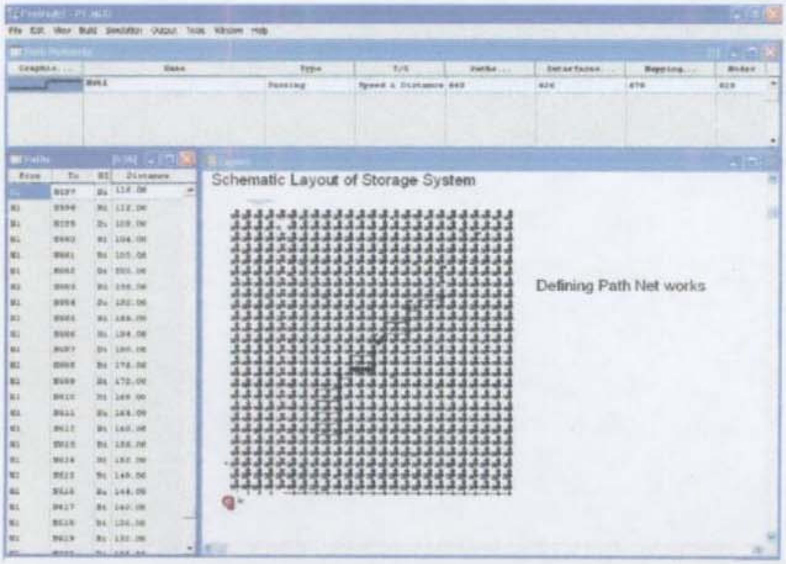


Icon	Name	Speed (fpm)	Stats	Notes...
	e1	150	Time Series	
	e2	150	Time Series	
	e3	150	Time Series	
	e4	150	Time Series	
	e5	150	Time Series	

Conveyor Only:
Width 2.4867 ft
Length 2.7333 ft

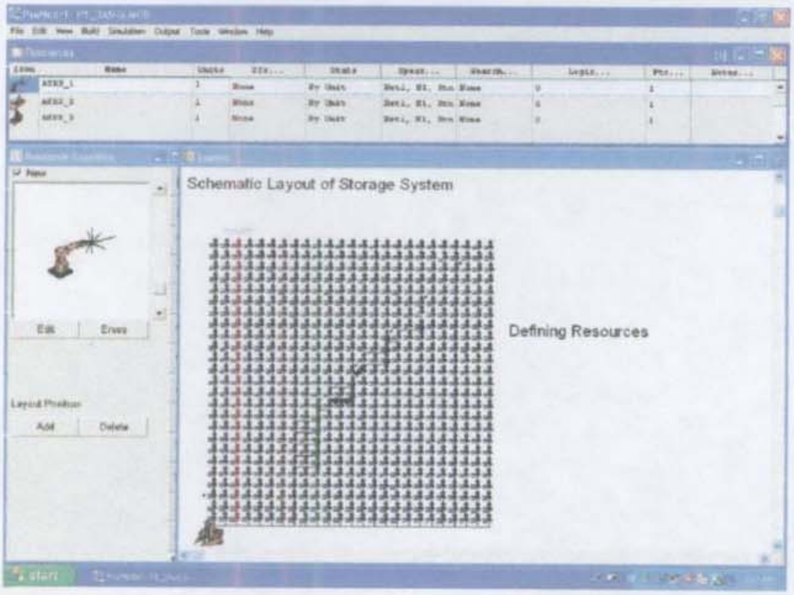
The network i.e. the path between locations and loading/unloading point is to be defined. This is essential to establish the route for the movement of ASRS. The interference between the location and the node is established. The screen shot of the same is shown in figure 5.3.

Figure 5.3 - Screen shot of Defining Path Networks



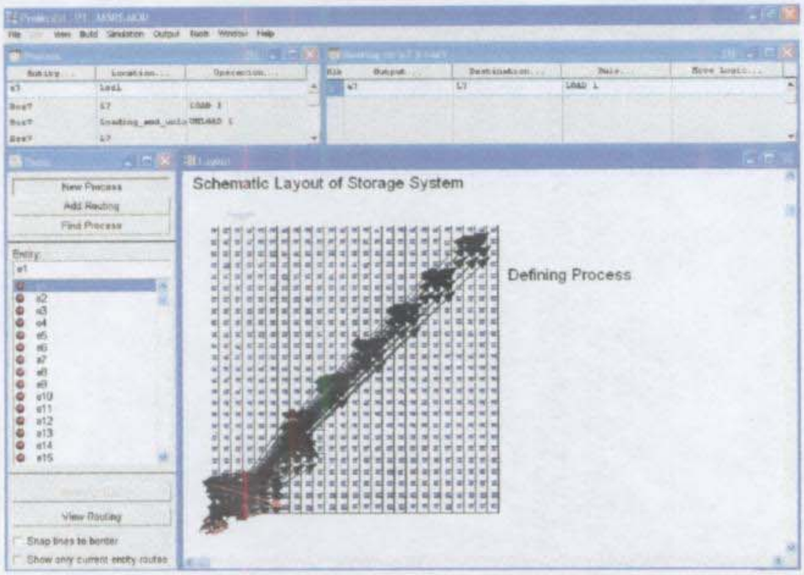
The material is transported from locations to loading and unloading point using machine. The details regarding the number of machines and speed, parking point etc are defined in the resource module. The screen shot of the same is shown in figure 5.4.

Figure 5.4 - Screen shot of Defining Resources



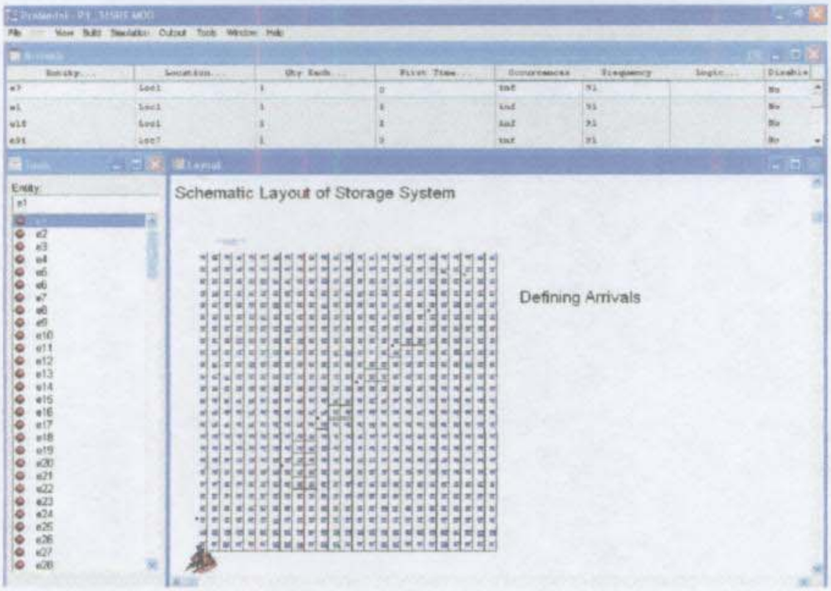
The process routing i.e., movement of the machine from loading / unloading point to the location and vice versa is specified. The screen shot of the same is shown in figure 5.5.

Figure 5.5 - Screen shot of Defining Process



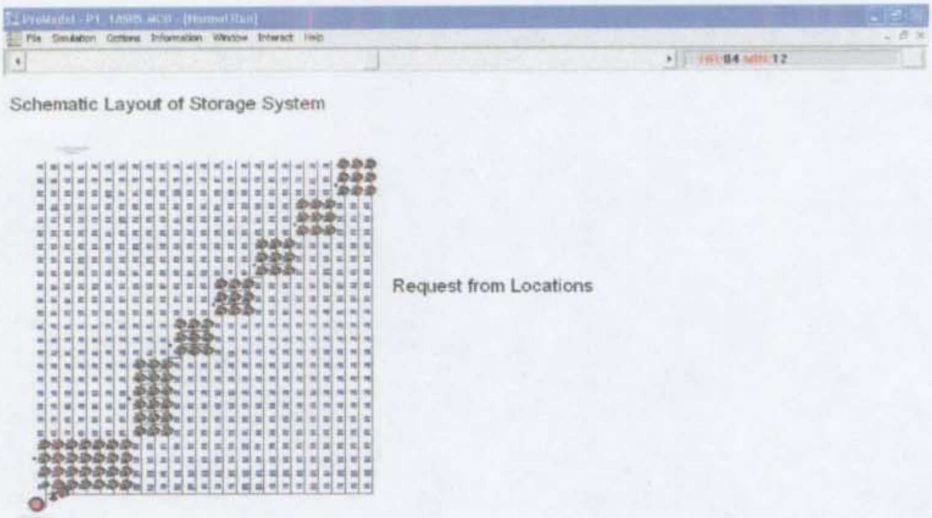
The arrival of the orders is specified in arrival module. The screen shot of the same is shown in figure 5.6.

Figure 5.6 - Screen shot of Defining Arrivals



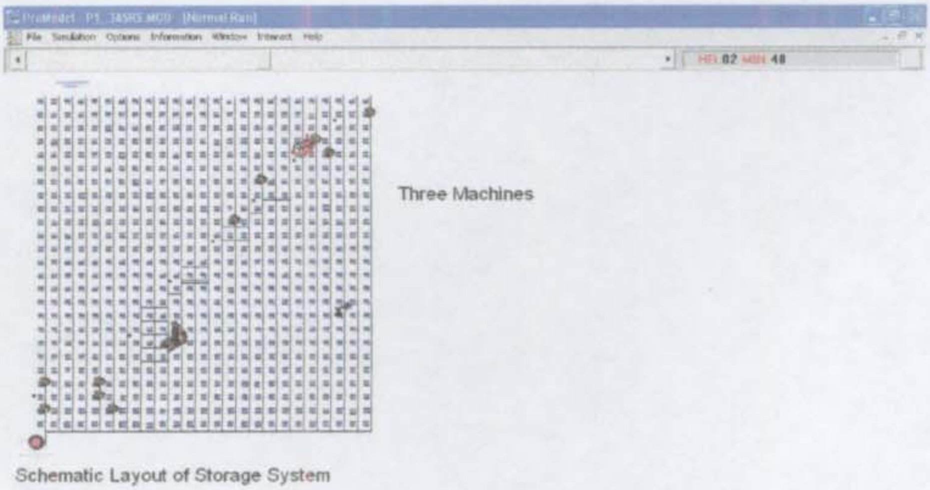
The waiting for request from different locations in a real time situation under simulation is shown in the screen shot figure 5.7.

Figure 5.7 - Screen shot of Request from Locations



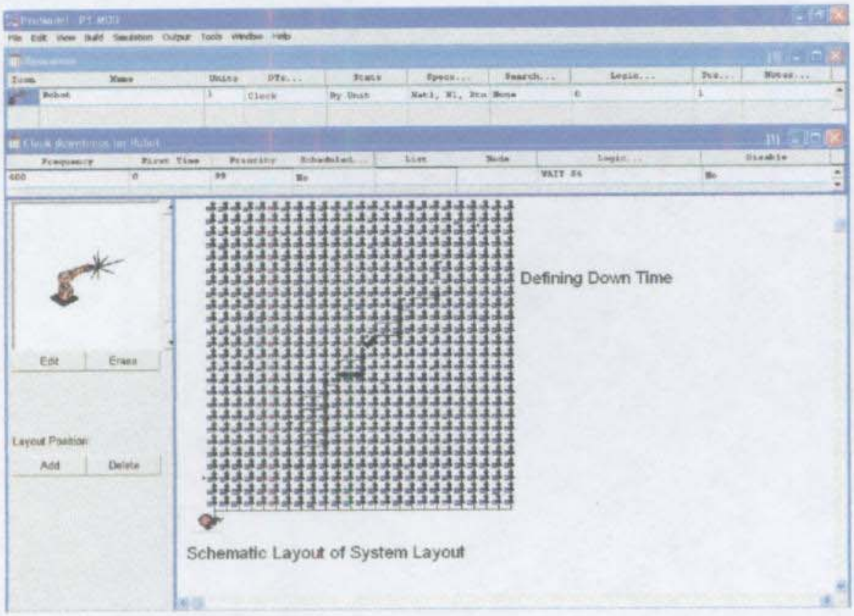
The screen shot of figure 5.8 shows loading of multiple AS/RS machines for transporting material.

Figure 5.8 - Screen shot of loading of multiple AS/RS machines



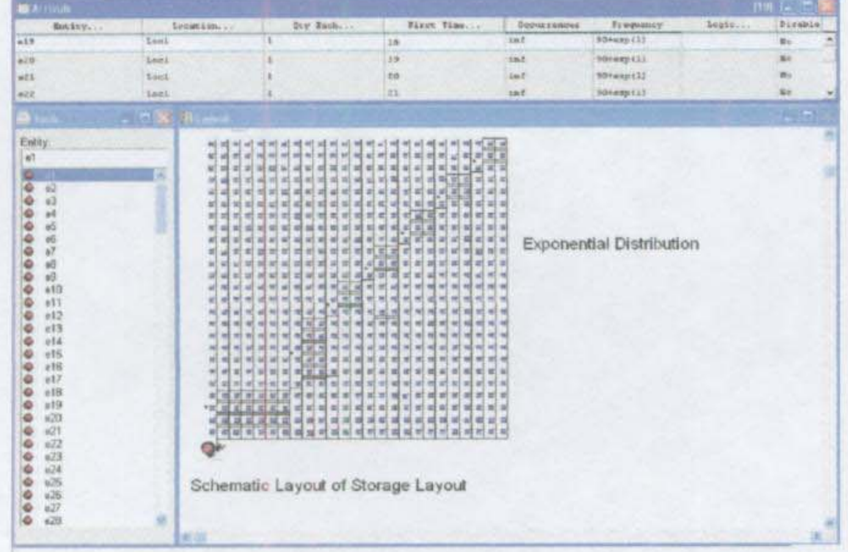
The screen shot figure 5.9 depicts the process of defining the down time for the machines.

Figure 5.9 - Screen shot of Defining down time



The screen shot figure 5.10 depicts the setting of different arrival time distribution for request.

Figure 5.10 - Screen shot of Defining different arrival time



For complex process, programming is required otherwise simulate module can be used to simulate the model for different lengths of time.

5.3 Data Input

Two data sets with 91, 149 requests are considered for building the model. After applying Cluster analysis discussed in chapter 3, the requests are grouped into clusters. So we have another two data sets with cluster formation. In total, four models are built in the software. Refer Figure 5.12, 5.13 for data setl ,data set2 before clustering. Figure 5.14, 5.15 for data setl, data set2 after clustering.

Figure -5. 12 **Data set 1 Before clustering.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1				25					26		27														
2	12		7			9	11	13					3						5						
3																				54		55			50
4	13		8			10	12	14					4						6						
5	15		10			12	14	16					6						8						
6				26					27		28														
7										33						24							27		
8		32										10					35								
9															31			47						43	
10										35						26							29		
11				27					28		29														
12		30										20					25								
13				24					25		26														
14					30									34							15				
15				23					24		25														
16					30									35							16				
17															30			46						42	
18	14		9			11	13	15					5						7						
19															32			48						44	
20		31										30					30								
21																				52		53			48
22				28					29		30														
23					40									36							17				
24																				53		54			49
25										34						25							28		

Figure -5.13 Data set 2- Before clustering.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1		4							7		1								3					25
2	2		2	7								6								4					
3	4		3	8						9		2								5					
4	4		7	9			13			2		8								6					
5	6			1						3		9								7					
6	5		9	2						5		5													
7			1	5						6		7								9					
8	6		1	3						1										1					
9		19			26		28		20		21						27					12			
10		20			27		29		21		22			14			28								
11		21			28		10				13			25			19					14			
12		12			19		21		23		24			16			20	28	31			15			
13		23					22		24		25			27			21					26			
14		24			21		23		25		26			18								27			
15		15			12		24		16		17			29			13					18			
16					13		25		27		28			20			14					19			
17						24										22		33	26		37				
18						35										33		34	37		28			36	
19				24		26										24			28		39			37	
20						37												36	39		30			38	
21						28										26		37	20					39	
22								33					37		35								44		
23								44					48										45		37
24								35					49		47										38
25								36			37		30		38								47		39

Figure – 5.14 Data set 1- After clustering.

```
       4   9  11   1   3   6   7   8  13  19  20  22  25  10  16  23   2  12  17  15  18  24   5  14  21
----------------------------------------------------------------------------------------------------------
  1|  25  26  27
  6|  26  27  28
 11|  27  28  29
 13|  24  25  26
 15|  23  24  25
 22|  28  29  30
  2|              12   7   9  11  13   3   5
  4|              13   8  10  12  14   4   6
  5|              15  10  12  14  16   6   8
 18|              14   9  11  13  15   5   7
  3|                                          54  55  50
 21|                                          52  53  48
 24|                                          53  54  49
  7|                                                      33  24  27
 10|                                                      35  26  29
 25|                                                      34  25  28
  8|                                                                  32  10  35
 12|                                                                  30  20  25
 20|                                                                  31  30  30
  9|                                                                              31  47  43
 17|                                                                              30  46  42
 19|                                                                              32  48  44
 14|                                                                                          30  34  15
 16|                                                                                          30  35  16
 23|                                                                                          40  36  17
```

Figure – 5.15 Data set 2- After clustering.

```
       1   3   4  10  12  20   2   5   7   9  11  14  17  22   6  16  18  19  21  24   8  13  15  23  25
----------------------------------------------------------------------------------------------------------
  1|   1   4       7   1   3                                                                          25
  2|   2   2   7       6   4
  3|   4   3   8   9   2   5
  4|   4   7   9   2   8   6          13
  5|   6       1   3   9   7
  6|   5   9   2   5   5
  7|       1   5   6   7   9
  8|   6   1   3   1       1
  9|                          19  26  28  20  21      27  12
 10|                          20  27  29  21  22  14  28
 11|                          21  28  10      13  25  19  14
 12|                          12  19  21  23  24  16  20  15          28  31
 13|                          23      22  24  25  27  21  26
 14|                          24  21  23  25  26  18      27
 15|                          15  12  24  16  17  29  13  18
 16|                              13  25  27  28  20  14  19
 17|                                                          24  22  33  26  37
 18|                                                          35  33  34  37  28  36
 19|          24                                              26  24      28  39  37
 20|                                                          37      36  39  30  38
 21|                                                          28  26  37  20      39
 22|                                                                                  33  37  35  44
 23|                                                                                  44  48      45  37
 24|                                                                                  35  49  47      38
 25|                                          37                                      36  30  38  47  39
```

5.4 System modeling and Simulation

Under FCFS policy, the retrieval and storing of containers back to their location, results in more distance to be traveled. If the requests are grouped together into clusters, it is possible to schedule the machine with in the clusters. In this work a simulation model is developed to study the performance of the system before and after clustering. Performance measures like Average stay in the system and Average time spent in move are used for evaluation.

5.4.1 Model Description

A 25 rows and 25 columns storage rack housing 625 storage bins of unit size is considered for simulation. AS/RS machine will move horizontally and vertically on the guided rails placed in between the storage racks. The machine is initially stationed at loading and unloading point, when request for the material is made; it travels to the location, retrieves the container and brings it to the loading and unloading station. Once the job is over, container is to be stored back into same position. The layout of a hypothetical storage rack of size25x25 is shown in figure 5.11

Two scenarios, before and after clustering are used to illustrate the importance of clustering. The request arrival pattern is assumed to follow exponential, normal, triangular and uniform distributions. The processing times for different request are assumed to be constant. The influence of Downtime, Number of machines, and different scheduling rules are also investigated.

The model is simulated to study the impact of clustering algorithm on performance of the AS/RS machine. The average minutes in the system and move are taken as measure of performance. The simulation experiment is carried out for a period of 100 hours.

Figure 5.11 Schematic Layout of Storage Area

25	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
24	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
23	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
22	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
21	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
20	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
19	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
18	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
17	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
16	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
15	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
14	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
13	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
12	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
11	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
10	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
9	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
8	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
7	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
6	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
5	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
4	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
3	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
2	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
1	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣	▣
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**

5.5 Analysis of simulation results

The simulation experiments are analyzed in 5 sections

(1) Before and after formation of clusters.
(2) Arrival distribution times.
(3) Downtime analysis.
(4) Number of Machines analysis.
(5) Scheduling rules.

5.5.1 Before and after formation of clusters

AS/RS machine is used to transport material from locations to loading and unloading points. If there are no requests, the machine is parked at loading point. Before the cluster formation, in the First Come First Serve policy, for retrieval of the parts the machine has to travel from unloading and loading point to location to pick the container and travel back to loading and unloading point. For storing back the container the machine travels from loading and unloading point to the location, deposits the container and comes back to the original loading and unloading position. Thus, four movements of machine are required for each request. As the current retrieval points are future storage points the similarity between requests are considered, then they are grouped into clusters. Using Clustering advantage the movement of the machine can be made within clusters. This reduces the distance traveled and average stay and time in move. The time required to satisfy the request and the time spent in the move for two data sets with before and after cluster analysis are tabulated in the Annexure 5.1. The average minutes in the system and move before and after cluster formation are shown in Figures 5.16, 5.17 respectively. From the analysis, it is found that the average stay in the system and move time in after cluster formation is much less compared to before cluster formation. Thus, moving AS/RS machine within and between the clusters enhances the productivity of the system.

