A Simulation Study to Evaluate the Effect of Flexibility on Flow Time

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To the memory of my father …

ABSTRACT

A SIMULATION STUDY TO EVALUATE THE EFFECT OF FLEXIBILITY ON FLOW TIME

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In today's competitive environment, companies are seeking for newer capabilities to survive. Especially, the manufacturing companies struggle to increase their inner potential by establishing the better manufacturing policies. In the increasing variety of demands and the products, it has been essential to include flexibility in the manufacturing policies. However, flexibility itself, without analyzing the type and conditions of the manufacturing system, may have no meaning. The level and the type of flexibility require to be adjusted and to be monitored for having the expected benefits fully. This thesis specifically intended to find effects of flexibility in job shop manufacturing. For this purpose, a hypothetical system with six machines and ten types of jobs at most with the six different operation types has been considered. Twelve scenarios are developed under four different cases (with/without transportation, with/without additional processing time), five level of flexibility, two different machine selection rule, and three types of dispatching rules. Developed models are experimented by the use of SIMAN simulation language. Findings have been tested statistically. Results indicated that full flexibility is a preferable state for most of the cases. However, in some cases chain configurations perform better since it combines the benefits of pooling and specialization.

Key Words: flexibility, job shop manufacturing, simulation

ÖZET

ESNEKLİĞİN AKIŞ SÜRESİ ÜZERİNDEKİ ETKİSİNİ ÖLÇEN BİR BENZETİM ÇALIŞMASI

UNUTMAZ, DURMUŞOĞLU, Zeynep Didem
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Günümüzün artan rekabetçi koşullarında, işletmeler, kendilerini ayakta tutacak yeni kabiliyetler arayışına girmiştir. Özellikle imalatçı firmalar kendi iç potansiyellerini ortaya çıkaracak üretim politikaları oluşturmak için çabalamaktadır. Artan talep ve ürün değişkenliğiyle "esnekliğin" üretim politikalarına dâhil edilmesi gereği ortaya çıkmıştır. Ancak; esneklik, imalat sisteminin tip ve koşulları dikkat edilmeksizin uygulandığında anlamsız sonuçlar doğurabilmektedir. Beklenen faydaların tamamından yararlanmak için, esneklik seviyesi ve çeşidinin ayarlanması ve yönetilmesi gerekmektedir. Bu tez ile amaçlanan esnekliğin atölye tipi üretim üzerindeki etkisinin belirlenmesidir. Bu amaçla altı makine, en fazla altı değişik operasyona sahip on tip işten oluşan, hipotetik bir sistem ele alınmıştır. Dört farklı durum (taşıma süresi olan/olmayan, ek işlem süresi olan/olmayan), beş farklı esneklik seviyesi, iki farklı makine seçim kuralı, üç farklı yönlendirme kuralı ve kombinasyonları; on iki senaryo altında modellenmiştir. Geliştirilen modeller SIMAN benzetim dili kullanılarak denenmiştir. Bulgular istatistiksel olarak test edilmiştir. Elde edilen sonuçlar "tam esneklik durumunun" genelde tercih edilebilir bir durum olduğunu göstermektedir. Buna karşın, bazı durumlarda, zincir yapılandırma, toplanma ve özelleşmenin avantajlarını bir araya getirerek daha iyi sonuçlar oluşturabilmektedir.

Anahtar Kelimeler: esneklik, atölye tipi üretim, benzetim

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LIST OF SYMBOLS / ABREVIATION

AFT	Average Flow Time
ANOVA	Analysis of Variance
CMS	Cellular Manufacturing Systems
CRM	Common Random Numbers
CV	Coefficient of variation
DES	Discrete Event Simulation
FCFS	First Come First Served
FMS	Flexible Manufacturing System
FSFS	First in System First Served
LV	Lateness variance
MAD	Mean Absolute Deviation of Lateness
MAPT	Minimum Average Processing Time
MJL	Mean Job Lateness
MSR	Machine Selection Rule
ORR	Order Review Release
PTJ	Percentage of tardy jobs
SFC	Shop Floor Control
WIP	Work in Process