Figure–5.16 Savings in average stay in system – Before & After

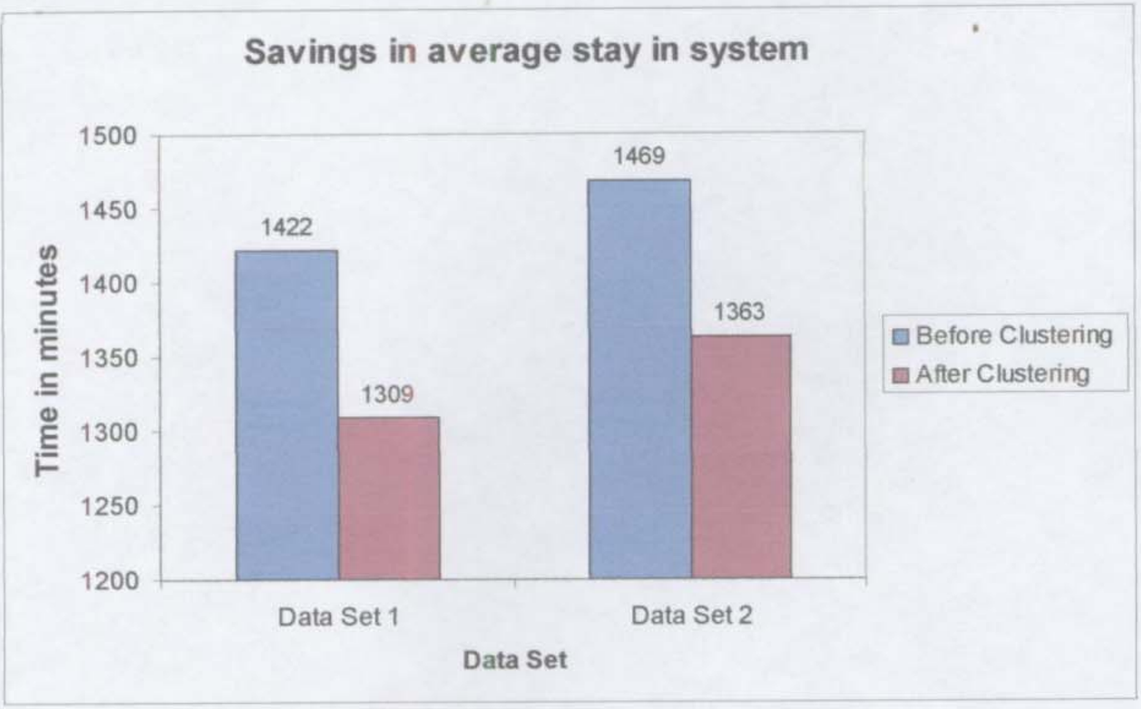
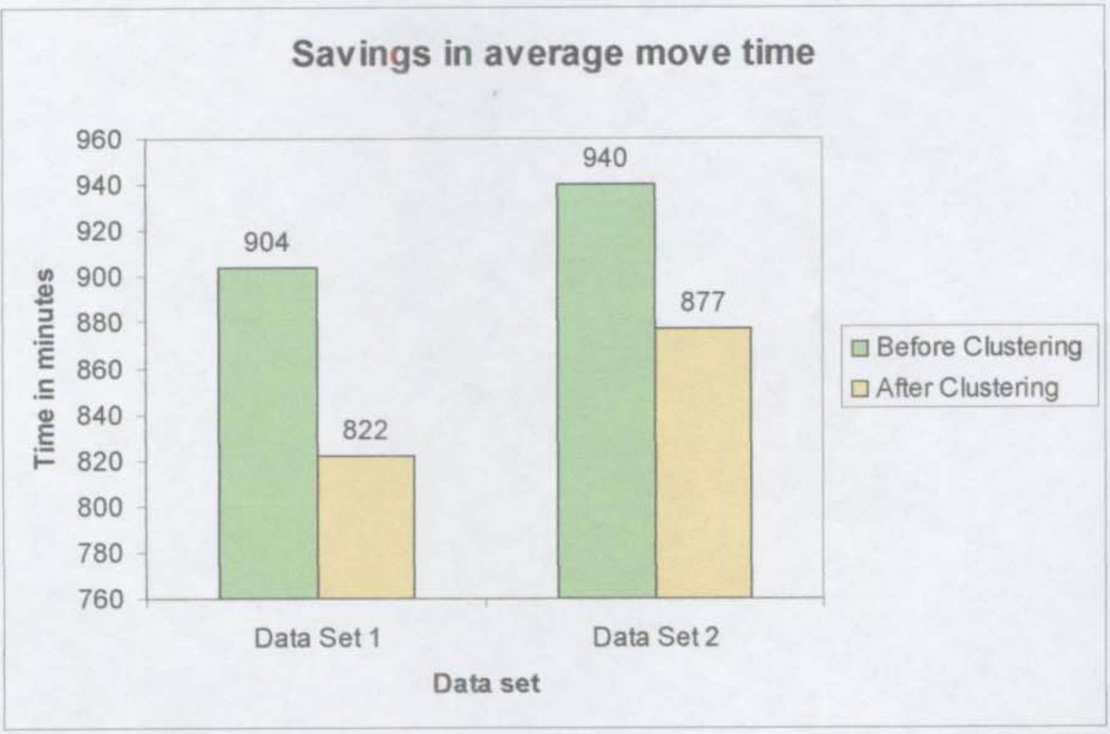


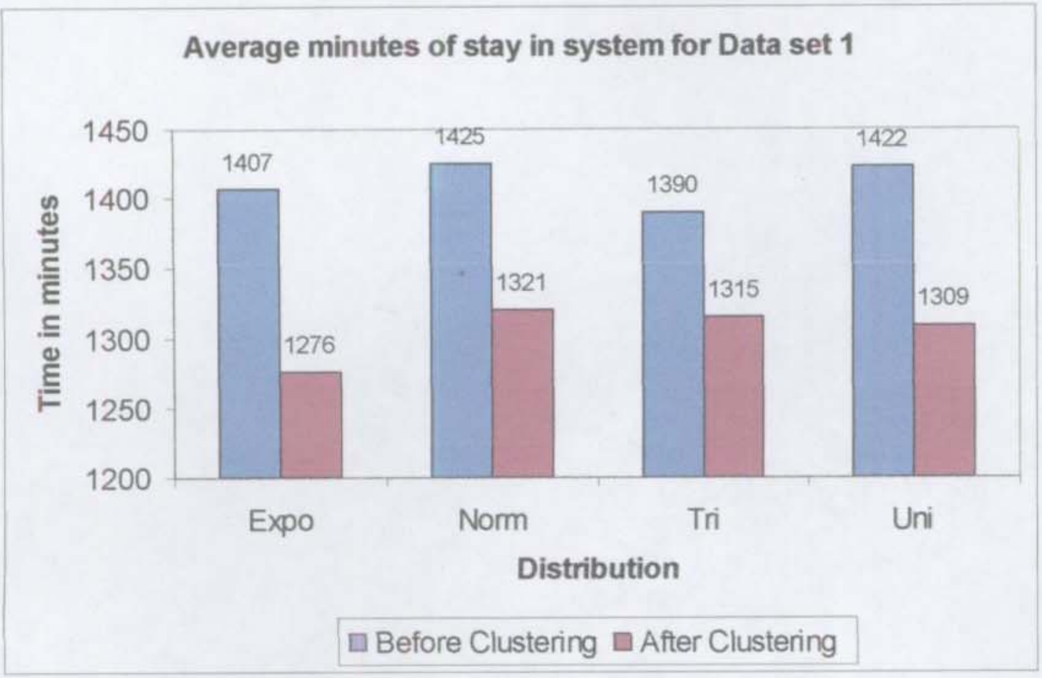
Figure – 5.17 Savings in average stay in Move – Before & After



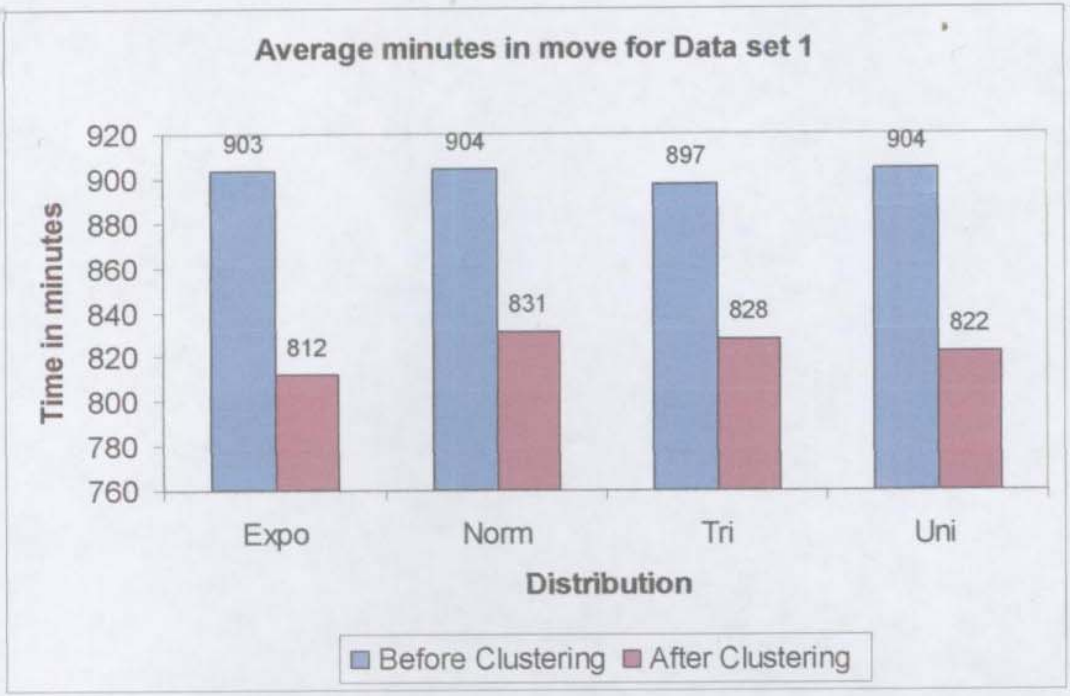
5.5.2 Arrival distribution times

The arrival of requests may follow any kind of distribution. Depending on the type, the system performance may vary. In order to investigate the influence of distribution patterns on system performance, several distributions like Normal, Exponential, Triangular, & Uniform distributions are considered in the before and after cluster formation scenario. Simulation is carried out considering the above distributions and the average minutes in the system and move are shown in Figures 5.18, 5.19, 5.20, 5.21 respectively. The output data is shown in annexure 5.2. It is observed that the average minutes in the system and move is less in after cluster formation compare to before cluster formation.

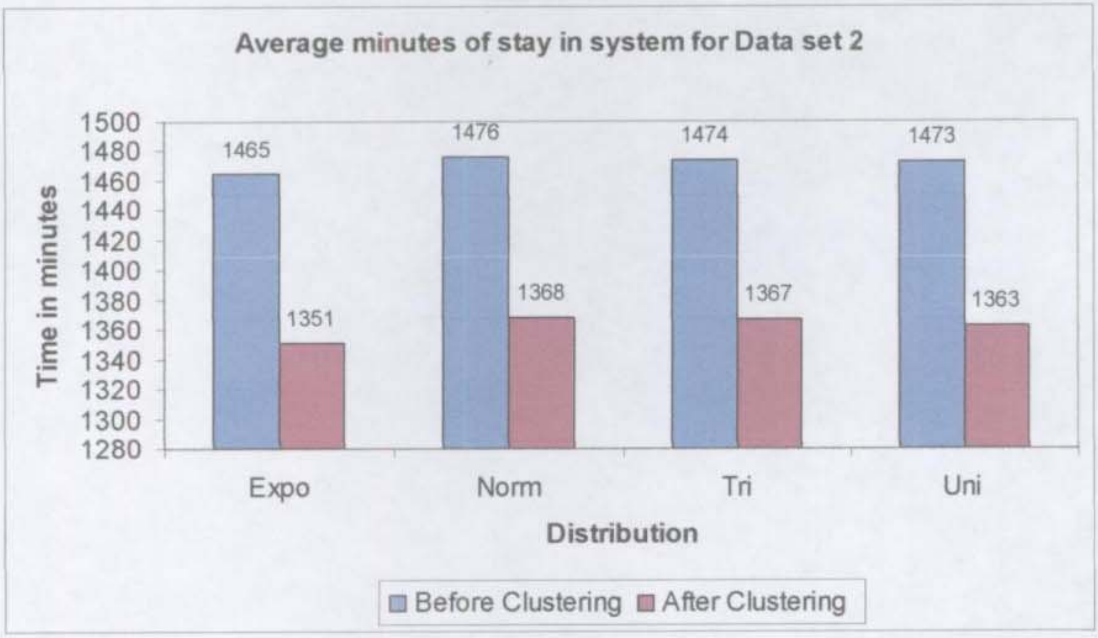
Figure–5.18 Savings in average stay in system, Data set 1 – Arrival Time Distribution



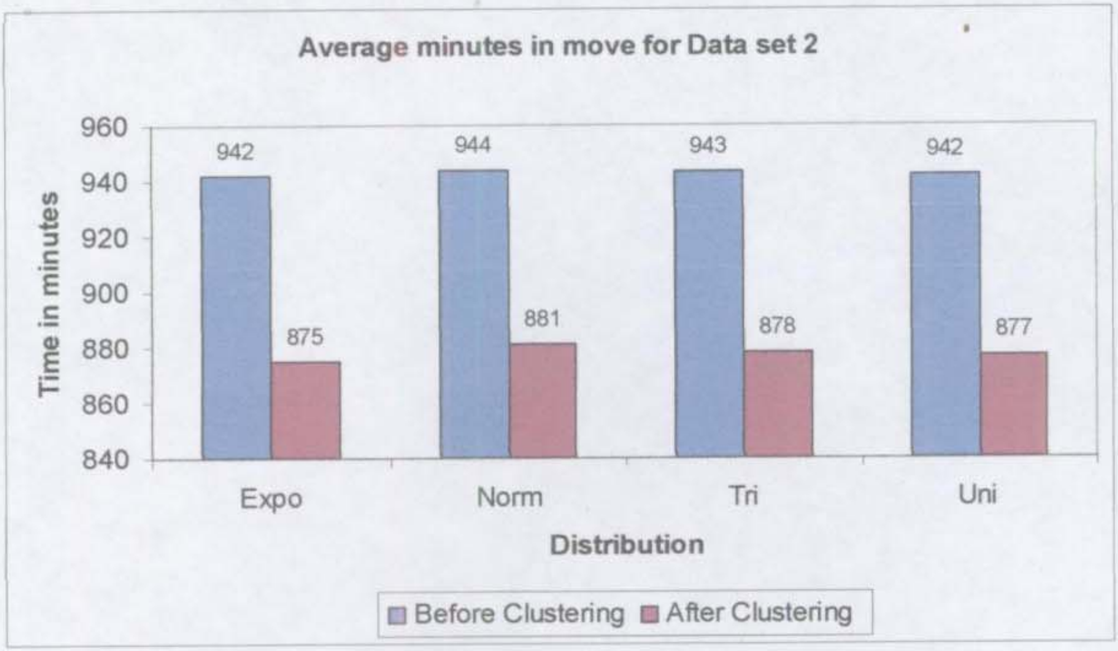
Figure–5.19 Savings in average move, Data set 1 – Arrival Time Distribution



Figure–5.20 Savings in average stay in system, data set 2 – Arrival Time Distribution



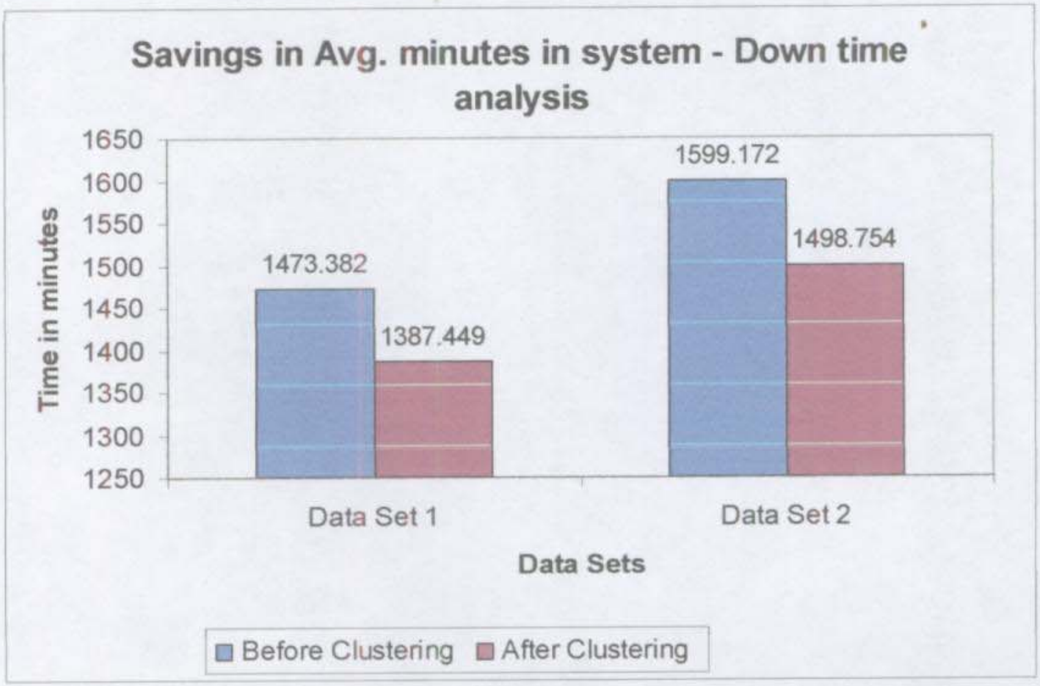
Figure–5.21 Savings in average move, data set 2 – Arrival Time Distribution



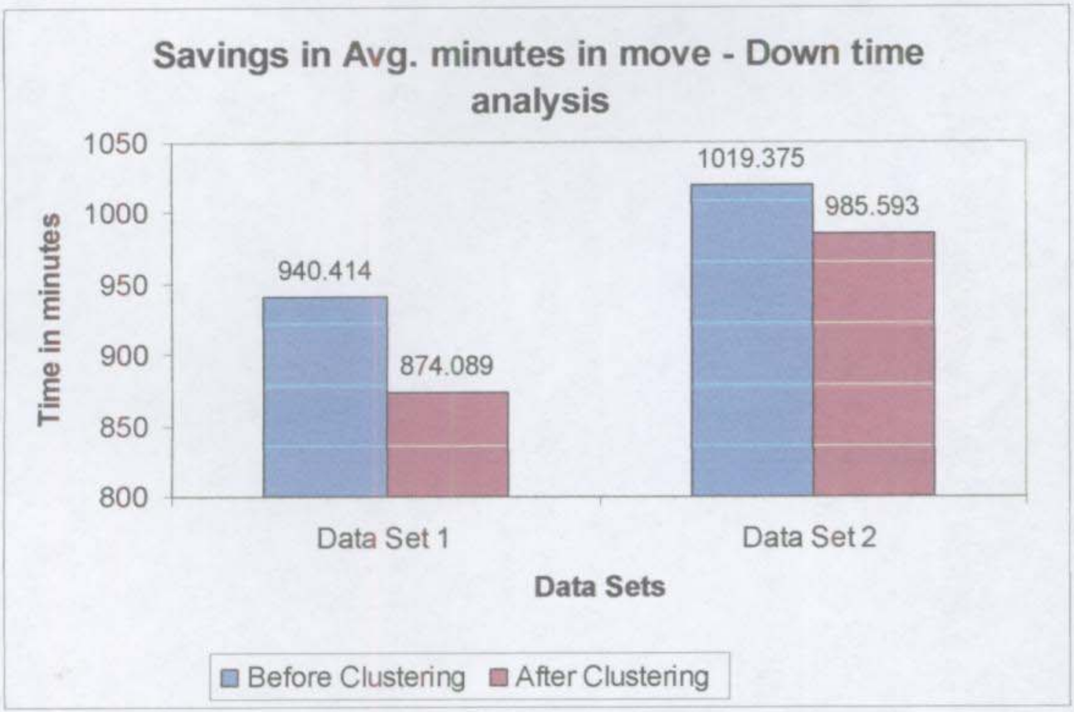
5.5.3 Downtime analysis

Manufacturing systems are subjected to various interruptions such as machine failure, tool failure, etc. The AS/RS machine used for transporting materials is also prone to failures. To model the breakdown, it is necessary to specify the time between failures and repair time. In this simulation model, the machine is made to break down for 1% to 10 % of the run time. Repair time is assumed to be 10 % of the down time. The average time spent in the system; move by AS/RS machine after cluster formation is less compared to before cluster formation and is shown in figure 5.22 & 5.23. The output data is shown in annexure5.3.

Figure–5.22 Savings in average stay in system – Down Time Analysis



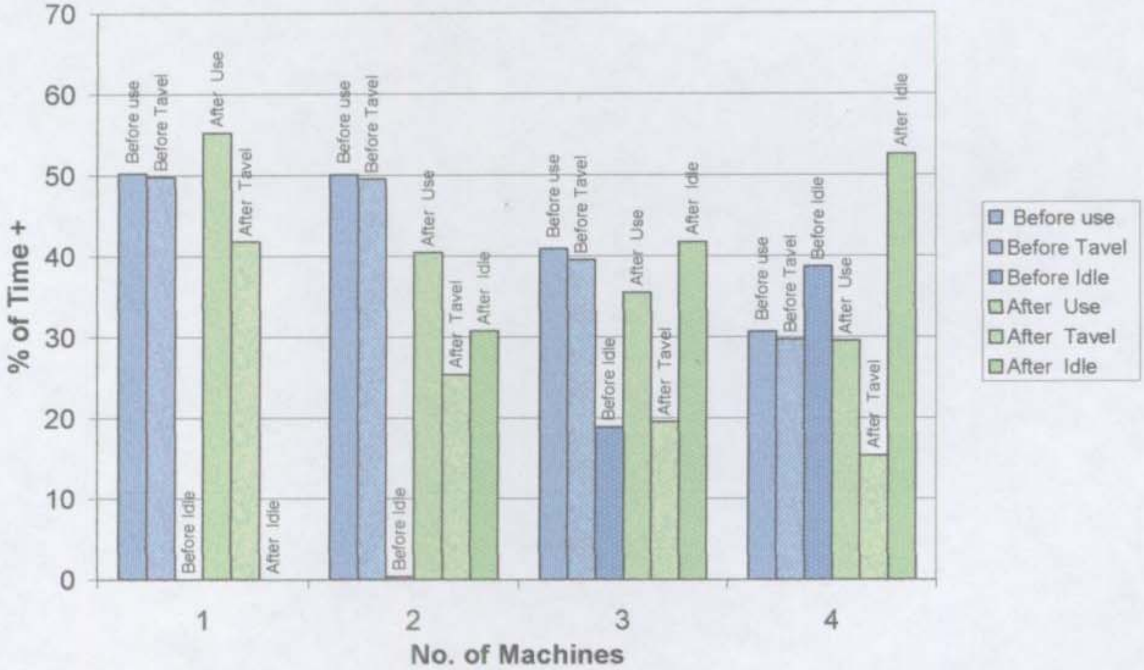
Figure–5.23 Savings in average move – Down Time Analysis



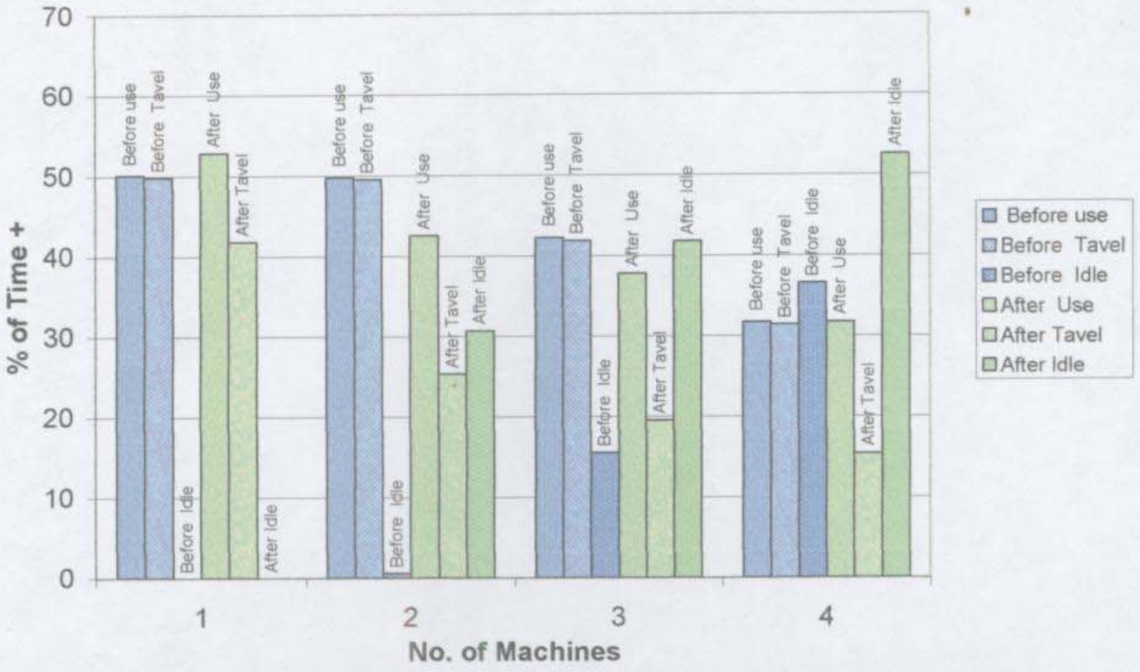
5.5.4 Number of Machines analysis

In this paper the number of AS/RS machines required for meeting the requests is determined by simulation modeling. The number of machines is varied and the average time spent in the system, travel and idle time of the machine are observed .It is found that the idle time increases and the travel time decreases as the number of machines is increased. The average time spent in the system, move by AS/RS machine after cluster formation is less compared to before cluster formation and is shown in figure 5.24 for data set1 and for before and after for data set2 is shown in figure 5.25.The figures 5.26 and 5.27 indicate the requirement of machines after cluster formation is almost half compared to before cluster formation. The output data is shown in annexure 5.4.

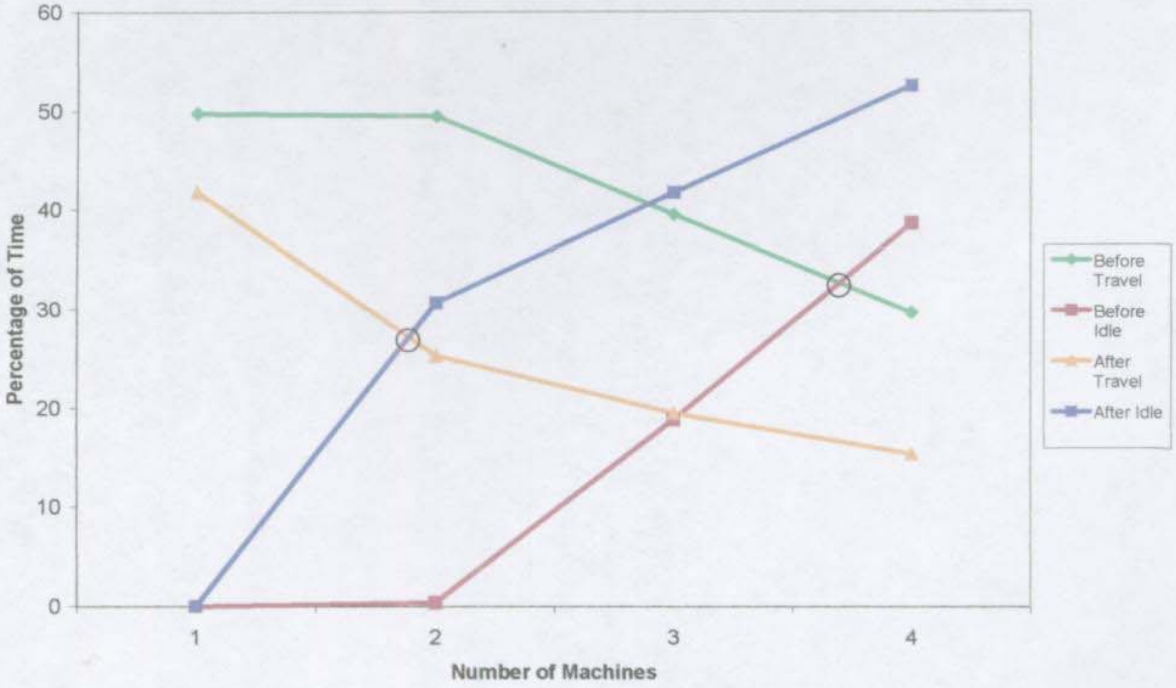
Figure–5.24 Idle & Travel time for data set1, Before and after cluster formation



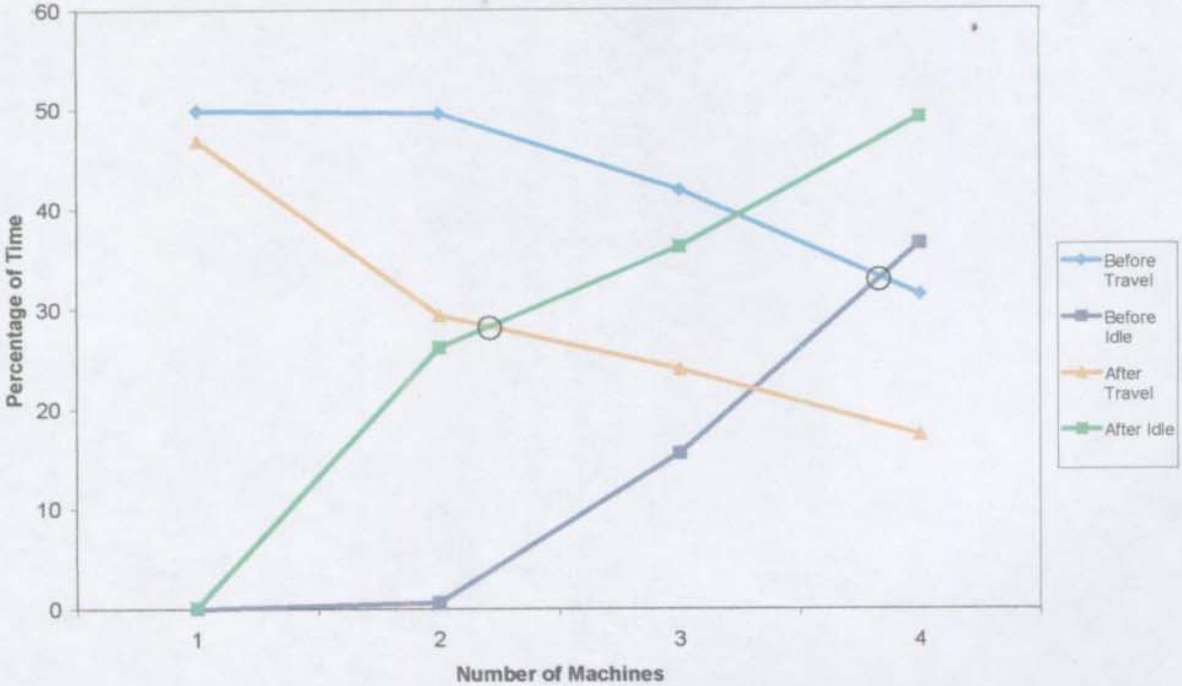
Figure–5.25 Idle & Travel time for data set2, Before and after cluster formation



Figure–5.26 Number of machine requirement in data set 1,Before and after



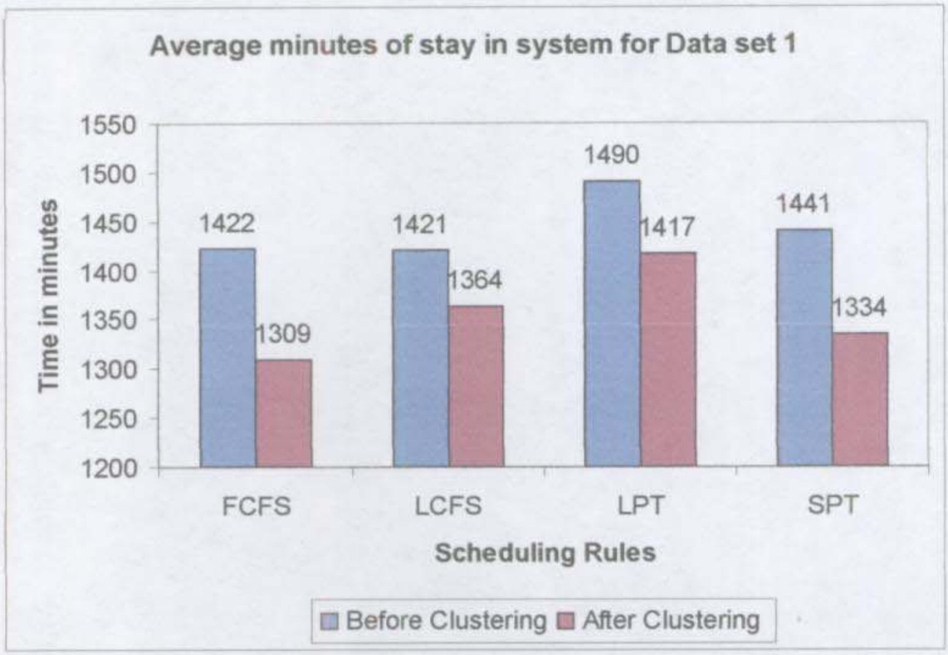
Figure–5.27 Number of machine requirement in data set 2,Before and after



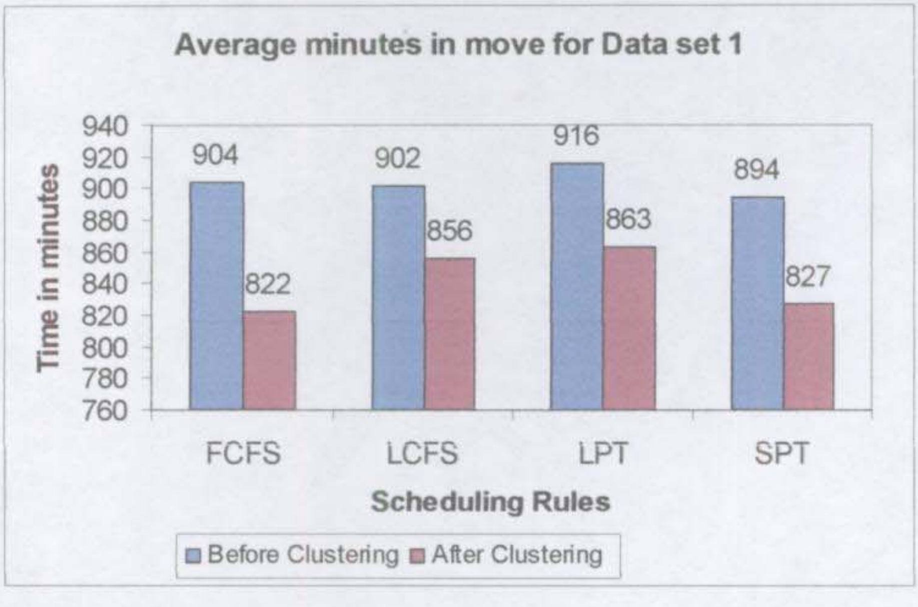
5.5.5 Scheduling rules

Panwalkar et al [4] have proposed more than hundred scheduling rules. Research in scheduling area mainly revolves around the combination of several dispatching rules. The utility and performance of a system varies under each of these rules. In this work rules such as FCFS, LCFS, SPT, and LPT are considered. With these rules, scheduling of AS/RS machine is carried out. It is found that The average time spent in the system, move by AS/RS machine after cluster formation is less compared to before cluster formation and is shown figures 5.28, 5.29, 5.30, 5.31 depict the influence of cluster formation on different dispatching rules. FCFS rule turns out to be the best choice. The output data is shown in annexure 5.5.

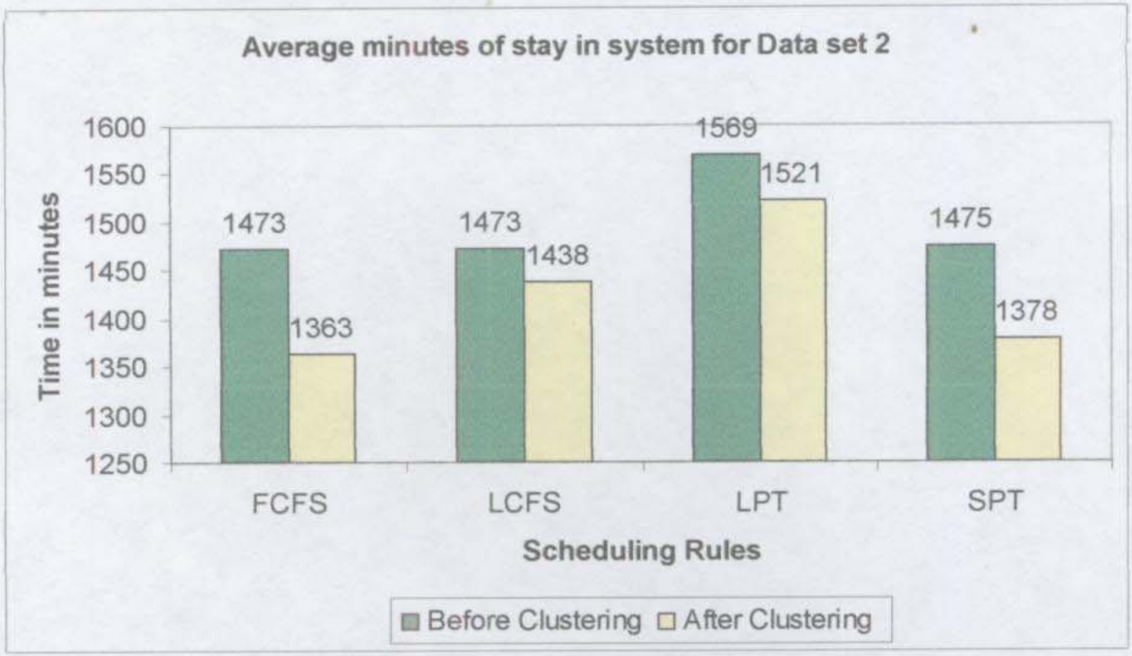
Figure–5.28 Savings in average stay in system, data set 1 – Scheduling Rules



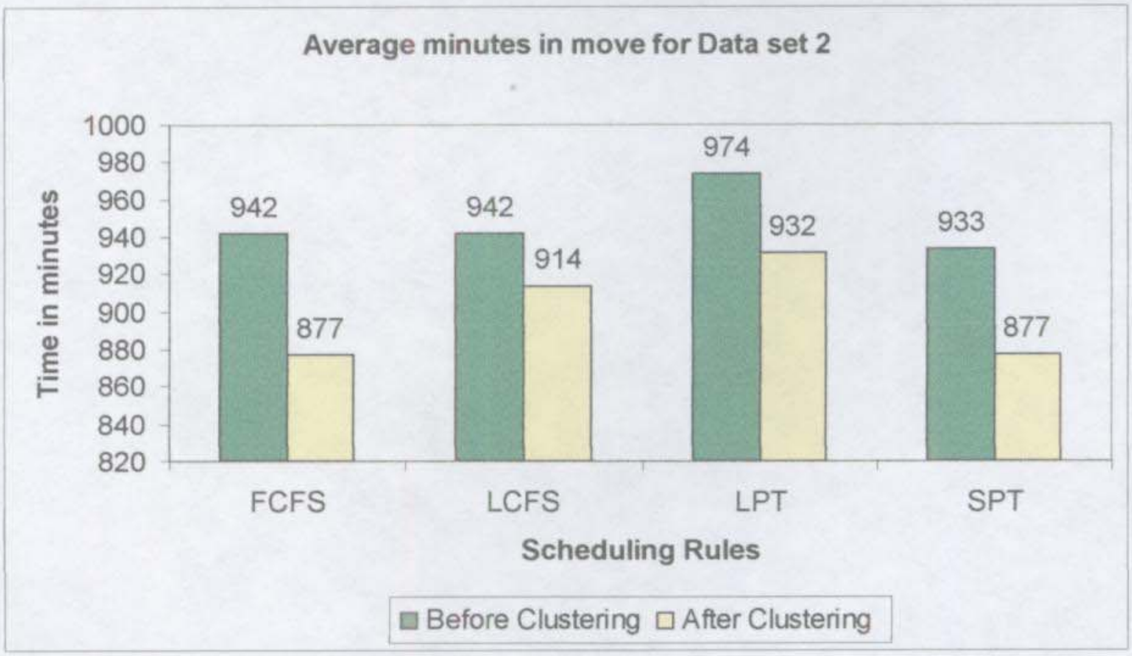
Figure–5.29 Savings in average move, data set 1 - Scheduling Rules



Figure–5.30 Savings in average stay in system, data set 2 - Scheduling Rules



Figure–5.31 Savings in average move, data set 2 - Scheduling Rules



5.6. Conclusions

The AS/RS machine is scheduled in two scenarios namely with and with out cluster formations. The effect of distribution of arrival time of requests is analyzed. It is observed that exponential distribution has resulted in least average stay in system and move. While considering the number of machines required for transportation it is observed that the requirement of machines in clusters is almost half compared to the requirement in before cluster formation.

The machines are prone to break down resulting in down time. The Breakdown of machine is considered with and without cluster formation, the average stay in system and move are less in after scenario compared to before cluster formation.

The influence of various dispatching rules on the performance of the system is investigated. It is found that FCFS rule is more favorable and it is evident from the study that the average time spent in the system, move in the clusters is less. Hence, there is an advantage of grouping the requests into clusters.

Results and Conclusions

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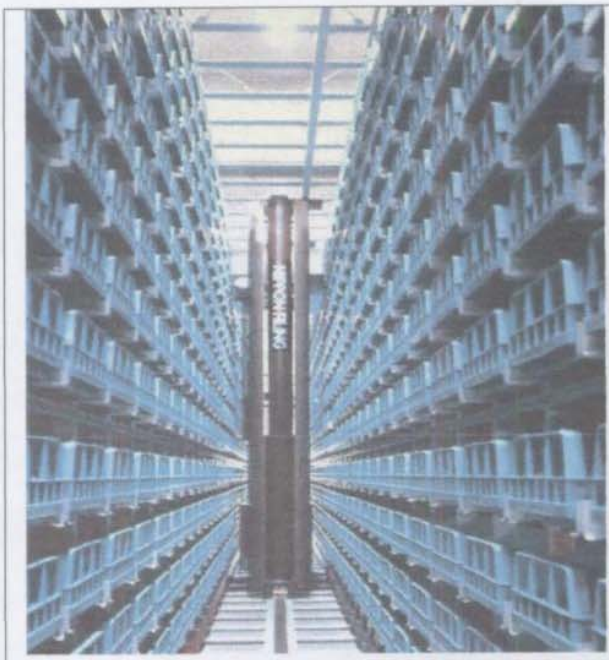

Chapter -6

Results and Conclusions

End......

Chapter – 6

6.0 Results and Conclusions

The work considers the scheduling problem of moving an AS/RS in a system with many storage and retrieval positions. As a queue discipline FIFO or any other physical criterion will lead to an enormous distance traveled by the AS/RS, it was felt that the short term scheduling could be achieved better by employing a suitable algorithm.

In the first chapter, an introduction to FMS Scheduling, need for the research, context and proposed solution along with the thesis overview are provided.

In the second chapter, the literature review carried out highlights the shortcomings of the present research in the area, which provide direction for the current research.

In the third chapter, it was felt that grouping the requests together into clusters and dealing with clusters separately could reduce the total distance traveled. Using Cluster analysis concept, an attempt is made to explore the similarity between the locations to cluster requests. The sequencing of the requests and scheduling of AS/RS machines are carried out using the developed routing logic. The sequence of requests in the clusters reduces the frequency distance traveled, and results in savings. The research has explored the potential of the similarity existing between the requests for retrieval and storage. A performance measure for handling interval level data is developed. It is not necessary that one will be getting always Perfect clusters; there will be formation of imperfect clusters also. The effect of distance traveled outside cluster and distance not traveled inside cluster on efficiency and efficacy is also analyzed.

It was further shown that employing GA on clustered data would reduce the distance traveled within clusters. Sequence for scheduling of AS/RS machine is carried out using genetic algorithm to arrive at the best sequence of the request for storage and retrieval with in clusters with an objective of minimization of distance.

During the work, it was observed that the convergence of the solution was influenced by factors such as crossover, mutation operators, number of generations and the length of the sequence. The crossover operator alone cannot improve the solution. Mutation results in the avoidance of similar sequences. The effect of crossover operator, mutation operator and a combination of the two operators on convergence of the solution was also investigated. The study on the effect of the GA parameters on the convergence of the solutions for different length of sequence confirmed that the convergence of the solution is influenced by the length of the sequence. During the evolution process, it was observed that the final sequence generated gets reversed in some cases without any change in the total distance traveled. It is observed that there is a significant savings in the distance traveled. Several datasets with the initial sequences and final best sequence with distance traveled are presented in this work.

This work also explored a scientific approach to fix the levels of significant factors influencing the genetic evolution. Orthogonal Array experimentation technique was employed to determine the effect of GA parameters on convergence of solution. A L_{27} 3^{13} design is used for the conduction of experiments. The factors mutation and number of generations and the interaction between these two turned out to be significant in the analysis of variance The level setting for probability of crossover at 0.9, number of generations at 100, probability of mutation at 0.1 is recommended.

Further collaborative evidence was obtained with simulation also. The AS/RS machine is scheduled in two scenarios namely with and with out cluster formations. The effect of distribution of arrival time of requests is analyzed. The optimum number of machines required, considering the time spent in travel and idle time is determined. The machines are prone to break down resulting in down time. The down time analysis of machines is also studied. The influence of various dispatching rules on the performance of the system is investigated. It is evident from the study that the average time spent in the system, move in the clusters is less .Hence, there is an advantage of grouping the requests into clusters.

Finally, considering a common dataset we have applied clustering analysis, GA and simulation. In clustering, frequency distance from loading/unloading point to locations is minimized. There is 46 % savings with cluster formation and proposed routing logic.

The application of GA for developing a sequence to minimize the distance traveled inside clusters we were able to obtain considerable savings of more than 50% savings in inter container distance traveled as shown in table 6.1 for the common data set, whereas for the different data sets the savings realized are shown in Annexure 4.7.

Validation is made through simulation study ,where we have used the time data, ie, the time required to move from loading /unloading point to location are built into the model. The time taken is proportional to distance traveled. For the common dataset, the average stay in system and move shown in table 6.1.

Thus the present work is able to address the material handling issue of AS/RS machines in toto by application of cluster analysis approach to formation of clusters of requests, developing measures for interval type data, generating the best sequence using Genetic algorithm ,using scientific methodology for setting parameters and simulation modeling of before and after cluster formation scenario. The outcome of research is significant reduction in distance traveled, average stay in system and average move time as shown below.

Table 6.1

<table>
<tr><th>Sl.No</th><th>Approach</th><th>Savings</th></tr>
<tr><td>1</td><td>Cluster analysis</td><td><table>
<tr><td>NUMBER OF CLUSTERS</td><td>7</td></tr>
<tr><td>NUMBER OF REQUESTS</td><td>91</td></tr>
<tr><td>TOT_D_MAT</td><td>64829</td></tr>
<tr><td>DTIC</td><td>64829</td></tr>
<tr><td>DNTIC(VOIDS)</td><td>0</td></tr>
<tr><td>DTOC(EXCEPTIONS)</td><td>0</td></tr>
<tr><td>DNTOC</td><td>14055</td></tr>
<tr><td>DTIC_LOGIC</td><td>139896</td></tr>
<tr><td>EFFICIENCY</td><td>1.0</td></tr>
<tr><td>EFFICACY</td><td>1.0</td></tr>
<tr><td>SAVINGS</td><td>0.461</td></tr>
</table></td></tr>
<tr><td>2.</td><td>Genetic algorithm</td><td><table>
<tr><th>Cluster No.</th><th>Max. Distance Before</th><th>Distance After</th></tr>
<tr><td>1</td><td>150</td><td>57</td></tr>
<tr><td>2</td><td>170</td><td>70</td></tr>
<tr><td>3</td><td>84</td><td>36</td></tr>
<tr><td>4</td><td>123</td><td>50</td></tr>
<tr><td>5</td><td>112</td><td>50</td></tr>
<tr><td>6</td><td>73</td><td>32</td></tr>
<tr><td>7</td><td>112</td><td>43</td></tr>
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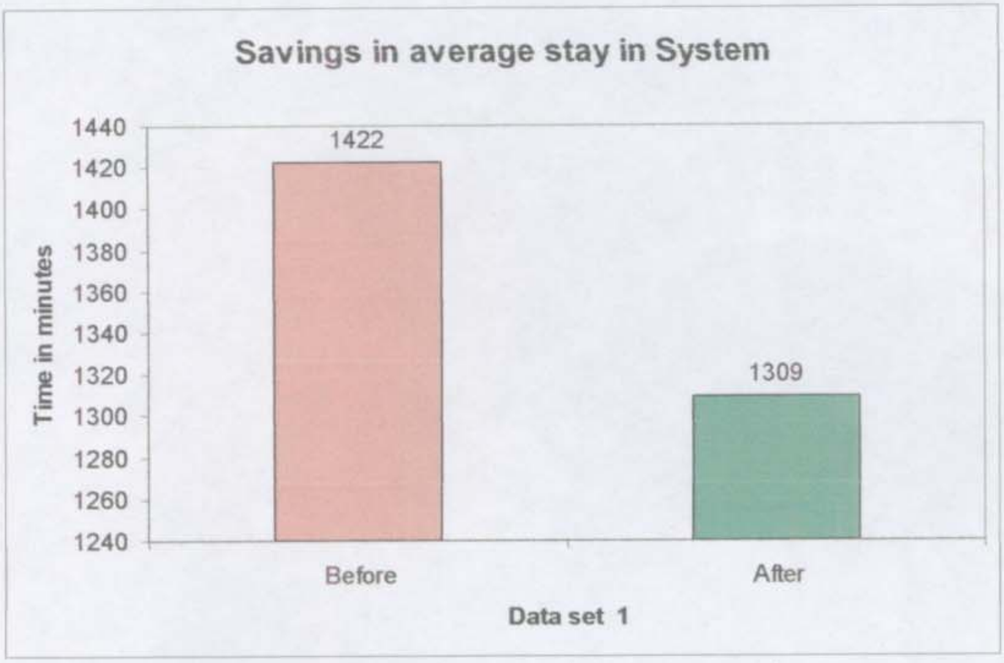
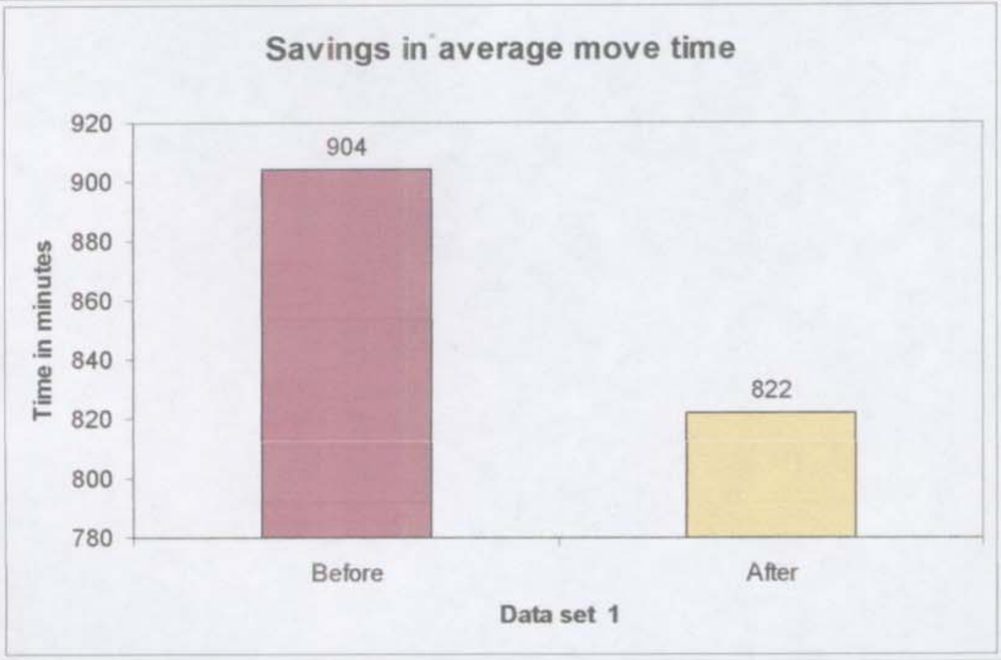
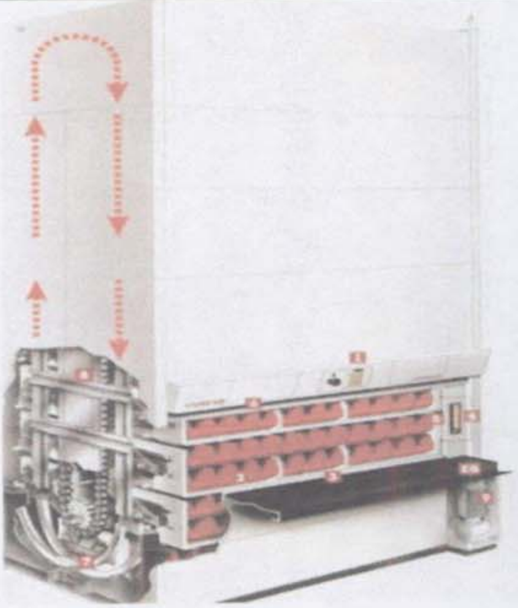
</table>

3.	**Simulation**
	
	



Chapter – 7

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Annexure – 3.1

Output of the common data set – Clustering

INPUT FREQUENCY MATRIX

```
      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25
-------------------------------------------------------------------------------------------------------
 1|              25                  26      27
 2|  12       7           9  11  13                   3                       5
 3|                                                                              54      55          50
 4|  13       8          10  12  14                   4                       6
 5|  15      10          12  14  16                   6                       8
 6|              26                  27      28
 7|                                      33                      24                          27
 8|      32                                      10                  35
 9|                                                          31          47                      43
10|                                      35                      26                          29
11|              27                  28      29
12|      30                                      20                  25
13|              24                  25      26
14|                  30                                  34                          15
15|              23                  24      25
16|                  30                                  35                          16
17|                                                          30          46                      42
18|  14       9          11  13  15                   5                       7
19|                                                          32          48                      44
20|      31                                      30                  30
21|                                                                              52      53          48
22|              28                  29      30
23|                  40                                  36                          17
24|                                                                              53      54          49
25|                                      34                      25                          28
```

NATURAL SEEDS

FINAL ROW GROUP FORMATION

CLUSTER NO	TOTAL MEMBERS	MEMBERS
1	6	1 6 11 13 15 22
2	4	2 4 5 18
3	3	3 21 24
4	3	7 10 25
5	3	8 12 20
6	3	9 17 19
7	3	14 16 23

FINAL COLUMN GROUP FORMATION

CLUSTER NO	TOTAL MEMBERS	MEMBERS
1	7	1 3 6 7 8 13 19
2	3	2 12 17
3	3	4 9 11
4	3	5 14 21
5	3	10 16 23
6	3	15 18 24
7	3	20 22 25

MATRIX BEFORE DIAGONALISATION

```
     1  3  6  7  8 13 19  2 12 17  4  9 11  5 14 21 10 16 23 15 18 24 20 22 25
 1|                               25 26 27
 6|                               26 27 28
11|                               27 28 29
13|                               24 25 26
15|                               23 24 25
22|                               28 29 30
 2| 12  7  9 11 13  3  5
 4| 13  8 10 12 14  4  6
 5| 15 10 12 14 16  6  8
18| 14  9 11 13 15  5  7
 3|                                                                   54 55 50
21|                                                                   52 53 48
24|                                                                   53 54 49
 7|                                                 33 24 27
10|                                                 35 26 29
25|                                                 34 25 28
 8|                      32 10 35
12|                      30 20 25
20|                      31 30 30
 9|                                                          31 47 43
17|                                                          30 46 42
19|                                                          32 48 44
14|                                        30 34 15
16|                                        30 35 16
23|                                        40 36 17
```

TOTAL FREQUENCY IN EACH CLUSTER

```
  0.0   0.0 477.0   0.0   0.0   0.0   0.0
282.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0 468.0
  0.0   0.0   0.0   0.0 261.0   0.0   0.0
  0.0 243.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0 363.0   0.0
  0.0   0.0   0.0 253.0   0.0   0.0   0.0
```

MATRIX AFTER DIAGONALISATION

```
      4  9 11  1  3  6  7  8 13 19 20 22 25 10 16 23  2 12 17 15 18 24  5 14 21
--------------------------------------------------------------------------------
  1| 25 26 27
  6| 26 27 28
 11| 27 28 29
 13| 24 25 26
 15| 23 24 25
 22| 28 29 30
  2|          12  7  9 11 13  3  5
  4|          13  8 10 12 14  4  6
  5|          15 10 12 14 16  6  8
 18|          14  9 11 13 15  5  7
  3|                               54 55 50
 21|                               52 53 48
 24|                               53 54 49
  7|                                        33 24 27
 10|                                        35 26 29
 25|                                        34 25 28
  8|                                                 32 10 35
 12|                                                 30 20 25
 20|                                                 31 30 30
  9|                                                          31 47 43
 17|                                                          30 46 42
 19|                                                          32 48 44
 14|                                                                   30 34 15
 16|                                                                   30 35 16
 23|                                                                   40 36 17
```

FINAL RESULTS OF GROUPING WITH NATURAL SEEDS

TOTAL FREQUENCY IN EACH CLUSTER

```
477.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0 282.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0 468.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0 261.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0 243.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0 363.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0 253.0
```

```
NUMBER OF CLUSTERS                                            =7
NUMBER OF REQUESTS                                            =91
TOTAL DISTANCE TRAVELED BEFORE (TOT_D_MAT)                    =2347.000000
DISTANCE TRAVELED INSIDE CLUSTERS (DTIC)                      =2347.000000
DISTANCE NOT TRAVELED INSIDE CLUSTER (DNTIC)(VOIDS)           =0.000000
DISTANCE TRAVELED OUTSIDE CLUSTER (DTOC)(EXCEPTIONS)          =0.000000
DISTANCE NOT TRAVELED OUTSIDE CLUSTERS (DNTOC)                =14055.000000
DISTANCE TRAVELED INSIDE CLUSTER WITH LOGIC (DTIC_LOGIC)      =5210.000000
EFFICIENCY                                                    = 1.000000
EFFICACY                                                      = 1.000000
SAVINGS                                                       = 0.445
```

```
IDEAL SEEDS
________________________________________________________________

FINAL ROW GROUP FORMATION
________________________________________________________________
CLUSTER NO| TOTAL MEMBERS  | MEMBERS
________________________________________________________________
 1              6              1 2 3 4 5 6
 2              4              7 8 9 10
 3              3              11 12 13
 4              3              14 15 16
 5              3              17 18 19
 6              3              20 21 22
 7              3              23 24 25

FINAL ROW GROUP FORMATION

________________________________________________________________
CLUSTER NO| TOTAL MEMBERS  | MEMBERS
________________________________________________________________
 1              3              1 2 3
 2              7              4 5 6 7 8 9 10
 3              3              11 12 13
 4              3              14 15 16
 5              3              17 18 19
 6              3              20 21 22
 7              3              23 24 25

TOTAL FREQUENCY IN EACH CLUSTER

477.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0 282.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0 468.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0 261.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0 243.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0 363.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0 253.0
```

```
      4  9 11  1  3  6  7  8 13 19 20 22 25 10 16 23  2 12 17 15 18 24  5 14 21
 
  1| 25 26 27
  6| 26 27 28
 11| 27 28 29
 13| 24 25 26
 15| 23 24 25
 22| 28 29 30
  2|          12  7  9 11 13  3  5
  4|          13  8 10 12 14  4  6
  5|          15 10 12 14 16  6  8
 18|          14  9 11 13 15  5  7
  3|                               54 55 50
 21|                               52 53 48
 24|                               53 54 49
  7|                                        33 24 27
 10|                                        35 26 29
 25|                                        34 25 28
  8|                                                 32 10 35
 12|                                                 30 20 25
 20|                                                 31 30 30
  9|                                                          31 47 43
 17|                                                          30 46 42
 19|                                                          32 48 44
 14|                                                                   30 34 15
 16|                                                                   30 35 16
 23|                                                                   40 36 17
```

FINAL RESULTS OF GROUPING WITH NATURAL AND IDEAL SEEDS

TOTAL FREQUENCY IN EACH CLUSTER

```
477.0  0.0   0.0   0.0   0.0   0.0   0.0
  0.0 282.0  0.0   0.0   0.0   0.0   0.0
  0.0   0.0 468.0  0.0   0.0   0.0   0.0
  0.0   0.0   0.0 261.0  0.0   0.0   0.0
  0.0   0.0   0.0   0.0 243.0  0.0   0.0
  0.0   0.0   0.0   0.0   0.0 363.0  0.0
  0.0   0.0   0.0   0.0   0.0   0.0 253.0
```

```
NUMBER OF CLUSTERS                                              =7
NUMBER OF REQUESTS                                              =91
TOTAL DISTANCE TRAVELED BEFORE (TOT_D_MAT)                      =2347.000000
DISTANCE TRAVELED INSIDE CLUSTERS (DTIC)                        =2347.000000
DISTANCE NOT TRAVELED INSIDE CLUSTER (DNTIC)(VOIDS)             =0.000000
DISTANCE TRAVELED OUTSIDE CLUSTER (DTOC)(EXCEPTIONS)            =0.000000
DISTANCE NOT TRAVELED OUTSIDE CLUSTERS (DNTOC)                  =14055.000000
DISTANCE TRAVELED INSIDE CLUSTER WITH LOGIC (DTIC_LOGIC)        =5210.000000
THROUGHPUT BEFORE                                               = 4.653
THROUGHPUT AFTER                                                = 8.384
EFFICIENCY                                                      = 1.000000
EFFICACY                                                        = 1.000000
SAVINGS                                                         = 0.445
```

FINAL RESULTS OF GROUPING WITH NATURAL AND IDEAL SEEDS OF FREQUENCY DISTANCE MATRIX

```
TOTAL FREQUENCY IN EACH CLUSTER

9315.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0 4075.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0 17853.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0 7815.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0 5772.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0 12480.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0 7519.0

NUMBER OF CLUSTERS                                              =7
NUMBER OF REQUESTS                                              =91
TOTAL DISTANCE TRAVELED BEFORE (TOT_D_MAT)                      =64829.000000
DISTANCE TRAVELED INSIDE CLUSTERS (DTIC)                        =64829.000000
DISTANCE NOT TRAVELED INSIDE CLUSTER (DNTIC)(VOIDS)             =0.000000
DISTANCE TRAVELED OUTSIDE CLUSTER (DTOC)(EXCEPTIONS)            =0.000000
DISTANCE NOT TRAVELED OUTSIDE CLUSTERS (DNTOC)                  =14055.000000
DISTANCE TRAVELED INSIDE CLUSTER WITH LOGIC (DTIC_LOGIC)        =139896.000000
EFFICIENCY                                                      = 1.000000
EFFICACY                                                        = 1.000000
SAVINGS                                                         = 0.461
```

Annexure – 3.2

Data for Measures of Grouping

Max_d_mat	10000	0.5	
Max_d_inc	5000		
Max_d_outc	5000		
Tot_d_mat	5000		x axis % DTOC

	% DNTIC	% DTOC	DTIC	DNTIC	DTOC	DNTOC	Efficiency	Efficacy
0	0	0	5000	0	0	5000	1.00	1.00
10	0	10	5000	0	500	4500	0.95	0.90
20	0	20	5000	0	1000	4000	0.90	0.80
30	0	30	5000	0	1500	3500	0.85	0.70
40	0	40	5000	0	2000	3000	0.80	0.60
50	0	50	5000	0	2500	2500	0.75	0.50
60	0	60	5000	0	3000	2000	0.70	0.40
70	0	70	5000	0	3500	1500	0.65	0.30
80	0	80	5000	0	4000	1000	0.60	0.20
90	0	90	5000	0	4500	500	0.55	0.10
100	0	100	5000	0	5000	0	0.50	0.00
0	10	0	4500	500	0	5000	0.95	0.91
10	10	10	4500	500	500	4500	0.90	0.82
20	10	20	4500	500	1000	4000	0.85	0.73
30	10	30	4500	500	1500	3500	0.80	0.64
40	10	40	4500	500	2000	3000	0.75	0.55
50	10	50	4500	500	2500	2500	0.70	0.45
60	10	60	4500	500	3000	2000	0.65	0.36
70	10	70	4500	500	3500	1500	0.60	0.27
80	10	80	4500	500	4000	1000	0.55	0.18
90	10	90	4500	500	4500	500	0.50	0.09
100	10	100	4500	500	5000	0	0.45	0.00
0	20	0	4000	1000	0	5000	0.90	0.83
10	20	10	4000	1000	500	4500	0.85	0.75
20	20	20	4000	1000	1000	4000	0.80	0.67
30	20	30	4000	1000	1500	3500	0.75	0.58
40	20	40	4000	1000	2000	3000	0.70	0.50
50	20	50	4000	1000	2500	2500	0.65	0.42
60	20	60	4000	1000	3000	2000	0.60	0.33
70	20	70	4000	1000	3500	1500	0.55	0.25
80	20	80	4000	1000	4000	1000	0.50	0.17
90	20	90	4000	1000	4500	500	0.45	0.08
100	20	100	4000	1000	5000	0	0.40	0.00
0	30	0	3500	1500	0	5000	0.85	0.77
10	30	10	3500	1500	500	4500	0.80	0.69
20	30	20	3500	1500	1000	4000	0.75	0.62
30	30	30	3500	1500	1500	3500	0.70	0.54
40	30	40	3500	1500	2000	3000	0.65	0.46

50	30	50	3500	1500	2500	2500	0.60	0.38
60	30	60	3500	1500	3000	2000	0.55	0.31
70	30	70	3500	1500	3500	1500	0.50	0.23
80	30	80	3500	1500	4000	1000	0.45	0.15
90	30	90	3500	1500	4500	500	0.40	0.08
100	30	100	3500	1500	5000	0	0.35	0.00
0	40	0	3000	2000	0	5000	0.80	0.71
10	40	10	3000	2000	500	4500	0.75	0.64
20	40	20	3000	2000	1000	4000	0.70	0.57
30	40	30	3000	2000	1500	3500	0.65	0.50
40	40	40	3000	2000	2000	3000	0.60	0.43
50	40	50	3000	2000	2500	2500	0.55	0.36
60	40	60	3000	2000	3000	2000	0.50	0.29
70	40	70	3000	2000	3500	1500	0.45	0.21
80	40	80	3000	2000	4000	1000	0.40	0.14
90	40	90	3000	2000	4500	500	0.35	0.07
100	40	100	3000	2000	5000	0	0.30	0.00
0	50	0	2500	2500	0	5000	0.75	0.67
10	50	10	2500	2500	500	4500	0.70	0.60
20	50	20	2500	2500	1000	4000	0.65	0.53
30	50	30	2500	2500	1500	3500	0.60	0.47
40	50	40	2500	2500	2000	3000	0.55	0.40
50	50	50	2500	2500	2500	2500	0.50	0.33
60	50	60	2500	2500	3000	2000	0.45	0.27
70	50	70	2500	2500	3500	1500	0.40	0.20
80	50	80	2500	2500	4000	1000	0.35	0.13
90	50	90	2500	2500	4500	500	0.30	0.07
100	50	100	2500	2500	5000	0	0.25	0.00
0	60	0	2000	3000	0	5000	0.70	0.63
10	60	10	2000	3000	500	4500	0.65	0.56
20	60	20	2000	3000	1000	4000	0.60	0.50
30	60	30	2000	3000	1500	3500	0.55	0.44
40	60	40	2000	3000	2000	3000	0.50	0.38
50	60	50	2000	3000	2500	2500	0.45	0.31
60	60	60	2000	3000	3000	2000	0.40	0.25
70	60	70	2000	3000	3500	1500	0.35	0.19
80	60	80	2000	3000	4000	1000	0.30	0.13
90	60	90	2000	3000	4500	500	0.25	0.06
100	60	100	2000	3000	5000	0	0.20	0.00
0	70	0	1500	3500	0	5000	0.65	0.59
10	70	10	1500	3500	500	4500	0.60	0.53
20	70	20	1500	3500	1000	4000	0.55	0.47
30	70	30	1500	3500	1500	3500	0.50	0.41
40	70	40	1500	3500	2000	3000	0.45	0.35
50	70	50	1500	3500	2500	2500	0.40	0.29
60	70	60	1500	3500	3000	2000	0.35	0.24
70	70	70	1500	3500	3500	1500	0.30	0.18
80	70	80	1500	3500	4000	1000	0.25	0.12
90	70	90	1500	3500	4500	500	0.20	0.06

100	70	100	1500	3500	5000	0	0.15	0.00
0	80	0	1000	4000	0	5000	0.60	0.56
10	80	10	1000	4000	500	4500	0.55	0.50
20	80	20	1000	4000	1000	4000	0.50	0.44
30	80	30	1000	4000	1500	3500	0.45	0.39
40	80	40	1000	4000	2000	3000	0.40	0.33
50	80	50	1000	4000	2500	2500	0.35	0.28
60	80	60	1000	4000	3000	2000	0.30	0.22
70	80	70	1000	4000	3500	1500	0.25	0.17
80	80	80	1000	4000	4000	1000	0.20	0.11
90	80	90	1000	4000	4500	500	0.15	0.06
100	80	100	1000	4000	5000	0	0.10	0.00
0	90	0	500	4500	0	5000	0.55	0.53
10	90	10	500	4500	500	4500	0.50	0.47
20	90	20	500	4500	1000	4000	0.45	0.42
30	90	30	500	4500	1500	3500	0.40	0.37
40	90	40	500	4500	2000	3000	0.35	0.32
50	90	50	500	4500	2500	2500	0.30	0.26
60	90	60	500	4500	3000	2000	0.25	0.21
70	90	70	500	4500	3500	1500	0.20	0.16
80	90	80	500	4500	4000	1000	0.15	0.11
90	90	90	500	4500	4500	500	0.10	0.05
100	90	100	500	4500	5000	0	0.05	0.00
0	100	0	0	5000	0	5000	0.50	0.50
10	100	10	0	5000	500	4500	0.45	0.45
20	100	20	0	5000	1000	4000	0.40	0.40
30	100	30	0	5000	1500	3500	0.35	0.35
40	100	40	0	5000	2000	3000	0.30	0.30
50	100	50	0	5000	2500	2500	0.25	0.25
60	100	60	0	5000	3000	2000	0.20	0.20
70	100	70	0	5000	3500	1500	0.15	0.15
80	100	80	0	5000	4000	1000	0.10	0.10
90	100	90	0	5000	4500	500	0.05	0.05
100	100	100	0	5000	5000	0	0.00	0.00

Annexure 3.3

Output for different data sets – Clustering

3.3.1 Frequency matrix – Before

```
     1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
--------------------------------------------------------------------------------
 1|          16             16    17                                  18
 2|  7              4  6  8              3                 5
 3|                                                          48    49       50
 4|  8     3        5  7  9              4                 6             24
 5| 10     5        7    11              6
 6|          16             17
 7|                            23                24
 8|    32                            31             30
 9|                                           41       42                24
10| 19                         25                26                   24
11|          17             18    19
12|    30                            29          27 28
13|          14                   16
14|             36          26             34                   35
15|          13             14             22
16|             37                      20 35                   36
17|                                           40       41       38       42
18|  9     4        6  8 10              5                 7
19|                                           42       43                44
20|    31                            30             29
21|                                                          46    47       48
22|                         19    20
23|       20    38                         36                   37
24|                                                          47    48       49
25|                            24                25                   23
```

Figure 3.3.1a Frequency matrix – After

```
     4  9 11 20 22 25  1  3  6  7  8 13 19 10 16 23  2 12 17 15 18 24  5 14 21
--------------------------------------------------------------------------------
 1| 16 16 17                                     18
 6| 16 17
11| 17 18 19
13| 14    16
15| 13 14                                                                22
22|    19 20
 3|          48 49 50
21|          46 47 48
24|          47 48 49
 2|                    7     4  6  8  3  5
 4|                    8  3  5  7  9  4  6                         24
 5|                   10  5  7    11  6
18|                    9  4  6  8 10  5  7
 7|                                        23 24
10|                   19                   25 26 24
25|                                        24 25 23
 8|                                                 32 31 30
12|                                           27    30 29 28
20|                                                 31 30 29
 9|                                                          41 42 43
17|                                                          40 41 42       38
19|                                                          42 43 44
14|    26                                                             36 34 35
16|                                  20                               37 35 36
23|                      20                                           38 36 37
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	7
NUMBER OF REQUESTS	92
TOT D MAT	64398
DTIC	58549
DNTIC(VOIDS)	162
DTOC(EXCEPTIONS)	5849
DNTOC	13819
DTIC LOGIC	150316
EFFICIENCY	0.849927
EFFICACY	0.906893
SAVINGS	0.416

3.3.2 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
   ----------------------------------------------------------------------------
  1|                      21 26 22    24 27    28       25             20 35 23
  2| 10  8       12    14                   15     9             11    16
  3|                      27 32 28    30 33    34 19 35 31
  4|                      22 27 23    25 28          30 26                   24
  5|     2     4  6                          9     3    15 20     5    10
  6| 10  4     6  8                         11     5              7    12
  7| 12  7     9 11    13                   14     8                   15
  8| 16 11    13 15          25 21    23    18    12             14    19
  9|       43       46             42                      40 41    44
 10|    15       19       24    25    27 30    31    32 28                   26
 11|  8  3     5  7     9 12                       4              6    11
 12|       45       48             44                      42       46    47
 13|       38             26 31 27       32    33    34 30                   28
 14| 15 10    12 14    16                   17    11             13    18
 15|                         34 30    32 35    36    37 33                   31
 16| 12  6     8       12                   13     7       24     9    14
 17|       42       45             41                      39 40    43    44
 18| 15  9    11 13                         16                   12    17
 19|                      23 28 24    26       30    31 27                   25
 20|                   22 25 30 26    28 31    32    33                      27
 21|       44       47             43                      41 42          46
 22| 10  5     7  9    11             17    12     6              8    13
 23|       46       49             45                      43 44    47    48
 24|                      28 33       31 34    35    36 32                   30
 25| 31    47       50    35       46       33             44 45    48    49
```

Figure 3.3.2a Frequency matrix – After

```
      8  9 10 12 13 15 17 18 25  1  2  4  5  7 14 16 21 23  3  6 11 19 20 22 24
   ----------------------------------------------------------------------------
  1| 21 26 22 24 27 28    25 23                         20                   35
  3| 27 32 28 30 33 34 35 31                      19
  4| 22 27 23 25 28    30 26 24
 10| 24    25 27 30 31 32 28 26    15    19
 13| 26 31 27    32 33 34 30 28                            38
 15|    34 30 32 35 36 37 33 31
 19| 23 28 24 26    30 31 27 25
 20| 25 30 26 28 31 32 33    27             22
 24| 28 33    31 34 35 36 32 30
  2|                            10  8    12 14 15  9 11 16
  5|                      15        2  4  6     9  3  5 10          20
  6|                            10  4  6  8    11  5  7 12
  7|                            12  7  9 11 13 14  8    15
  8|    25 21 23                16 11 13 15    18 12 14 19
 11| 12                          8  3  5  7  9     4  6 11
 14|                            15 10 12 14 16 17 11 13 18
 16|                            12  6  8    12 13  7  9 14          24
 18|                            15  9 11 13    16    12 17
 22|          17                10  5  7  9 11 12  6  8 13
  9|                                                       43 46 42 40 41 44
 12|                                                       45 48 44 42    46 47
 17|                                                       42 45 41 39 40 43 44
 21|                                                       44 47 43 41 42    46
 23|                                                       46 49 45 43 44 47 48
 25| 35                         31             33          47 50 46 44 45 48 49
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	3
NUMBER OF REQUESTS	209
TOT D MAT	141698
DTIC	131333
DNTIC(VOIDS)	529
DTOC(EXCEPTIONS)	10365

DNTOC	10410
DTIC LOGIC	306333
EFFICIENCY	0.748536
EFFICACY	0.923404
SAVINGS	0.460

3.3.3 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
 -------------------------------------------------------------------------------
  1|          25             26    27
  2| 12     7         9 11 13              3                 5
  3|                                                          54    55       50
  4| 13     8       10 12 14              4                 6
  5| 15    10       12 14 16              6                 8
  6|          26             27    28
  7|                            33                24                   27
  8|    32                            10             35
  9|                                           31       47                43
 10|                            35                26                   29
 11|          27             28    29
 12|    30                            20             25
 13|          24             25    26
 14|             30                         34                   15
 15|          23             24    25
 16|             30                         35                   16
 17|                                           30       46                42
 18| 14     9       11 13 15              5                 7
 19|                                           32       48                44
 20|    31                            30             30
 21|                                                          52    53       48
 22|          28             29    30
 23|             40                         36                   17
 24|                                                          53    54       49
 25|                            34                25                   28
```

Figure 3.3.3a Frequency matrix – After

```
      4  9 11  1  3  6  7  8 13 19 20 22 25 10 16 23  2 12 17 15 18 24  5 14 21
 -------------------------------------------------------------------------------
  1| 25 26 27
  6| 26 27 28
 11| 27 28 29
 13| 24 25 26
 15| 23 24 25
 22| 28 29 30
  2|          12  7  9 11 13  3  5
  4|          13  8 10 12 14  4  6
  5|          15 10 12 14 16  6  8
 18|          14  9 11 13 15  5  7
  3|                               54 55 50
 21|                               52 53 48
 24|                               53 54 49
  7|                                        33 24 27
 10|                                        35 26 29
 25|                                        34 25 28
  8|                                                 32 10 35
 12|                                                 30 20 25
 20|                                                 31 30 30
  9|                                                          31 47 43
 17|                                                          30 46 42
 19|                                                          32 48 44
 14|                                                                   30 34 15
 16|                                                                   30 35 16
 23|                                                                   40 36 17
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	7
NUMBER OF REQUESTS	91
TOT D MAT	64829
DTIC	64829
DNTIC(VOIDS)	0
DTOC(EXCEPTIONS)	0

DNTOC	14055
DTIC LOGIC	139896
EFFICIENCY	1.0
EFFICACY	1.0
SAVINGS	0.461

3.3.4 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
    ---------------------------------------------------------------------------
  1|  1     4                    7     1                       3             25
  2|  2     2  7                       6                       4
  3|  4     3  8                 9     2                       5
  4|  4     7  9       13        2     8                       6
  5|  6        1                 3     9                       7
  6|  5     9  2                 5     5
  7|        1  5                 6     7                       9
  8|  6     1  3                 1                             1
  9|    19       26    28    20    21                27             12
 10|    20       27    29    21    22       14       28
 11|    21       28    10          13       25       19             14
 12|    12       19    21    23    24       16       20 28 31       15
 13|    23             22    24    25       27       21             26
 14|    24       21    23    25    26       18                      27
 15|    15       12    24    16    17       29       13             18
 16|             13    25    27    28       20       14             19
 17|                24                            22    33 26    37
 18|                35                            33    34 37    28       36
 19|          24    26                            24       28    39       37
 20|                37                                  36 39    30       38
 21|                28                            26    37 20             39
 22|                      33             37    35                      44
 23|                      44             48                            45    37
 24|                      35             49    47                            38
 25|                      36       37    30    38                      47    39
```

Figure 3.3.4a Frequency matrix – After

```
      1  3  4 10 12 20  2  5  7  9 11 14 17 22  6 16 18 19 21 24  8 13 15 23 25
    ---------------------------------------------------------------------------
  1|  1  4     7  1  3                                                       25
  2|  2  2  7     6  4
  3|  4  3  8  9  2  5
  4|  4  7  9  2  8  6       13
  5|  6     1  3  9  7
  6|  5  9  2  5  5
  7|     1  5  6  7  9
  8|  6  1  3  1     1
  9|                   19 26 28 20 21    27 12
 10|                   20 27 29 21 22 14 28
 11|                   21 28 10    13 25 19 14
 12|                   12 19 21 23 24 16 20 15       28 31
 13|                   23    22 24 25 27 21 26
 14|                   24 21 23 25 26 18    27
 15|                   15 12 24 16 17 29 13 18
 16|                      13 25 27 28 20 14 19
 17|                                           24 22 33 26 37
 18|                                           35 33 34 37 28 36
 19|       24                                  26 24    28 39 37
 20|                                           37    36 39 30 38
 21|                                           28 26 37 20    39
 22|                                                             33 37 35 44
 23|                                                             44 48    45 37
 24|                                                             35 49 47    38
 25|                               37                            36 30 38 47 39
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	4
NUMBER OF REQUESTS	149
TOT_D_MAT	92561
DTIC	88083
DNTIC(VOIDS)	509
DTOC(EXCEPTIONS)	4478

DNTOC	12085
DTIC_LOGIC	199254
EFFICIENCY	0.861946
EFFICACY	0.946417
SAVINGS	0.462

3.3.5 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
 -----------------------------------------------------------------------------
 1|       21             15       16          27       14             14
 2|       22             19       20          21                      28
 3|           5  6           3        7              8  4     5
 4|                                              32       33                44
 5| 18             19 21                   20
 6|           4  8           8        9             10  6     7
 7| 13             14 16                   15                 9
 8|                            24       26                         35
 9| 16             16 18                   17
10| 17             18 20                   19
11|                                              40       31                42
12|       14             16       17          18                      15
13|    48                                                       26       27
14|       23             17       28          39                      26
15| 14             15 17                   20
16|       21             18       19          20                      17
17|                            25       37                         36
18| 16             17 19                   18
19|                            26       28                         37
20|           3  7           4        8              9  5     6
21|                                              31       22                43
22|       21             20       21          12                      19
23|    49                                                       37       48
24|           5  8           6       10             11  7     8
25|    50                                                       28       39
```

Figure 3.3.5a Frequency matrix – After

```
     3  8 11 15 23  4  5  9 12 17 18 20 16 19 25  1  6  7 14 10 13 22  2 21 24
 -----------------------------------------------------------------------------
 1| 21 15 16 27 14                14
 2| 22 19 20 21 28
12| 14 16 17 18 15
14| 23 17 28 39 26
16| 21 18 19 20 17
22| 21 20 21 12 19
 3|                 5  6  3  7  8  4  5
 6|                 4  8  8  9 10  6  7
20|                 3  7  4  8  9  5  6
24|                 5  8  6 10 11  7  8
 4|                                     32 33 44
11|                                     40 31 42
21|                                     31 22 43
 5|                                              18 19 21 20
 7|                                   9          13 14 16 15
 9|                                              16 16 18 17
10|                                              17 18 20 19
15|                                              14 15 17 20
18|                                              16 17 19 18
 8|                                                          24 26 35
17|                                                          25 37 36
19|                                                          26 28 37
13|                                                                   48 26 27
23|                                                                   49 37 48
25|                                                                   50 28 39
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	6
NUMBER OF REQUESTS	111
TOT_D_MAT	57724
DTIC	57215
DNTIC(VOIDS)	0

DTOC(EXCEPTIONS)	509.000000
DNTOC	13495
DTIC_LOGIC	122716
EFFICIENCY	0.981827
EFFICACY	0.991182
SAVINGS	0.469

3.3.6 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
   ----------------------------------------------------------------------------
  1|              1 15 29                         24     20 30 18        16
  2|           6              7     5        8
  3|           3              1     2        5
  4|           5              6              7
  5|             24 36 28                         13     29    37
  6|             26 28 20                               21    29       17
  7|             23    27                         12     28    26       14
  8|    24 27             25             28
  9|    25 28                   27       29
 10|           4              5     3
 11| 36                               28                                  37
 12|       29             27    28       30
 13|             22 24 16                         11     17             13
 14|    28 31             29    30       32
 15|                                           38                37          36
 16| 47                               49                                  48
 17|                                           37                 1          35
 18|                                                 22    33       24
 19|                                           36                35          34
 20|                                                 30    21       32
 21|             11 13                            10    16    14       12
 22|    27 30             28    29       31
 23|                                                 31    32       33
 24|    23                24    25       27
 25| 28                               25                                  39
```

Figure 3.3.6a Frequency matrix – After

```
      5  6  7 16 18 20 23  4  9 11 14  2  3  8 10 13  1 12 24 15 21 25 17 19 22
   ----------------------------------------------------------------------------
  1|  1 15 29 24 20 18 16                                                 30
  5| 24 36 28 13 29 37
  6| 26 28 20    21 29 17
  7| 23    27 12 28 26 14
 13| 22 24 16 11 17    13
 21| 11 13    10 16 14 12
  2|                       6  7  5  8
  3|                       3  1  2  5
  4|                       5  6     7
 10|                       4  5  3
  8|                                  24 27 25    28
  9|                                  25 28    27 29
 12|                                     29 27 28 30
 14|                                  28 31 29 30 32
 22|                                  27 30 28 29 31
 24|                                  23    24 25 27
 11|                                                 36 28 37
 16|                                                 47 49 48
 25|                                                 28 25 39
 15|                                                          38 37 36
 17|                                                          37  1 35
 19|                                                          36 35 34
 18|                                                                   22 33 24
 20|                                                                   30 21 32
 23|                                                                   31 32 33
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	6
NUMBER OF REQUESTS	105
TOT D MAT	64178
DTIC	63578
DNTIC(VOIDS)	239
DTOC(EXCEPTIONS)	600.000000

DNTOC	13440
DTIC LOGIC	135262
EFFICIENCY	0.976760
EFFICACY	0.986975
SAVINGS	0.473

3.3.7 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
 -----------------------------------------------------------------------------
  1|      33             30       31          37                      34
  2|      37             29       25          21                      38
  3|         12  6          13        7             18  4    25
  4|                                             32       13                24
  5|28             19 20                   20
  6|         14  8          15        9             10 16    27
  7|23             14 16                   15
  8|                           24       36                         35
  9|25             16 28                   17
 10|27             18 20                   19
 11|                                             40       11                22
 12|      34             36       22          33                      25
 13|   38                                                       36       27
 14|      25             27       38          29                      36
 15|24             15 27                   16
 16|      36             38       39          40                      37
 17|                           25       47                         36
 18|26             17 29                   18
 19|                           26       38                         37
 20|         13  7          14        8             19 15    26
 21|                                             31       12                23
 22|      28             30       21          30                      29
 23|   49                                                       47       48
 24|         15  9          16       10             21  7    18
 25|   45                                                       38       29
```

Figure 3.3.7a Frequency matrix – After

```
      3  8 11 15 23  4  5  9 12 17 18 20 16 19 25  1  6  7 14 10 13 22  2 21 24
 -----------------------------------------------------------------------------
  1|33 30 31 37 34
  2|37 29 25 21 38
 12|34 36 22 33 25
 14|25 27 38 29 36
 16|36 38 39 40 37
 22|28 30 21 30 29
  3|               12  6 13  7 18  4 25
  6|               14  8 15  9 10 16 27
 20|               13  7 14  8 19 15 26
 24|               15  9 16 10 21  7 18
  4|                                    32 13 24
 11|                                    40 11 22
 21|                                    31 12 23
  5|                                             28 19 20 20
  7|                                             23 14 16 15
  9|                                             25 16 28 17
 10|                                             27 18 20 19
 15|                                             24 15 27 16
 18|                                             26 17 29 18
  8|                                                         24 36 35
 17|                                                         25 47 36
 19|                                                         26 38 37
 13|                                                                  38 36 27
 23|                                                                  49 47 48
 25|                                                                  45 38 29
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	6
NUMBER OF REQUESTS	109
TOT_D_MAT	69328
DTIC	69328
DNTIC(VOIDS)	0
DTOC(EXCEPTIONS)	0

DNTOC	13541
DTIC_LOGIC)	145153
EFFICIENCY	1.00
EFFICACY	1.00
SAVINGS	0.477

3.3.8 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
    ---------------------------------------------------------------------------
  1|  1  6                                          2  5
  2|  5  1                                          1  4
  3|          25    23                21 24       27          22
  4|             10             14                                  13       11
  5|             12          14 16                                  15       13
  6|          28    20                24 27    29 30          25
  7|             13          15 17                                  16
  8|          27    25                23 26    28 29          24
  9|             14          16 18       22                         17       15
 10|  2  3                                          4  6       22
 11|                   32          24       35                   31    23 46
 12|                         17 19                                  18       16
 13|                   34          26       37                   33    25 48
 14|                24                22 25    27 28          23
 15|          29    27                25 28    30 31
 16|             11          13 15                                           12
 17|          30    28                26 29    31 32          27
 18|       25             26                               37
 19|                   35          27       38                   34    26 39
 20|                      27                               38
 21|                   31          23 30    34                   30    22 35
 22|  4  3                                             8
 23|                   33          25       36                   22    34 47
 24|     2 24             15                               36
 25|                   46          28       39                   35    37 30
```

Figure 3.3.8a Frequency matrix – After

```
      5  9 10 22 25  4  6 12 13 15 16 20  3  8 19  7 11 14 21 23 24  1  2 17 18
    ---------------------------------------------------------------------------
  1| 10    14 13 11
  2| 11 13 15    12
  4| 12 14 16 15 13
 10| 13 15 17 16
 16| 14 16 18 17 15          22
 22|    17 19 18 16
  3|                25 23 21 24    27 22
  6|                28 20 24 27 29 30 25
  8|                27 25 23 26 28 29 24
 14|                   24 22 25 27 28 23
 15|                29 27 25 28 30 31
 17|                30 28 26 29 31 32 27
  5|                                     25 26 37
  7|                                        27 38
  9|                                     24 15 36                      2
 12|                                              32 24 35 31 23 46
 11|                                              34 26 37 33 25 48
 13|                                              35 27 38 34 26 39
 19|                      30                      31 23 34 30 22 35
 21|                                              33 25 36 22 34 47
 23|                                              46 28 39 35 37 30
 25|                                                                 1  6  2  5
 18|                                                                 5  1  1  4
 20|                                                       22        2  3  4  6
 24|                                                                 4  3     8
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	5
NUMBER OF REQUESTS	128
TOT D MAT	85127
DTIC	82919
DNTIC(VOIDS)	233.000000
DTOC(EXCEPTIONS)	2208.000000

DNTOC	12650
DTIC LOGIC	178115
EFFICIENCY	0.924296
EFFICACY	0.971403
SAVINGS	0.477

3.3.9 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
-----------------------------------------------------------------------------------
  1|             25 17 29                         34    20    38       26
  2|          16              7    15        8
  3|          13              4    12        5
  4|          15              6    14        7
  5|             24 16 28                         33    19    37       15
  6|             26 18 20                         35    21    39       27
  7|             23 15 27                         32    18    36       14
  8|    14 17             15    16       28
  9|    25 28             26    27       29
 10|          24              5    13        6
 11| 26                               18                                  27
 12|    16 19             37    28       20
 13|             22 14 26                         11    17    15       23
 14|    28 21             29    20       22
 15|                                           28                27          36
 16| 37                               19                                  38
 17|                                           17                16          35
 18|                                                 22    43       34
 19|                                           26                25          34
 20|                                                 10    31       22
 21|             11 13 15                         10    16    14       12
 22|    27 10             28    19       31
 23|                                                 21    22       33
 24|    13 36             14    25       37
 25| 28                               20                                  29
```

Figure 3.3.9a Frequency matrix – After

```
      5  6  7 16 18 20 23  4  9 11 14  2  3  8 10 13  1 12 24 15 21 25 17 19 22
-----------------------------------------------------------------------------------
  1| 25 17 29 34 20 38 26
  5| 24 16 28 33 19 37 15
  6| 26 18 20 35 21 39 27
  7| 23 15 27 32 18 36 14
 13| 22 14 26 11 17 15 23
 21| 11 13 15 10 16 14 12
  2|                      16  7 15  8
  3|                      13  4 12  5
  4|                      15  6 14  7
 10|                      24  5 13  6
  8|                                  14 17 15 16 28
  9|                                  25 28 26 27 29
 12|                                  16 19 37 28 20
 14|                                  28 21 29 20 22
 22|                                  27 10 28 19 31
 24|                                  13 36 14 25 37
 11|                                                 26 18 27
 16|                                                 37 19 38
 25|                                                 28 20 29
 15|                                                          28 27 36
 17|                                                          17 16 35
 19|                                                          26 25 34
 18|                                                                   22 43 34
 20|                                                                   10 31 22
 23|                                                                   21 22 33
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	6
NUMBER OF REQUESTS	115
TOT D MAT	64047
DTIC	64047
DNTIC(VOIDS)	0
DTOC(EXCEPTIONS)	0

DNTOC	13460
DTIC LOGIC	133420
EFFICIENCY	1.00
EFFICACY	1.00
SAVINGS	0.479

3.3.10 Frequency matrix – Before

```
     1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
-------------------------------------------------------------------------------
 1| 12 24                                            3 15
 2| 14 26                                            5 17
 3|          15    23                11 14    36 17          12
 4|             20          12 34                                  23       21
 5|             22          14 36                                  15       13
 6|          18    36                24 27    39 10          25
 7|             13          15 37                                  26       24
 8|          17    25                33 16    38 29          34
 9|             14          16 38                                  17       15
10| 13 25                                            4 16
11|                   32          14       25                   31    23 46
12|             25          17 39                                  28       26
13|                   34          26       27                   33    25 48
14|          16    14                12 15    37 18          13
15|          19    17                15 18    30 31          26
16|             21          13 35                                  34       12
17|          20    28                36 19    31 22          17
18|       25             16                               27
19|                   45          37       28                   34    26 49
20|       26             37                               28
21|                   31          33       24                   30    22 45
22|  5  7                                            6  8
23|                   43          35       26                   32    24 47
24|       14             25                               36
25|                   36          38       29                   35    27 50
```

Figure 3.3.10a Frequency matrix – After

```
     1  2 17 18  4  6 12 13 15 16 20  5  9 10 22 25  7 11 14 21 23 24  3  8 19
-------------------------------------------------------------------------------
 1| 12 24  3 15
 2| 14 26  5 17
10| 13 25  4 16
22|  5  7  6  8
 3|             15 23 11 14 36 17 12
 6|             18 36 24 27 39 10 25
 8|             17 25 33 16 38 29 34
14|             16 14 12 15 37 18 13
15|             19 17 15 18 30 31 26
17|             20 28 36 19 31 22 17
 4|                                  20 12 34 23 21
 5|                                  22 14 36 15 13
 7|                                  13 15 37 26 24
 9|                                  14 16 38 17 15
12|                                  25 17 39 28 26
16|                                  21 13 35 34 12
11|                                                 32 14 25 31 23 46
13|                                                 34 26 27 33 25 48
19|                                                 45 37 28 34 26 49
21|                                                 31 33 24 30 22 45
23|                                                 43 35 26 32 24 47
25|                                                 36 38 29 35 27 50
18|                                                                   25 16 27
20|                                                                   26 37 28
24|                                                                   14 25 36
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	5
NUMBER OF REQUESTS	133
TOT_D_MAT	90521
DTIC	90521
DNTIC(VOIDS)	0
DTOC(EXCEPTIONS)	0

DNTOC	12762
DTIC_LOGIC	184972
EFFICIENCY	1.00
EFFICACY	1.00
SAVINGS	0.489

3.3.11 Frequency matrix – Before

```
      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
    ---------------------------------------------------------------------------
 1| 18    10 22                15    11                      19
 2|    12       29    21    23    24       26       20                25
 3|    13       20    32    14    15       17       21                16
 4| 17     9 21                13    10                      18
 5|    14       11    23    25    16       28       32                27
 6|    16       13    25    27    38       30       14                29
 7| 14     6 28                19    17                      15
 8|                24                            22    23 26    17       35
 9|     9       26    28    10    11       13       27                12
10|    12       28    30    22    33       15       19                34
11| 16     8 20                12    19                      17
12|                15                            33    24 27    28       36
13|                26                            24    35 38    19       37
14| 13     5 27                18    16                      14
15|    15       12    34    16    27       19       23                18
16|                17                            35    26 29    30       38
17| 15     7 29                10    28                      16
18|                28                            26    37 40    11       39
19|                      33             47    35                      44    36
20| 19    11 23                24    12                      10
21|                      34             48    36                      45    37
22|    12       27    29    11    22       24       28                23
23|                      35             49    37                      46    38
24|                      36             50    38                      47    39
25| 12     4 26                11    14                      13
```

Figure 3.3.11a Frequency matrix – After

```
      1  3  4 10 12 20  2  5  7  9 11 14 17 22  6 16 18 19 21 24  8 13 15 23 25
    ---------------------------------------------------------------------------
 1| 18 10 22 15 11 19
 4| 17  9 21 13 10 18
 7| 14  6 28 19 17 15
11| 16  8 20 12 19 17
14| 13  5 27 18 16 14
17| 15  7 29 10 28 16
20| 19 11 23 24 12 10
25| 12  4 26 11 14 13
 2|                   12 29 21 23 24 26 20 25
 3|                   13 20 32 14 15 17 21 16
 5|                   14 11 23 25 16 28 32 27
 6|                   16 13 25 27 38 30 14 29
 9|                    9 26 28 10 11 13 27 12
10|                   12 28 30 22 33 15 19 34
15|                   15 12 34 16 27 19 23 18
22|                   12 27 29 11 22 24 28 23
 8|                                           24 22 23 26 17 35
12|                                           15 33 24 27 28 36
13|                                           26 24 35 38 19 37
16|                                           17 35 26 29 30 38
18|                                           28 26 37 40 11 39
19|                                                             33 47 35 44 36
21|                                                             34 48 36 45 37
23|                                                             35 49 37 46 38
24|                                                             36 50 38 47 39
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	4
NUMBER OF REQUESTS	162
TOT_D_MAT	101489
DTIC	101489
DNTIC(VOIDS)	0
DTOC(EXCEPTIONS)	0

DNTOC	12291
DTIC_LOGIC	207226
EFFICIENCY	1.00
EFFICACY	1.00
SAVINGS	0.490

3.3.12 Frequency matrix – Before

```
     1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
   ---------------------------------------------------------------------------
 1|                      21 25 22    24 24    22    22 25                   20
 2| 23 18    30 22    24                   25    19             11    16
 3|                      26 22 26    20 30    24    31 21                   20
 4|                      25 25 23    25 24    29    20 26                   24
 5| 27 22    34 26    28                   29    23             25    10
 6| 29 24    26 28    20                   21    22             22    22
 7| 22 27    29 21    23                   24    18             10    15
 8| 26 21    33 25    27                   28    22             14    19
 9|       43       46             42                      30 41    34    45
10|                      21 22 25    26 20    21    30 28                   26
11| 28 23    35 27     9                   20     4             26    21
12|       35       38             34                      32 43    26    47
13|                      30 21 26    22 22    31    31 30                   21
14| 25 21    32 24    26                   27    21             13    18
15|                      29 24 25    25 25    32    31 23                   31
16| 21 26    28 30    22                   23    27             29    14
17|       32       25             31                      39 40    33    44
18| 24 29    22 23    25                   16    20             12    27
19|                      23 28 23    26 25    30    31 27                   22
20|                      26 20 28    28 21    31    32 22                   22
21|       24       37             33                      31 42    25    46
22| 20 25    27 29    21                   22    26             28    23
23|       36       29             35                      43 44    47    48
24|                      30 23 25    29 24    32    31 22                   20
25|       37       40             36                      34 45    28    49
```

Figure 3.3.12a Frequency matrix – After

```
     8  9 10 12 13 15 17 18 25  1  2  4  5  7 14 16 21 23  3  6 11 19 20 22 24
   ---------------------------------------------------------------------------
 1| 21 25 22 24 24 22 22 25 20
 3| 26 22 26 20 30 24 31 21 20
 4| 25 25 23 25 24 29 20 26 24
10| 21 22 25 26 20 21 30 28 26
13| 30 21 26 22 22 31 31 30 21
15| 29 24 25 25 25 32 31 23 31
19| 23 28 23 26 25 30 31 27 22
20| 26 20 28 28 21 31 32 22 22
24| 30 23 25 29 24 32 31 22 20
 2|                            23 18 30 22 24 25 19 11 16
 5|                            27 22 34 26 28 29 23 25 10
 6|                            29 24 26 28 20 21 22 22 22
 7|                            22 27 29 21 23 24 18 10 15
 8|                            26 21 33 25 27 28 22 14 19
11|                            28 23 35 27  9 20  4 26 21
14|                            25 21 32 24 26 27 21 13 18
16|                            21 26 28 30 22 23 27 29 14
18|                            24 29 22 23 25 16 20 12 27
22|                            20 25 27 29 21 22 26 28 23
 9|                                                       43 46 42 30 41 34 45
12|                                                       35 38 34 32 43 26 47
17|                                                       32 25 31 39 40 33 44
21|                                                       24 37 33 31 42 25 46
23|                                                       36 29 35 43 44 47 48
25|                                                       37 40 36 34 45 28 49
```

Statistics after Cluster formation -Frequency distance matrix

NUMBER OF CLUSTERS	3
NUMBER OF REQUESTS	213
TOT D MAT	148712
DTIC	148712
DNTIC(VOIDS)	0
DTOC(EXCEPTIONS)	0
DNTOC	10836
DTIC LOGIC	299510

EFFICIENCY	1.00
EFFICACY	1.00
SAVINGS	0.496

Annexure 4.1
Output data for different types of Crossovers

The analysis has been carried out for Data Set 1 and experimental setup 27, keeping single inversion as the Mutation

Sl.No.	Simple Cross Over	Cyclic Cross Over	PMX Cross Over
1	0.4717	0.556604	0.72642
2	0.4717	0.613208	0.72642
3	0.4717	0.613208	0.72642
4	0.59434	0.613208	0.72642
5	0.64151	0.613208	0.72642
6	0.66981	0.613208	0.72642
7	0.66981	0.613208	0.72642
8	0.72642	0.613208	0.72642
9	0.72642	0.613208	0.72642
10	0.72642	0.613208	0.72642
11	0.87736	0.613208	0.72642
12	0.87736	0.613208	0.80189
13	0.87736	0.613208	0.80189
14	0.87736	0.613208	0.80189
15	0.87736	0.613208	0.80189
16	0.87736	0.613208	0.80189
17	0.87736	0.613208	0.80189
18	0.87736	0.613208	0.80189
19	0.87736	0.613208	0.80189
20	0.87736	0.613208	0.80189
21	0.87736	0.613208	0.80189
22	0.87736	0.613208	0.80189
23	0.87736	0.613208	0.80189
24	1	0.613208	0.80189
25	1	0.613208	0.80189
26	1	0.613208	0.80189
27	1	0.613208	0.80189
28	1	0.613208	0.80189
29	1	0.783019	0.80189
30	1	0.783019	0.80189
31	1	0.783019	0.80189
32	1	0.783019	0.80189
33	1	0.783019	0.80189
34	1	0.783019	0.80189
35	1	0.783019	0.80189
36	1	0.783019	0.80189
37	1	0.783019	0.80189

38	1	0.783019	0.80189
39	1	0.783019	0.80189
40	1	0.783019	0.80189
41	1	0.783019	0.80189
42	1	0.783019	0.80189
43	1	0.783019	0.80189
44	1	0.783019	0.80189
45	1	0.783019	0.80189
46	1	0.783019	0.80189
47	1	0.783019	0.80189
48	1	0.783019	0.80189
49	1	0.783019	0.80189
50	1	0.783019	0.80189
51	1	0.783019	0.80189
52	1	0.783019	0.80189
53	1	0.783019	0.80189
54	1	0.783019	0.80189
55	1	0.783019	0.80189
56	1	0.783019	0.80189
57	1	0.783019	0.80189
58	1	0.783019	0.80189
59	1	0.783019	0.80189
60	1	0.783019	0.80189
61	1	0.783019	0.80189
62	1	0.783019	0.80189
63	1	0.783019	0.80189
64	1	0.783019	0.80189
65	1	0.783019	0.80189
66	1	0.783019	0.80189
67	1	0.783019	0.80189
68	1	0.783019	0.81132
69	1	0.783019	0.81132
70	1	0.783019	0.81132
71	1	0.783019	0.81132
72	1	0.783019	0.81132
73	1	0.783019	0.81132
74	1	0.915094	0.81132
75	1	0.924528	0.81132
76	1	0.924528	0.81132
77	1	0.924528	0.81132
78	1	0.924528	0.81132
79	1	0.924528	0.81132
80	1	0.924528	0.81132

81	1	0.924528	0.81132
82	1	0.924528	0.81132
83	1	0.924528	0.81132
84	1	0.924528	0.81132
85	1	0.924528	0.81132
86	1	0.924528	0.81132
87	1	0.924528	1
88	1	0.924528	1
89	1	0.924528	1
90	1	0.924528	1
91	1	0.924528	1
92	1	0.924528	1
93	1	0.924528	1
94	1	0.924528	1
95	1	0.924528	1
96	1	0.924528	1
97	1	0.924528	1
98	1	0.924528	1
99	1	0.924528	1
100	1	0.924528	1

Annexure – 4.2
Output data for different types of Mutation

Effect of Mutation on Convergence for Data set 1 Experimental setup 27

Sl.No	Simple Inversion	Multiple Inversion	Multiple Insertion
1.	0.4717	0.4717	0.4717
2.	0.48113	0.5	0.4717
3.	0.48113	0.51887	0.4717
4.	0.48113	0.68868	0.4717
5.	0.48113	0.68868	0.4717
6.	0.66981	0.68868	0.4717
7.	0.72642	0.68868	0.4717
8.	0.72642	0.68868	0.4717
9.	0.72642	0.68868	0.4717
10.	0.72642	0.68868	0.4717
11.	0.72642	0.68868	0.4717
12.	0.72642	0.68868	0.4717
13.	0.72642	0.68868	0.4717
14.	0.72642	0.68868	0.4717
15.	0.72642	0.68868	0.4717
16.	0.72642	0.68868	0.5566
17.	0.72642	0.68868	0.5566
18.	0.87736	0.68868	0.5566
19.	0.87736	0.68868	0.5566
20.	0.87736	0.68868	0.5566
21.	0.87736	0.68868	0.5566
22.	0.87736	0.68868	0.5566
23.	0.87736	0.68868	0.5566
24.	0.87736	0.68868	0.5566
25.	0.87736	0.68868	0.5566
26.	0.87736	0.68868	0.66981
27.	0.87736	0.68868	0.80189
28.	0.87736	0.68868	0.80189
29.	0.87736	0.68868	0.80189
30.	0.87736	0.68868	0.80189
31.	0.87736	0.68868	0.80189
32.	0.87736	0.68868	0.80189
33.	0.87736	0.68868	0.80189
34.	0.87736	0.68868	0.80189
35.	0.87736	0.68868	0.80189
36.	0.87736	0.68868	0.80189
37.	0.87736	0.68868	0.80189

38.	1	0.68868	0.80189
39.	1	0.68868	0.80189
40.	1	0.68868	0.80189
41.	1	0.68868	0.80189
42.	1	0.68868	0.80189
43.	1	0.68868	0.80189
44.	1	0.68868	0.80189
45.	1	0.68868	0.80189
46.	1	0.68868	0.80189
47.	1	0.68868	0.80189
48.	1	0.68868	0.80189
49.	1	0.68868	0.80189
50.	1	0.68868	0.80189
51.	1	0.68868	0.80189
52.	1	0.68868	0.80189
53.	1	0.68868	0.80189
54.	1	0.68868	0.80189
55.	1	0.68868	0.80189
56.	1	0.68868	0.81132
57.	1	0.68868	0.81132
58.	1	0.9717	0.81132
59.	1	0.9717	0.81132
60.	1	0.9717	0.81132
61.	1	0.9717	0.81132
62.	1	0.9717	0.81132
63.	1	0.9717	0.81132
64.	1	0.9717	0.81132
65.	1	0.9717	0.81132
66.	1	0.9717	0.87736
67.	1	0.9717	0.87736
68.	1	0.9717	0.87736
69.	1	0.9717	0.87736
70.	1	0.9717	0.87736
71.	1	0.9717	0.87736
72.	1	0.9717	1
73.	1	0.9717	1
74.	1	0.9717	1
75.	1	0.9717	1
76.	1	0.9717	1
77.	1	0.9717	1
78.	1	0.9717	1
79.	1	0.9717	1
80.	1	0.9717	1

81.	1	0.9717	1
82.	1	0.9717	1
83.	1	0.9717	1
84.	1	0.9717	1
85.	1	0.9717	1
86.	1	0.9717	1
87.	1	0.9717	1
88.	1	0.9717	1
89.	1	1	1
90.	1	1	1
91.	1	1	1
92.	1	1	1
93.	1	1	1
94.	1	1	1
95.	1	1	1
96.	1	1	1
97.	1	1	1
98.	1	1	1
99.	1	1	1
100.	1	1	1

Annexure – 4.3

Output data for different types of Combination of Crossover and Mutation

The analysis has been carried out for Problem 1 and experimental setup 27

C1M1	C1M2	C1M3	C2M1	C2M2	C2M3	C3M1	C3M2	C3M3
0.622642	0.4717	0.4717	0.81132	0.4717	0.61321	0.4717	0.4717	0.4717
0.622642	0.51887	0.4717	0.81132	0.4717	0.61321	1	0.59434	0.4717
0.622642	0.51887	0.62264	0.81132	0.4717	0.61321	1	0.59434	0.4717
0.622642	0.51887	0.62264	0.81132	0.4717	0.61321	1	0.59434	0.62264
0.622642	0.51887	0.66038	0.81132	0.4717	0.61321	1	0.59434	0.62264
0.622642	0.59434	0.87736	0.81132	0.4717	0.61321	1	0.59434	0.62264
0.622642	0.59434	0.87736	0.81132	0.4717	0.61321	1	0.59434	0.62264
0.622642	0.59434	0.87736	0.81132	0.5566	0.61321	1	0.59434	0.62264
0.622642	0.59434	0.87736	0.81132	0.5566	0.61321	1	0.59434	0.62264
0.622642	0.59434	0.87736	0.81132	0.5566	0.61321	1	0.59434	0.62264
0.622642	0.59434	0.87736	0.81132	0.5566	0.61321	1	0.59434	0.62264
0.745283	0.59434	0.87736	0.81132	0.5566	0.68868	1	0.59434	0.62264
0.745283	0.59434	0.87736	0.81132	0.5566	0.68868	1	0.59434	0.62264
0.745283	0.59434	0.87736	1	0.5566	0.68868	1	0.59434	0.64151
0.745283	0.59434	0.87736	1	0.5566	0.68868	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.68868	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.64151
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.74528
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.74528
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.74528
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.74528
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.74528
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.87736
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.87736
0.745283	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.87736
0.801887	0.66981	0.87736	1	0.5566	0.92453	1	0.74528	0.87736
0.801887	0.81132	0.87736	1	0.5566	0.92453	1	0.74528	0.87736
0.801887	0.81132	0.87736	1	0.5566	0.92453	1	0.74528	0.87736

0.801887	0.81132	0.87736	1	0.5566	0.92453	1	0.74528	0.87736
0.801887	0.81132	0.87736	1	0.5566	0.92453	1	0.74528	0.87736
0.801887	0.81132	0.87736	1	0.64151	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.64151	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.64151	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	0.87736	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	1	0.87736	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	1	1	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	1	1	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	1	1	1	0.9434	0.92453	1	0.74528	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736

0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	0.87736
0.801887	1	1	1	0.9434	0.92453	1	1	1
0.801887	1	1	1	0.9434	0.92453	1	1	1
0.801887	1	1	1	0.9434	0.92453	1	1	1
0.801887	1	1	1	0.9434	0.92453	1	1	1
0.801887	1	1	1	0.9434	0.92453	1	1	1
0.801887	1	1	1	0.9434	0.92453	1	1	1
0.801887	1	1	1	0.9434	0.92453	1	1	1

C1M1 C1 – Simple Cross over – M1 – Single Inversion
C1M2 C1 – Simple Cross over – M2 – Multiple Inversion
C1M3 C1 – Simple Cross over – M3 – Multiple Insertion

C2M1 C1 – Cyclic Cross over – M1 – Single Inversion
C2M2 C2 – Cyclic Cross over – M2 – Multiple Inversion
C2M3 C2 – Cyclic Cross over – M3 – Multiple Insertion

C3M1 C3 – PMX Cross over – M1 – Single Inversion
C3M2 C3 – PMX Cross over – M2 – Multiple Inversion
C3M3 C3 – PMX Cross over – M3 – Multiple Insertion

Annexure – 4.4

Output data for different Data Sets

Convergence of solution for different Data sets with PMX Cross Over & Multiple Inversion

Experimental setup 27

Data Set 1	Data Set 2	Data Set 3	Data Set 4	Data Set 5	Data Set 6
0.4717	0.78417	0.63333	0.64865	0.54587	0.67266
0.4717	0.78417	0.66667	0.64865	0.77064	0.67266
0.4717	0.94245	0.66667	0.64865	0.77064	0.69065
0.4717	0.94245	0.66667	0.64865	0.77064	0.69065
0.51887	0.94245	0.66667	0.64865	0.77064	0.69065
0.51887	0.94245	0.66667	0.64865	0.77064	0.69065
0.59434	0.94245	0.66667	0.64865	0.77064	0.69065
0.59434	0.94245	0.66667	0.72973	0.77064	0.72302
0.71698	0.94245	0.66667	0.72973	0.77064	0.72302
0.71698	0.94245	0.66667	0.72973	0.77064	0.72302
0.71698	0.94245	0.66667	0.72973	0.80734	0.72302
0.71698	0.94245	0.72667	0.72973	0.80734	0.72302
0.71698	0.94245	0.72667	0.72973	0.80734	0.72302
0.71698	0.94245	0.72667	0.72973	0.80734	0.72302
0.71698	0.94245	0.72667	0.72973	0.80734	0.72302
0.71698	0.94245	0.72667	0.72973	0.80734	0.72302
0.71698	0.94245	0.72667	0.72973	0.80734	0.72302
0.71698	0.94245	0.72667	0.72973	0.80734	0.72662
0.71698	0.94245	0.72667	0.72973	0.80734	0.72662
0.71698	0.94245	0.72667	0.72973	0.80734	0.72662
0.71698	0.94245	0.72667	0.72973	0.80734	0.72662
0.71698	0.94245	0.72667	0.72973	0.80734	0.72662
0.71698	0.94245	0.72667	0.72973	0.80734	0.72662
1	0.94245	0.72667	0.72973	0.80734	0.72662
1	0.94245	0.82	0.72973	0.80734	0.72662
1	0.94245	0.82	0.72973	0.80734	0.72662
1	0.94245	0.82	0.72973	0.80734	0.72662
1	0.94245	0.82	0.78378	0.80734	0.72662
1	0.94245	0.82	0.78378	0.90826	0.72662
1	0.94245	0.82	0.78378	0.90826	0.72662
1	0.94245	0.82	0.78378	0.90826	0.72662
1	0.94245	0.82	0.78378	0.90826	0.72662

1	0.94245	0.82	0.78378	0.90826	0.81295
1	0.94245	0.82	0.78378	0.90826	0.81295
1	0.94245	0.82	0.78378	0.90826	0.81295
1	0.94245	0.82	0.78378	0.90826	0.81295
1	0.94245	0.82	0.78378	0.90826	0.81295
1	0.94245	0.82	0.78378	0.90826	0.81295
1	0.94245	0.82	0.78378	0.90826	0.81295
1	0.94245	0.82	0.78378	0.90826	0.81295
1	0.94245	0.82	0.78378	0.90826	0.82734
1	0.94245	0.82	0.78378	0.90826	0.82734
1	0.94245	0.82	0.78378	0.90826	0.82734
1	0.94245	0.91333	0.78378	0.90826	0.82734
1	0.94245	0.91333	0.78378	0.90826	0.83453
1	0.94245	0.91333	0.78378	0.90826	0.83453
1	0.94245	0.91333	0.78378	0.90826	0.83453
1	0.94245	0.91333	0.78378	0.90826	0.83453
1	0.94245	0.91333	0.81081	0.90826	0.83453
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813

1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.83813
1	0.94245	0.91333	0.81081	0.90826	0.84532
1	0.94245	0.91333	0.81081	0.90826	0.84532
1	0.94245	0.91333	0.81081	0.90826	0.84532
1	0.94245	0.91333	0.81081	0.90826	0.84532
1	0.94245	0.91333	0.81081	0.90826	0.84532
1	0.94245	0.91333	0.81081	0.90826	0.84532
1	0.94245	0.91333	0.81081	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	0.94245	0.91333	0.83784	0.90826	0.84532
1	1	0.91333	0.83784	0.90826	0.84532
1	1	0.91333	0.83784	0.90826	0.84532
1	1	0.91333	0.83784	0.90826	0.84532
1	1	0.91333	0.83784	0.90826	0.84532
1	1	0.91333	0.83784	0.90826	0.84532
1	1	0.91333	0.83784	0.90826	0.84532
1	1	0.91333	0.83784	0.90826	0.84532

Annexure – 4.5

Output of OA Experiment for data set 1

Expt. No.	Replicate 1	Replicate 2	Replicate 3	Replicate 4	Replicate 5
1	0.8018	0.849	0.849	0.6226	0.8018
2	0.8018	0.6226	0.8018	0.8018	0.7452
3	0.849	0.8018	0.8018	0.8018	0.8773
4	0.7452	0.8018	0.8018	0.8018	0.6698
5	0.7358	0.8018	0.8018	0.8018	0.7169
6	0.809	0.6226	0.849	1	0.7452
7	0.8018	0.7452	0.6698	0.8018	0.8018
8	0.8018	0.7452	0.849	0.8018	1
9	0.8018	0.849	0.849	0.7452	0.7358
10	0.8018	0.8018	0.8018	1	0.8018
11	0.849	0.8018	0.6226	0.8018	0.8018
12	0.849	0.7452	0.849	0.8018	0.849
13	0.8018	0.7452	0.8018	0.8018	0.8018
14	0.8018	0.849	0.8018	0.8018	1
15	0.8018	0.7452	0.8018	0.8773	0.8018
16	0.8773	0.7452	0.7358	0.7264	0.8018
17	0.8018	0.8113	0.8018	0.849	0.8773
18	0.849	0.849	0.7452	1	0.6226
19	0.8018	0.7358	0.7452	0.8018	0.8018
20	0.8018	0.7169	0.8018	0.8018	0.7452
21	0.8679	0.8773	0.8018	0.8018	0.8773
22	0.8018	0.8018	1	0.7452	0.849
23	0.849	0.8773	0.8018	0.8018	0.8773
24	0.8018	0.8773	0.8018	0.8018	0.8018
25	0.8207	0.8018	0.8018	0.849	0.8018
26	0.7452	0.8018	0.7358	0.8018	0.8018
27	1	0.8018	0.8773	0.8018	0.8018
Total	**22.0713**	**21.2245**	**21.6019**	**22.0453**	**21.8095**

Annexture 4.6

Final output of Genetic Algorithm

```
JOBS=  7
NO OF ROWS= 25
NO OF COLUMNS=25

MUTATION PROBABILITY=  15
CROSSOVER PROBABILITY=  90

POPULATION = 14 extendedpopulation = 19
_____________________________________________

job and location details
_____________________________________________
job  row   column  units
_____________________________________________
 1    8     6  10
 2   20    20  30
 3    3     3  20
 4   22    22  40
 5    2     2  25
 6   16    18  32
 7   10    15  30
```

GENERATION 1

Sequence	Sequence	Distance	Fitness value
1	5 3 7 1 4 2 6	72.000000	0.784173
2	5 2 3 7 4 6 1	138.000000	0.309353
3	3 4 7 5 2 1 6	160.000000	0.151079
4	4 5 1 6 7 2 3	128.000000	0.381295
5	1 2 3 4 5 6 7	177.000000	0.028777
6	5 3 7 1 4 2 6	72.000000	0.784173
7	5 2 3 7 4 6 1	138.000000	0.309353
8	3 4 7 5 2 1 6	160.000000	0.151079
9	4 5 1 6 7 2 3	128.000000	0.381295
10	1 2 3 4 5 6 7	177.000000	0.028777
11	5 3 7 1 4 2 6	72.000000	0.784173
12	5 2 3 7 4 6 1	138.000000	0.309353
13	3 4 7 5 2 1 6	160.000000	0.151079
14	4 5 1 6 7 2 3	128.000000	0.381295

GENERATION 2

Sequence	Sequence	Distance	Fitness value
sequence 1	5 3 7 1 4 2 6	72.000000	0.784173
sequence 2	5 2 3 7 4 6 1	138.000000	0.309353
sequence 3	3 4 7 5 2 1 6	160.000000	0.151079
sequence 4	4 5 1 6 7 2 3	128.000000	0.381295
sequence 5	1 2 3 4 5 6 7	177.000000	0.028777
sequence 6	5 3 7 1 4 2 6	72.000000	0.784173
sequence 7	5 2 3 7 4 6 1	138.000000	0.309353
sequence 8	3 4 7 5 2 1 6	160.000000	0.151079
sequence 9	4 5 1 6 7 2 3	128.000000	0.381295
sequence 10	1 2 3 4 5 6 7	177.000000	0.028777
sequence 11	5 3 7 1 4 2 6	72.000000	0.784173
sequence 12	5 2 3 7 4 6 1	138.000000	0.309353
sequence 13	3 4 7 5 2 1 6	160.000000	0.151079
sequence 14	4 5 1 6 7 2 3	128.000000	0.381295
sequence 15	1 2 7 5 3 6 4	102.000000	0.568345
sequence 16	5 7 3 4 2 1 6	128.000000	0.381295
sequence 17	1 3 7 4 5 6 2	122.000000	0.424460
sequence 18	5 6 3 1 4 2 7	115.000000	0.474820
sequence 19	0 0 0 0 0 0 0	0.000000	0.000000

GENERATION 3

Sequence	Sequence	Distance	Fitness value
sequence 1	5 3 7 1 4 2 6	72.000000	0.784173
sequence 2	5 3 7 1 4 2 6	72.000000	0.784173
sequence 3	5 3 7 1 4 2 6	72.000000	0.784173
sequence 4	5 3 7 1 4 2 6	72.000000	0.784173
sequence 5	1 2 3 4 5 6 7	177.000000	0.028777
sequence 6	5 3 7 1 4 2 6	72.000000	0.784173
sequence 7	5 2 3 7 4 6 1	138.000000	0.309353
sequence 8	3 4 7 5 2 1 6	160.000000	0.151079
sequence 9	4 5 1 6 7 2 3	128.000000	0.381295
sequence 10	1 2 3 4 5 6 7	177.000000	0.028777
sequence 11	5 3 7 1 4 2 6	72.000000	0.784173
sequence 12	5 2 3 7 4 6 1	138.000000	0.309353
sequence 13	3 4 7 5 2 1 6	160.000000	0.151079
sequence 14	4 5 1 6 7 2 3	128.000000	0.381295
sequence 15	5 3 7 6 4 2 1	70.000000	0.798561
sequence 16	4 5 6 1 7 2 3	150.000000	0.223022
sequence 17	5 3 1 7 4 2 6	50.000000	0.942446
sequence 18	5 2 3 1 4 6 7	127.000000	0.388489
sequence 19	0 0 0 0 0 0 0	0.000000	0.000000

GENERATION 4

Sequence	Sequence	Distance	Fitness value
sequence 1	5 3 1 7 4 2 6	50.000000	0.942446
sequence 2	5 3 1 7 4 2 6	50.000000	0.942446
sequence 3	5 3 7 6 4 2 1	70.000000	0.798561
sequence 4	5 3 7 6 4 2 1	70.000000	0.798561
sequence 5	1 2 3 4 5 6 7	177.000000	0.028777
sequence 6	5 3 7 1 4 2 6	72.000000	0.784173
sequence 7	5 2 3 7 4 6 1	138.000000	0.309353
sequence 8	3 4 7 5 2 1 6	160.000000	0.151079
sequence 9	4 5 1 6 7 2 3	128.000000	0.381295
sequence 10	1 2 3 4 5 6 7	177.000000	0.028777
sequence 11	5 3 7 1 4 2 6	72.000000	0.784173
sequence 12	5 2 3 7 4 6 1	138.000000	0.309353
sequence 13	3 4 7 5 2 1 6	160.000000	0.151079
sequence 14	4 5 1 6 7 2 3	128.000000	0.381295
sequence 15	5 4 7 1 3 2 6	118.000000	0.453237
sequence 16	4 3 7 5 2 1 6	160.000000	0.151079
sequence 17	5 3 7 6 4 2 1	70.000000	0.798561
sequence 18	5 3 1 7 4 2 6	50.000000	0.942446
sequence 19	0 0 0 0 0 0 0	0.000000	0.000000

GENERATION 93

Sequence	Sequence	Distance	Fitness value
sequence 1	4 2 6 7 3 5 1	50.000000	0.942446
sequence 2	4 2 6 7 3 5 1	50.000000	0.942446
sequence 3	4 2 6 7 3 5 1	50.000000	0.942446
sequence 4	4 2 6 7 3 5 1	50.000000	0.942446
sequence 5	1 2 3 4 5 6 7	177.000000	0.028777
sequence 6	5 3 7 1 4 2 6	72.000000	0.784173
sequence 7	5 2 3 7 4 6 1	138.000000	0.309353
sequence 8	3 4 7 5 2 1 6	160.000000	0.151079
sequence 9	4 5 1 6 7 2 3	128.000000	0.381295
sequence 10	1 2 3 4 5 6 7	177.000000	0.028777
sequence 11	5 3 7 1 4 2 6	72.000000	0.784173
sequence 12	5 2 3 7 4 6 1	138.000000	0.309353
sequence 13	3 4 7 5 2 1 6	160.000000	0.151079
sequence 14	4 5 1 6 7 2 3	128.000000	0.381295
sequence 15	1 2 3 4 5 6 7	177.000000	0.028777
sequence 16	5 2 3 7 4 6 1	138.000000	0.309353
sequence 17	3 2 7 4 5 6 1	158.000000	0.165468
sequence 18	1 2 4 7 3 5 6	100.000000	0.582734
sequence 19	4 2 5 7 3 6 1	128.000000	0.381295

GENERATION 95

Sequence	Sequence	Distance	Fitness value
sequence 1	4 2 6 7 3 5 1	50.000000	0.942446
sequence 2	4 2 6 7 3 5 1	50.000000	0.942446
sequence 3	4 2 6 7 3 5 1	50.000000	0.942446
sequence 4	4 2 6 7 3 5 1	50.000000	0.942446
sequence 5	1 2 3 4 5 6 7	177.000000	0.028777
sequence 6	5 3 7 1 4 2 6	72.000000	0.784173
sequence 7	5 2 3 7 4 6 1	138.000000	0.309353
sequence 8	3 4 7 5 2 1 6	160.000000	0.151079
sequence 9	4 5 1 6 7 2 3	128.000000	0.381295
sequence 10	1 2 3 4 5 6 7	177.000000	0.028777
sequence 11	5 3 7 1 4 2 6	72.000000	0.784173
sequence 12	5 2 3 7 4 6 1	138.000000	0.309353
sequence 13	3 4 7 5 2 1 6	160.000000	0.151079
sequence 14	4 5 1 6 7 2 3	128.000000	0.381295
sequence 15	4 2 6 7 1 5 3	42.000000	1.000000
sequence 16	4 5 3 6 7 2 1	120.000000	0.438849
sequence 17	5 2 3 7 4 6 1	138.000000	0.309353
sequence 18	4 2 6 7 3 5 1	50.000000	0.942446
sequence 19	4 2 5 7 3 6 1	128.000000	0.381295

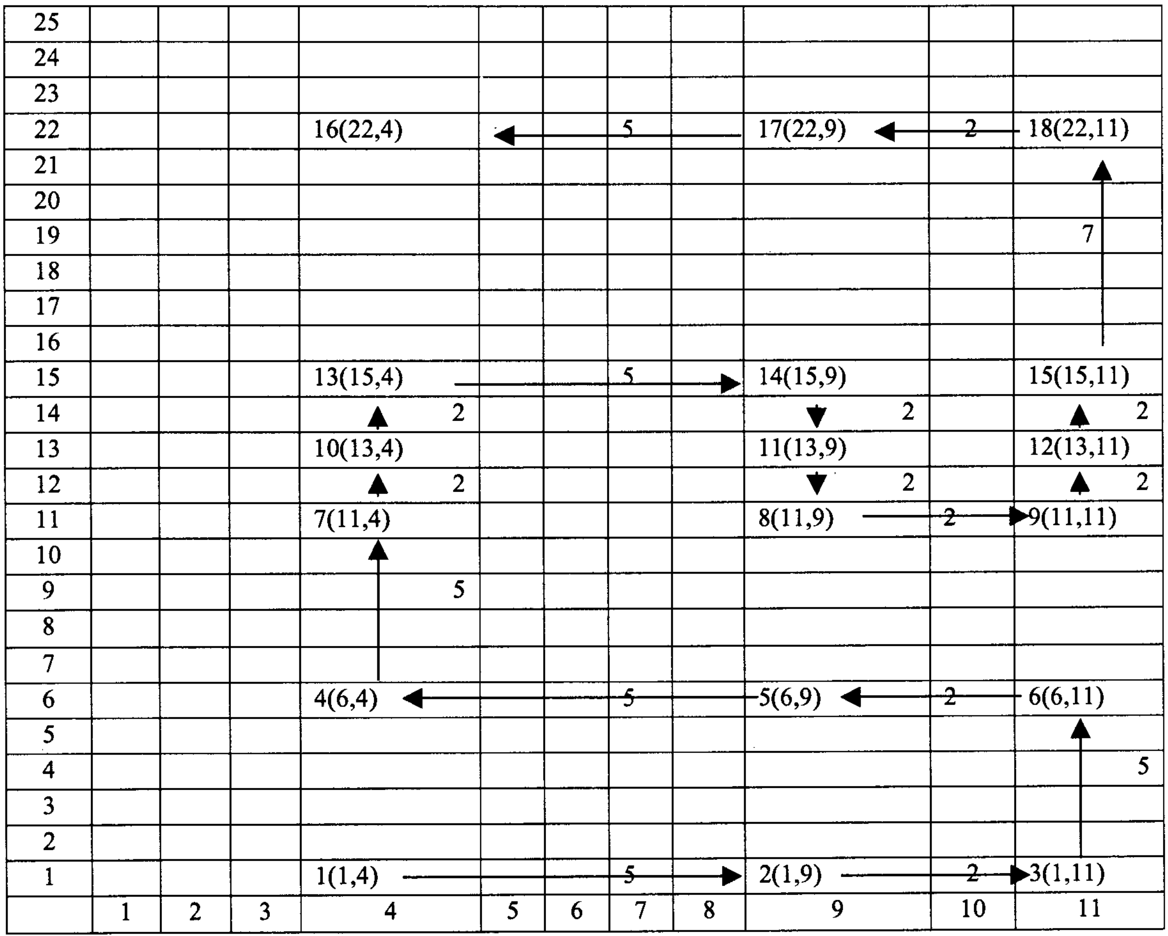
GENERATION 100

Sequence	Sequence	Distance	Fitness value
sequence 1	4 2 6 7 1 5 3	42.000000	1.000000
sequence 2	4 2 6 7 1 5 3	42.000000	1.000000
sequence 3	4 2 6 7 1 5 3	42.000000	1.000000
sequence 4	4 2 6 7 1 5 3	42.000000	1.000000
sequence 5	1 2 3 4 5 6 7	177.000000	0.028777
sequence 6	5 3 7 1 4 2 6	72.000000	0.784173
sequence 7	5 2 3 7 4 6 1	138.000000	0.309353
sequence 8	3 4 7 5 2 1 6	160.000000	0.151079
sequence 9	4 5 1 6 7 2 3	128.000000	0.381295
sequence 10	1 2 3 4 5 6 7	177.000000	0.028777
sequence 11	5 3 7 1 4 2 6	72.000000	0.784173
sequence 12	5 2 3 7 4 6 1	138.000000	0.309353
sequence 13	3 4 7 5 2 1 6	160.000000	0.151079
sequence 14	4 5 1 6 7 2 3	128.000000	0.381295
sequence 15	4 6 3 5 2 1 7	113.000000	0.489209
sequence 16	3 1 2 7 4 6 5	108.000000	0.525180
sequence 17	4 2 6 7 1 5 3	42.000000	1.000000
sequence 18	4 2 6 7 1 5 3	42.000000	1.000000
sequence 19	4 2 5 7 3 6 1	128.000000	0.381295

Annexure 4.7

Output data for common data set

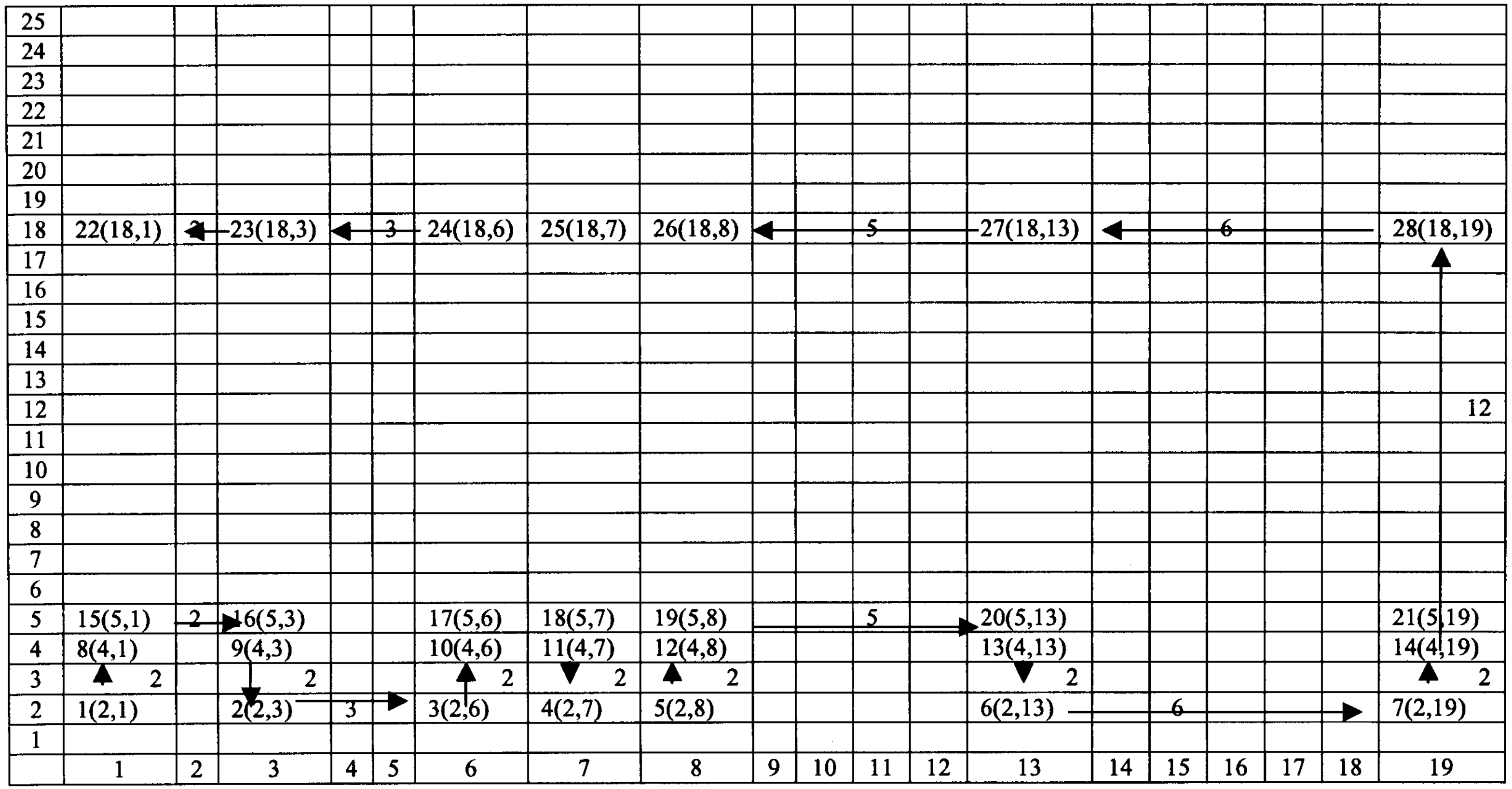
Cluster – 1



25											
24											
23											
22				16(22,4)	←		5		17(22,9) ←	2	18(22,11)
21											↑
20											
19											7
18											
17											
16											
15				13(15,4)			5	→	14(15,9)		15(15,11)
14				↑ 2					↓	2	↑ 2
13				10(13,4)					11(13,9)		12(13,11)
12				↑ 2					↓	2	↑ 2
11				7(11,4)					8(11,9)	2 →	9(11,11)
10				↑							
9				5							
8											
7											
6				4(6,4) ←			5		5(6,9) ←	2	6(6,11)
5											↑
4											5
3											
2											
1				1(1,4)			5	→	2(1,9)	2 →	3(1,11)
	1	2	3	4	5	6	7	8	9	10	11

Route : 1 – 2 – 3 – 6 – 5 – 4 – 7 – 10 – 13 – 14 – 11 – 8 – 9 – 12 – 15 – 18 – 17 – 16
Distance: 57

Cluster – 2



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

Route: 1 – 8 – 15 – 16 – 9 – 2 – 3 – 10 – 17 – 18 – 11 – 4 – 5 – 12 – 19 – 20 – 13 – 6 – 7 – 14 – 21 – 28 – 27 – 26 – 25 – 24 – 23 – 22
Distance : 70

Cluster 3

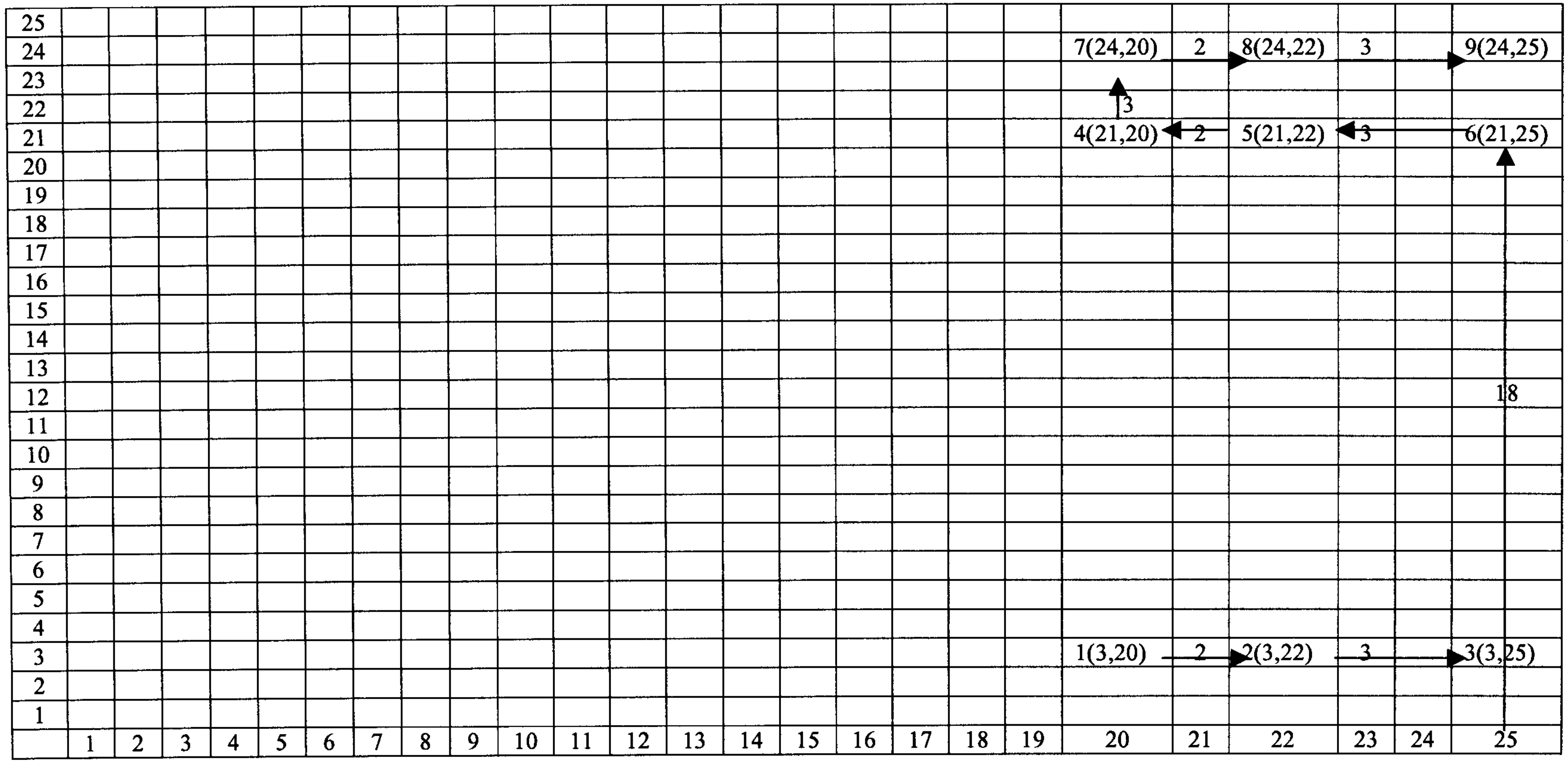
JOBS= 9
NO OF ROWS= 25
NO OF COLUMNS=25
MUTATION PROBABILITY= 15
CROSSOVER PROBABILITY= 90

POPULATION = 18 extendedpopulatio = 23

```
job  row   column  units
-------------------------
 1      3     20    10
 2      3     22    20
 3      3     25    12
 4     21     20    13
 5     21     22    14
 6     21     25    17
 7     24     20    13
 8     24     22    14
 9     24     25    15
```

sequence		distance	Fitness value
sequence 1	1 2 3 4 5 6 7 8 9	46.000000	0.961039
sequence 2	1 2 3 6 5 4 7 8 9	36.000000	1.000000
sequence 3	2 4 6 1 3 9 7 8 5	84.000000	0.714286
sequence 4	5 3 2 1 9 8 4 6 7	73.000000	0.785714
sequence 5	2 4 6 1 3 9 7 8 5	84.000000	0.714286
sequence 6	1 2 3 4 5 6 7 8 9	46.000000	0.961039
sequence 7	1 2 3 6 5 4 7 8 9	36.000000	1.000000
sequence 8	2 4 6 1 3 9 7 8 5	84.000000	0.714286
sequence 9	1 2 3 4 5 6 7 8 9	46.000000	0.961039
sequence 10	1 2 3 4 5 6 7 8 9	46.000000	0.961039
sequence 11	1 2 3 6 5 4 7 8 9	36.000000	1.000000
sequence 12	2 4 6 1 3 9 7 8 5	84.000000	0.714286
sequence 13	5 3 2 1 9 8 4 6 7	73.000000	0.785714
sequence 14	1 2 3 4 5 6 7 8 9	46.000000	0.961039
sequence 15	1 2 3 6 5 4 7 8 9	36.000000	1.000000
sequence 16	2 4 6 1 3 9 7 8 5	84.000000	0.714286
sequence 17	5 3 2 1 9 8 4 6 7	73.000000	0.785714
sequence 18	1 2 3 6 5 4 7 8 9	36.000000	1.000000

mmk gene==== 1.000000



Route: 1 – 2 – 3 – 6 – 5 – 4 – 7 – 8 – 9
Distance : 36

Cluster 4

JOBS= 9
NO OF ROWS= 25
NO OF COLUMNS=25
MUTATION PROBABILITY= 15
CROSSOVER PROBABILITY= 90

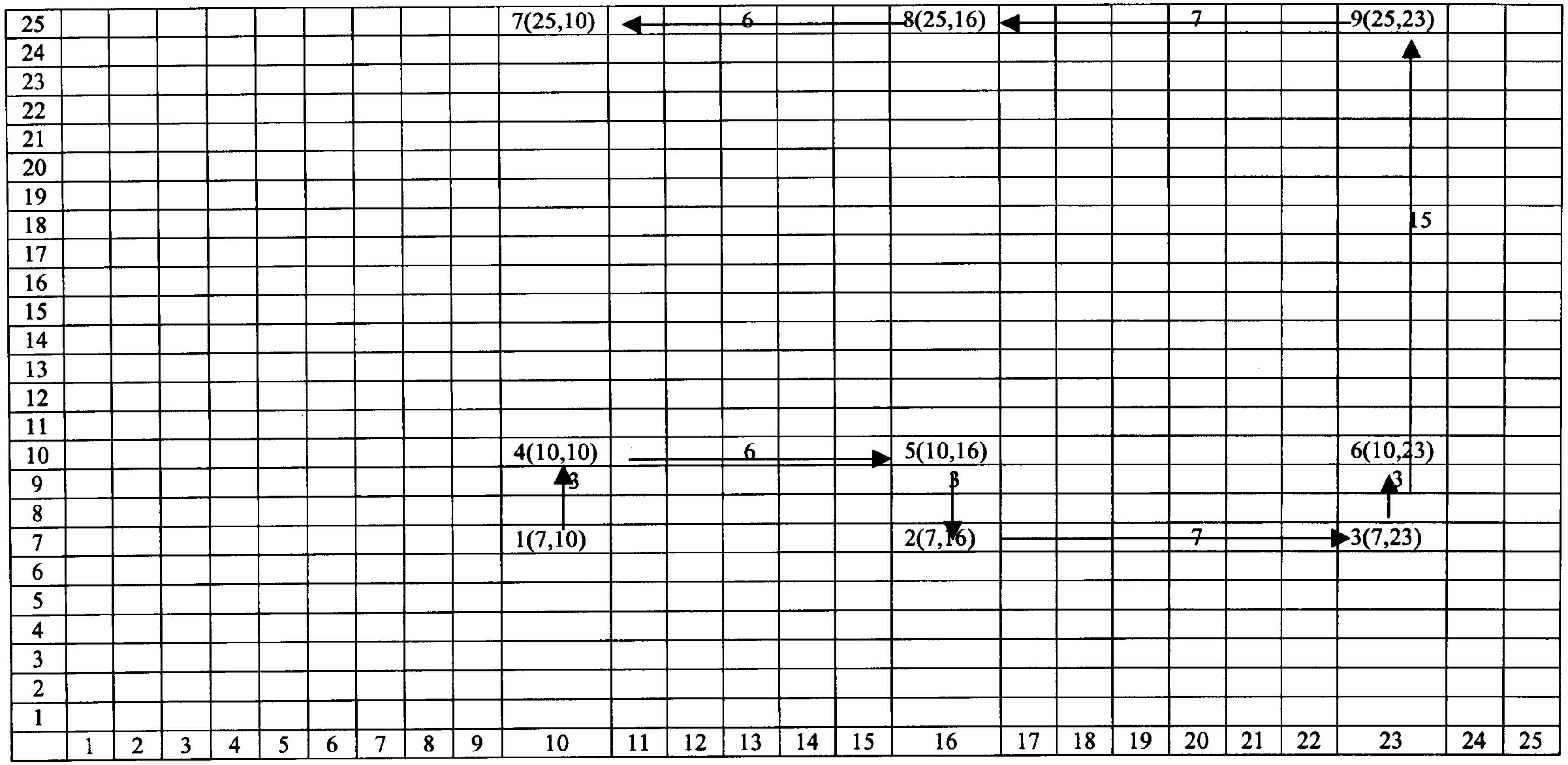
POPULATION = 18 extendedpopulatio = 23

```
 job  row   column  units

  1      7     10    10
  2      7     16     5
  3      7     23    17
  4     10     10    12
  5     10     16    12
  6     10     23    12
  7     25     10    13
  8     25     16    14
  9     25     23    13
```

sequence		distance	Fitness value
sequence 1	1 2 3 4 5 6 7 8 9	83.000000	0.770833
sequence 2	1 4 5 2 3 6 9 8 7	50.000000	1.000000
sequence 3	2 4 6 1 3 9 7 8 5	103.000000	0.631944
sequence 4	5 3 2 1 9 8 4 6 7	123.000000	0.493056
sequence 5	2 4 6 1 3 9 7 8 5	103.000000	0.631944
sequence 6	3 6 5 2 1 4 7 8 9	50.000000	1.000000
sequence 7	1 2 3 6 4 5 8 7 9	69.000000	0.868056
sequence 8	2 4 6 1 3 9 7 8 5	103.000000	0.631944
sequence 9	1 2 3 4 5 6 7 8 9	83.000000	0.770833
sequence 10	1 2 3 4 5 6 7 8 9	83.000000	0.770833
sequence 11	1 2 3 6 4 5 8 7 9	69.000000	0.868056
sequence 12	2 4 6 1 3 9 7 8 5	103.000000	0.631944
sequence 13	5 3 2 1 9 8 4 6 7	123.000000	0.493056
sequence 14	1 2 3 4 5 6 7 8 9	83.000000	0.770833
sequence 15	1 2 3 6 4 5 8 7 9	69.000000	0.868056
sequence 16	2 4 6 1 3 9 7 8 5	103.000000	0.631944
sequence 17	5 3 2 1 9 8 4 6 7	123.000000	0.493056
sequence 18	1 2 3 6 4 5 8 7 9	69.000000	0.868056

mmk gene==== 1.000000



Route: 1 – 4 – 5 – 2 – 3 – 6 – 9 – 8 – 7
Distance : 50

Cluster 5

JOBS= 9
NO OF ROWS= 25
NO OF COLUMNS=25
MUTATION PROBABILITY= 15
CROSSOVER PROBABILITY= 90

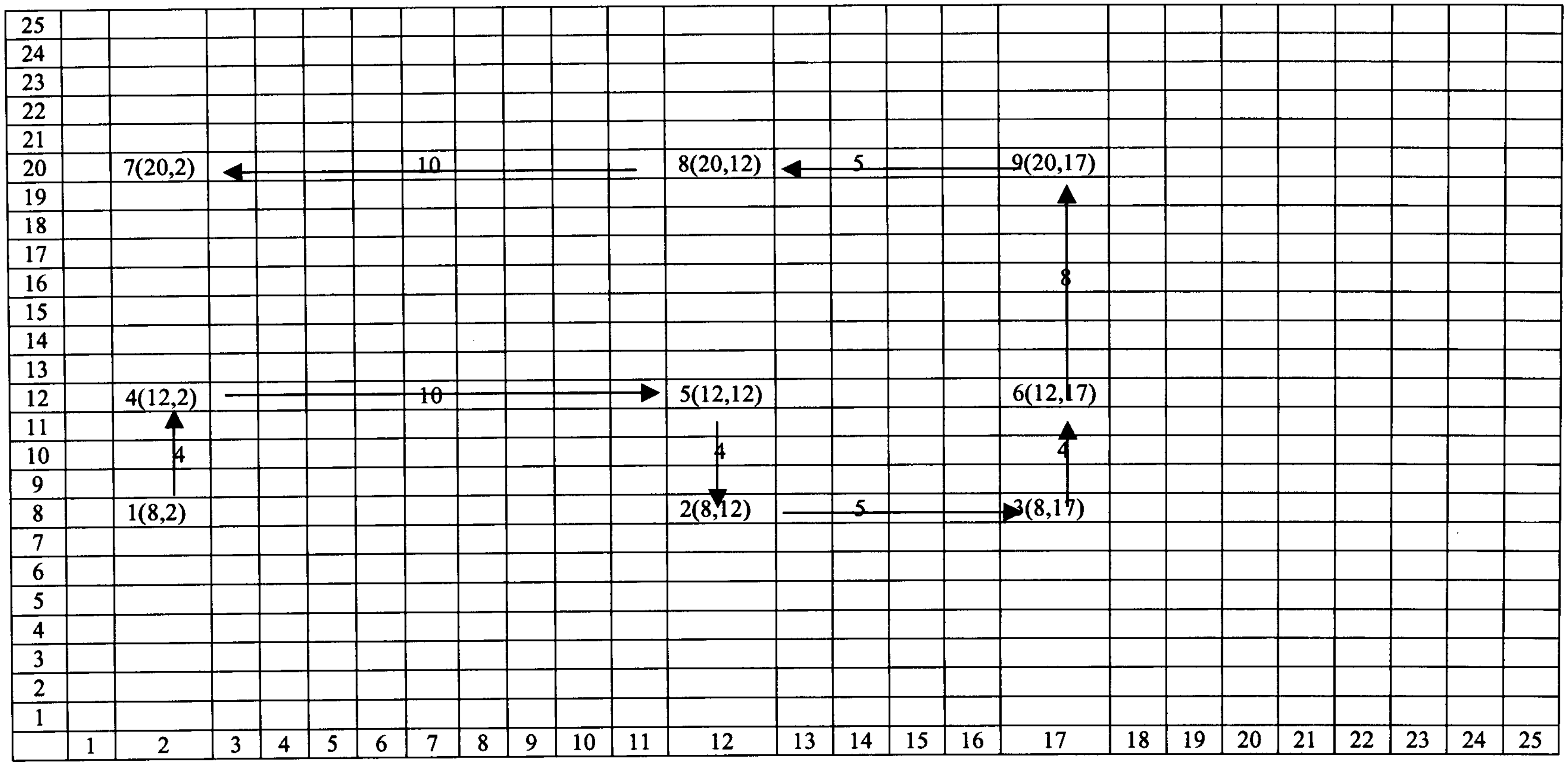
POPULATION = 18 extendedpopulatio = 23

```
job   row    column   units

 1      8       2      5
 2      8      12      7
 3      8      17     23
 4     12       2     24
 5     12      12     24
 6     12      17     23
 7     20       2     23
 8     20      12      3
 9     20      17     34
```

sequence		distance	Fitness value
sequence 1	1 2 3 4 5 6 7 8 9	87.000000	0.743056
sequence 2	1 4 5 2 3 6 9 8 7	50.000000	1.000000
sequence 3	2 4 6 1 3 9 7 8 5	108.000000	0.597222
sequence 4	5 3 2 1 9 8 4 6 7	112.000000	0.569444
sequence 5	2 4 6 1 3 9 7 8 5	108.000000	0.597222
sequence 6	3 6 5 2 1 4 7 8 9	50.000000	1.000000
sequence 7	1 2 3 6 4 5 8 7 9	77.000000	0.812500
sequence 8	2 4 6 1 3 9 7 8 5	108.000000	0.597222
sequence 9	1 2 3 4 5 6 7 8 9	87.000000	0.743056
sequence 10	1 2 3 4 5 6 7 8 9	87.000000	0.743056
sequence 11	1 2 3 6 4 5 8 7 9	77.000000	0.812500
sequence 12	2 4 6 1 3 9 7 8 5	108.000000	0.597222
sequence 13	5 3 2 1 9 8 4 6 7	112.000000	0.569444
sequence 14	1 2 3 4 5 6 7 8 9	87.000000	0.743056
sequence 15	1 2 3 6 4 5 8 7 9	77.000000	0.812500
sequence 16	2 4 6 1 3 9 7 8 5	108.000000	0.597222
sequence 17	5 3 2 1 9 8 4 6 7	112.000000	0.569444
sequence 18	1 2 3 6 4 5 8 7 9	77.000000	0.812500

mmk gene==== 1.000000



Route: 1 – 4 – 5 – 2 – 3 – 6 – 9 – 8 – 7
Distance: 50

Cluster 6

JOBS= 9
NO OF ROWS= 25
NO OF COLUMNS=25
MUTATION PROBABILITY= 15
CROSSOVER PROBABILITY= 90

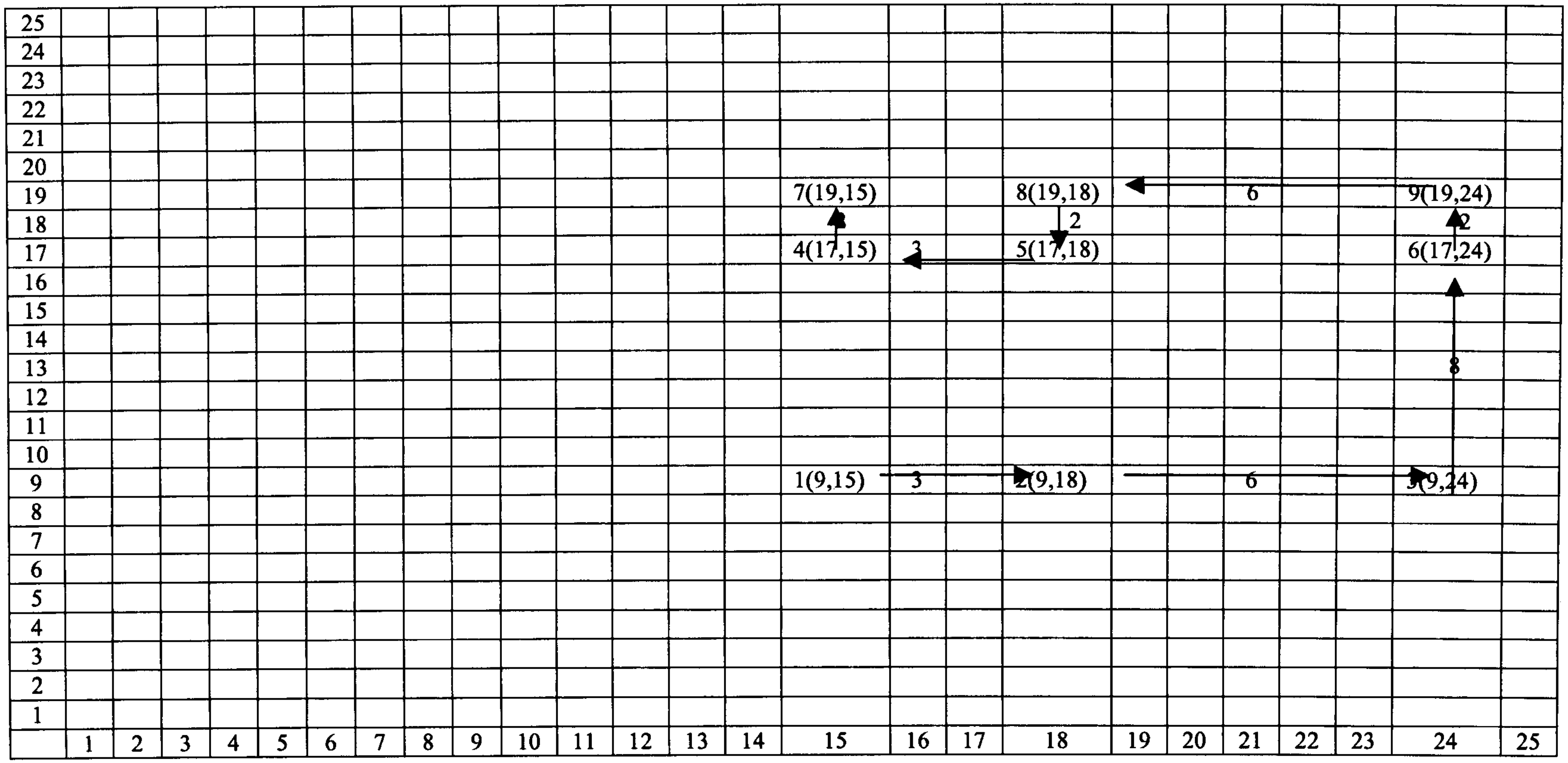
POPULATION = 18 extendedpopulatio = 23

```
job  row    column  units

 1     9     15    23
 2     9     18    12
 3     9     24    12
 4    17     15    12
 5    17     18    12
 6    17     24    12
 7    19     15    12
 8    19     18    12
 9    19     24    11
```

sequence		distance	Fitness value
sequence 1	1 2 3 4 5 6 7 8 9	55.000000	0.920530
sequence 2	1 4 5 2 3 6 9 8 7	44.000000	0.993378
sequence 3	2 4 6 1 3 9 7 8 5	70.000000	0.821192
sequence 4	5 3 2 1 9 8 4 6 7	73.000000	0.801324
sequence 5	2 4 6 1 3 9 7 8 5	70.000000	0.821192
sequence 6	3 6 5 2 1 4 7 8 9	44.000000	0.993378
sequence 7	1 2 3 6 9 8 5 4 7	32.000000	1.000000
sequence 8	2 4 6 1 3 9 7 8 5	70.000000	0.821192
sequence 9	1 2 3 4 5 6 7 8 9	55.000000	0.920530
sequence 10	1 2 3 4 5 6 7 8 9	55.000000	0.920530
sequence 11	1 2 3 6 9 8 5 4 7	32.000000	1.000000
sequence 12	2 4 6 1 3 9 7 8 5	70.000000	0.821192
sequence 13	5 3 2 1 9 8 4 6 7	73.000000	0.801324
sequence 14	1 2 3 4 5 6 7 8 9	55.000000	0.920530
sequence 15	1 2 3 6 9 8 5 4 7	32.000000	1.000000
sequence 16	2 4 6 1 3 9 7 8 5	70.000000	0.821192
sequence 17	5 3 2 1 9 8 4 6 7	73.000000	0.801324
sequence 18	1 2 3 6 9 8 5 4 7	32.000000	1.000000

mmk gene==== 1.000000



Route: 1 – 2 – 3 – 6 – 9 – 8 – 5 – 4 – 7
Distance: 32

Cluster 7

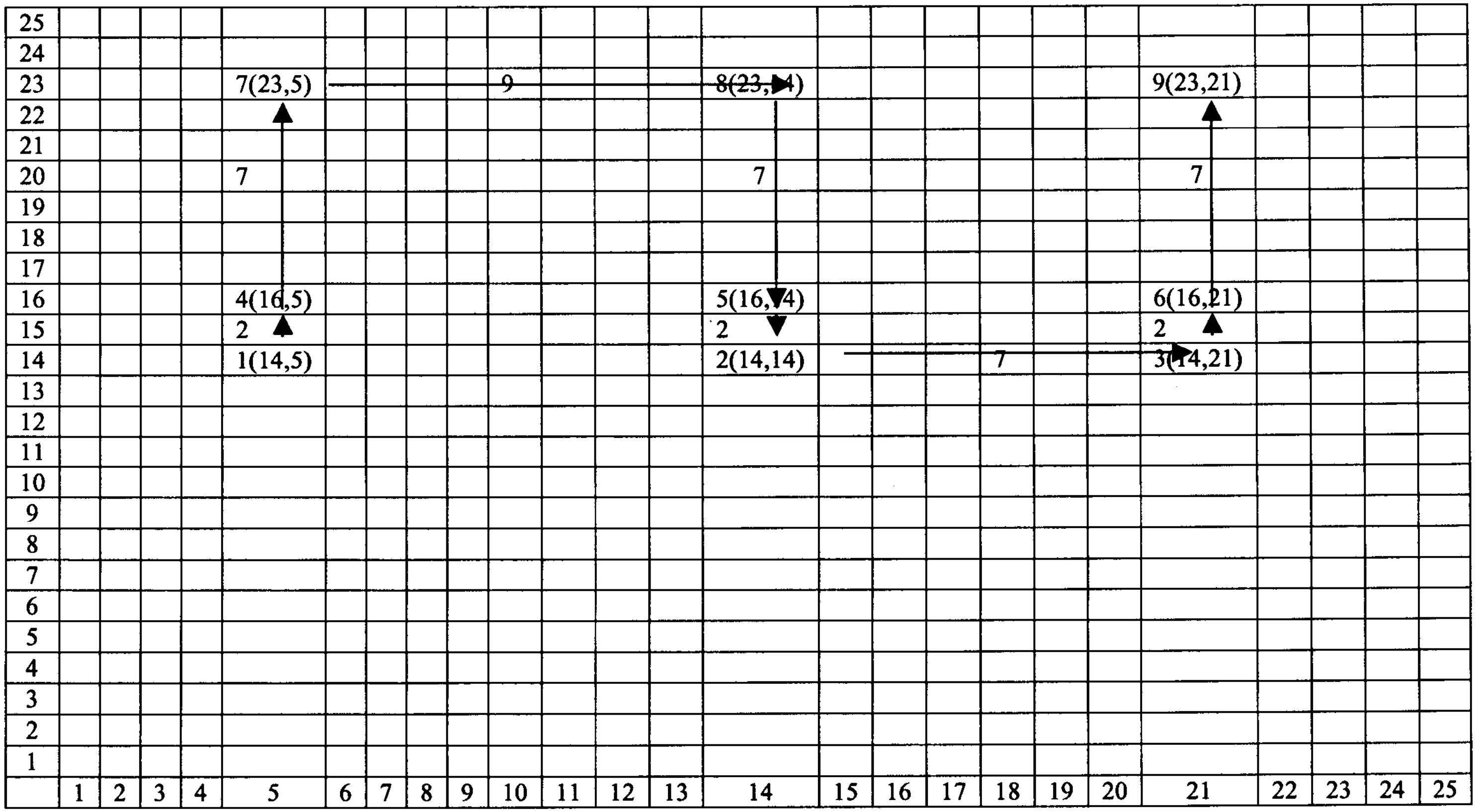
JOBS= 9
NO OF ROWS= 25
NO OF COLUMNS=25
MUTATION PROBABILITY= 15
CROSSOVER PROBABILITY= 90

POPULATION = 18 extended population = 23

```
 job  row   column  units
 
  1    14      5     2
  2    14     14     2
  3    14     21     3
  4    16      5     6
  5    16     14     8
  6    16     21    11
  7    23      5    12
  8    23     14    13
  9    23     21    16
```

sequence		distance	Fitness value
sequence 1	1 2 3 4 5 6 7 8 9	89.000000	0.704698
sequence 2	1 4 7 8 5 2 3 6 9	43.000000	1.000000
sequence 3	2 4 6 1 3 9 7 8 5	102.000000	0.617450
sequence 4	5 3 2 1 9 8 4 6 7	112.000000	0.550336
sequence 5	2 4 6 1 3 9 7 8 5	102.000000	0.617450
sequence 6	1 4 7 8 5 2 3 6 9	43.000000	1.000000
sequence 7	1 2 3 6 4 5 8 7 9	75.000000	0.798658
sequence 8	2 4 6 1 3 9 7 8 5	102.000000	0.617450
sequence 9	1 2 3 4 5 6 7 8 9	89.000000	0.704698
sequence 10	1 2 3 4 5 6 7 8 9	89.000000	0.704698
sequence 11	1 2 3 6 4 5 8 7 9	75.000000	0.798658
sequence 12	2 4 6 1 3 9 7 8 5	102.000000	0.617450
sequence 13	5 3 2 1 9 8 4 6 7	112.000000	0.550336
sequence 14	1 2 3 4 5 6 7 8 9	89.000000	0.704698
sequence 15	1 2 3 6 4 5 8 7 9	75.000000	0.798658
sequence 16	2 4 6 1 3 9 7 8 5	102.000000	0.617450
sequence 17	5 3 2 1 9 8 4 6 7	112.000000	0.550336
sequence 18	1 2 3 6 4 5 8 7 9	75.000000	0.798658

mmk gene==== 1.000000



Route: 1 – 4 – 7 – 8 – 5 – 2 – 3 – 6 – 9
Distance: 43

Annexure – 5.1

Before and After Clustering

Requests	Data Set 1 Before Clustering – with Inter arrival time following Uniform Distribution		Data Set 1 After Clustering – with Inter arrival time following Uniform Distribution	
	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move
Average	1422.587	904.2141	1309.032	822.1978

Requests	Data Set 2 Before Clustering – with Inter arrival time following Uniform Distribution		Data Set 2 After Clustering – with Inter arrival time following Uniform Distribution	
	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move
Average	1469.999	940.0353	1363.18	877.1347

Annexure – 5.2

Effect of Distribution for Data Set 1 Before Clustering

Requests	Exponential		Normal		Triangular		Uniform	
	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move
Average	1407.384	903.7841	1425.3	904.5626	1390.129	897.7195	1422.587	904.2141

Effect of Distribution for Data Set 1 After Clustering

Requests	Exponential		Normal		Triangular		Uniform	
	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move
Average	1276.2	812.07	1321.32	831.46	1315.62	828.33	1309.03	822.2

Effect of Distribution for Data Set 2 Before Clustering

Requests	Exponential		Normal		Triangular		Uniform	
	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move
Average	1465.873	942.3494	1476.124	944.6454	1474.907	943.9411	1473.676	942.9875

Effect of Distribution for Data Set 2 After Clustering

Requests	Exponential		Normal		Triangular		Uniform	
	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move	Avg. min Sys	Avg. min Move
Average	1351.35	875.3891	1368.597	881.2167	1367.008	878.9348	1363.18	877.175

Annexure – 5.3

Down Time Analysis

Data Set 1 Before Clustering

% Down Time	Avg. Min in Sys	Avg. Min in Move Logic
1	1387.46	895.4
2	1411.72	905.84
3	1442.41	918.33
4	1470.21	930.22
5	1497.84	940.1
6	1454.13	937.41
7	1488.46	951.61
8	1518.88	966.18
9	1549.46	978.38
10	1513.25	980.67
Average	**1473.382**	**940.414**

Data Set 1 After Clustering

% Down Time	Avg. Min in Sys	Avg. Min in Move Logic
1	1316.12	823.92
2	1334.32	830.67
3	1329.56	840.23
4	1390.07	861.68
5	1371.6	869.97
6	1419.18	886.98
7	1392.98	890.25
8	1421.32	903.58
9	1425.11	905.95
10	1474.23	927.66
Average	**1387.449**	**874.089**

Data Set 2 Before Clustering

% Down Time	Avg. Min in Sys	Avg. Min in Move Logic
1	1541.64	977.12
2	1569.22	988.57
3	1599.12	999.87
4	1518.07	994.21
5	1548.76	1008.46
6	1577.53	1017.26
7	1613.06	1032.05
8	1640.07	1045.16
9	1674.71	1057.31
10	1709.54	1073.74
Average	**1599.172**	**1019.375**

Data Set 2 After Clustering

% Down Time	Avg. Min in Sys	Avg. Min in Move Logic
1	1460.09	938.19
2	1377.89	931.45
3	1426.72	952.12
4	1439.01	956.12
5	1476.91	972.64
6	1549.13	998.95
7	1597.51	1014.92
8	1521.77	1012.55
9	1554.01	1031.44
10	1584.5	1047.55
Average	**1498.754**	**985.593**

Annexure – 5.4

Number of Machines

Data Set 1 Before Clustering - Single Machine

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	50.2	49.78	0.02

Data Set 1 Before Clustering - Two Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	50.2	49.77	0.02
AS/RS 2	49.97	49.25	0.78
Avg	50.085	49.51	0.4

Data Set 1 Before Clustering - Three Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	45.91	44.98	8.17
AS/RS 2	37.74	34.96	26.19
AS/RS 3	38.9	38.64	22.2
Avg.	40.85	39.52667	18.85333

Data Set 1 Before Clustering - Four Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	35.71	34.13	28.58
AS/RS 2	28.24	27.14	43.52
AS/RS 3	35.55	35.09	28.9
AS/RS 4	23.18	22.36	53.65
Avg	30.67	29.68	38.6625

Averages Before Clustering

Machine	Avg. % in use	Avg. % Travel to Use	Avg. % Idle
AS/RS 1	50.2	49.78	0.02
AS/RS 2	50.085	49.51	0.4
AS/RS 3	40.85	39.52667	18.85333
AS/RS 4	30.67	29.68	38.6625

Data Set 1 After Clustering - Single Machine

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	55.2	41.8	0

Data Set 1 After Clustering - Two Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	22.82	9.41	60.67
AS/RS 2	58.02	41.23	0.75
Avg	40.42	25.32	30.71

Data Set 1 After Clustering - Three Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	12.24	5.98	73.29
AS/RS 2	57.14	41.86	1
AS/RS 3	37.06	10.67	50.95
Avg.	35.48	19.50333	41.74667

Data Set 1 After Clustering - Four Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	8.9	4.62	79.21
AS/RS 2	59.45	39.46	1.08
AS/RS 3	31.65	12.99	54.37
AS/RS 4	18	4.56	75.57
Avg	29.5	15.4075	52.5575

Averages After Clustering

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	55.2	41.8	0
AS/RS 2	40.42	25.32	30.71
AS/RS 3	35.48	19.50333	41.74667
AS/RS 4	29.5	15.4075	52.5575

Data Set 2 Before Clustering - Single Machine

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	50.11	49.88	0.01

Data Set 2 Before Clustering - Two Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	49.58	49.17	1.25
AS/RS 2	50.03	49.96	0.01
Avg	49.805	49.565	0.63

Data Set 2 Before Clustering - Three Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	42.13	41.7	15.74
AS/RS 2	44.99	44.79	10.01
AS/RS 3	39.62	39.18	20.76
Avg.	42.246667	41.89	15.50333

Data Set 2 Before Clustering - Four Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	32.94	32.5	34.13
AS/RS 2	34.65	34.25	30.69
AS/RS 3	28.96	28.66	42.08
AS/RS 4	30.37	30.28	39.26
Avg	31.73	31.4225	36.54

Averages Before Clustering

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	50.11	49.88	0.01
AS/RS 2	49.805	49.565	0.63
AS/RS 3	42.24667	41.89	15.50333
AS/RS 4	31.73	31.4225	36.54

Data Set 2 After Clustering - Single Machine

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	52.87	46.85	0.15

Data Set 2 After Clustering – Two Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	30.71	14.4	51.09
AS/RS 2	54.35	44.4	1.25
Avg	42.53	29.4	26.17

Data Set 2 Before Clustering - Three Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	17.46	6.9	70.13
AS/RS 2	53.95	44.39	1.67
AS/RS 3	42.01	20.58	36.9
Avg.	37.806667	23.95667	36.23333

Data Set 2 Before Clustering - Four Machines

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	10.41	4.91	80.14
AS/RS 2	50.34	33.89	15.28
AS/RS 3	39.02	20.58	39.75
AS/RS 4	27.27	10.17	61.45
Avg	31.76	17.3875	49.155

Averages After Clustering

Machine	% in use	% Travel to Use	% Idle
AS/RS 1	52.87	46.85	0.15
AS/RS 2	42.53	29.4	26.17
AS/RS 3	37.80667	23.95667	36.23333
AS/RS 4	31.76	17.3875	49.155

Annexure 5.5

Scheduling Rules
Before Cluster for Data Set 1

Requests	FCFS		LCFS		LPT		SPT	
	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move
Average	1422.587	904.2141	1421.628	902.8232	1490.529	916.9846	1441.403	894.6532

Scheduling Rules – After Cluster for Data Set 1

Requests	FCFS		LCFS		LPT		SPT	
	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move
Average	1309.032	822.1978	1364.425	856.2755	1417.996	863.3869	1334.002	827.6129

Scheduling Rules – Before Cluster for Data Set 2

Requests	FCFS		LCFS		LCFS		SPT	
	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move
Average	1473.676	942.9875	1473.09	942.502	1569.055	974.1157	1475.45	933.0982

Scheduling Rules – After Cluster for Data Set 2

Requests	FCFS		LCFS		LPT		SPT	
	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move	Avg. Min in Sys	Avg. Min in Move
Average	1363.18	877.175	1438.527	914.3833	1521.19	932.2258	1378.181	877.2735