CHAPTER 1- INTRODUCTION

1.1 General Remarks

Tendencies such as the increasing spread of market globalization, new technological developments, the reduction of product life cycles and aggressive competition, are generating high levels of environmental changes and uncertainty for organizations of all types (Volberda, 1996; Sanchez, 1997). Nowadays, both manufacturing and service organizations (companies) operate in a highly dynamic and turbulent environment with unprecedented and unpredicted events. In this highly dynamic environment, markets frequently undergo considerable change during the period of product development and manufacturing. In such situations, adequate flexibility in various processes and manufacturing policies are required for the firms to incorporate required changes into the product and production processes without having to pay excessive penalty in terms of time or cost.

With many engineering systems operating under uncertain conditions and emerging requirements, interest in the ability of such systems to provide functionalities other than those originally specified has increased (Nilchian, 2005). Traditional sources of competitive advantages, such as quality and low costs are just the starting points of this mortal survival. But it is also recognized that quality and low costs may not be enough alone and companies need further adjustments. Managers are forced to continuously redefine their activities and strategies in order to gain competitive advantages in dynamic environment.

There are several studies in literature which proposes several different mechanisms to increase competiveness. Porter (1980) distinguishes two basic paths for competitiveness: cost leadership and differentiation. Leong et al. (1990) alternatively discovers that there are five dimensions of competitive priorities, cost, quality, delivery performance, flexibility, and innovativeness within manufacturing. Miltenburg (1995) proposed to add a sixth competitive priority to the list: performance. However, there are strong similarities between quality and performance as defined by Miltenburg (1995), and for ease of comparison, the five competitive priorities proposed by Leong et al. (1990) are considered here. The set of five competitive priorities and their manufacturing implications, as it is presented in Table 1.1, is summarized from Leong et al. (1990) and Miltenburg (1995). As it exposed in Table 1.1 these factors all required be traced, adjusted, and controlled. Within the competitive priorities, there are some trade-offs. This means the positive effects created by one priority are not usually linear. For example, flexibility is known as one of the most efficient sources of these competitive advantages (e.g. Ahmed et al., 1996; Volberda, 1996; Fattahi et al., 2007) however, it does not mean that fully flexible systems are all good in terms of the results that they create. "Flexibility" is also a system parameter which requires to be adjusted considering all these tradeoffs. This thesis specifically focuses on the adjustment of true level of "flexibility".

Table 1.1 The set of competitive priorities

Competitive priorities	**Manufacturing implications**
Cost	Keeping track of costs, and distribute it properly at various
Quality	Ensuring that the product and its process perform and conform to specification
Delivery performance	Dependable (on time) and fast (short lead-time) delivery of products, stock availability
Flexibility	Ability to handle volume and product mix changes, machine and workforce-related
Innovativeness	Time to market, how fast new products or process can be implemented

Flexibility is a broad concept that can refer to operational issues such as manufacturing flexibility, or to strategic decisions such as alterations in the organization's product-market combinations (Martin, 2006). Although flexibility concept has several implementations ranging from service to manufacturing organizations, this thesis is structured on the effects of flexibility for manufacturing systems. This thesis mainly investigates the effects of the different kinds and levels of flexibility on the average flow time. The hypothetical questions which this thesis tries to answer can be summarized as follows:

1) *What is the effect of different flexibility levels on the average flow time?*

2) *What is relation between control policies and flexibility level?*

3) *Can "chaining configuration" capture the most benefits of total flexibility?*

4) *Is there any relationship between the "machine selection mechanisms" and the dispatching rules implemented?*

5) *Do effects of flexibility on the average flow time differ depending on the shop utilization level?*

For this purpose, an experimental facility is created and average flow times are calculated for each level of flexibility using SIMAN simulation language.

In this introduction part, more details about the problem statement, necessity for this research can be found and at the end of this chapter general flow for the thesis is also given.

1.2 Problem Statement

A manufacturing system is a relatively complex arrangement of physical elements, (such as machines, equipment, and workers) and policies (such as order acceptance policy, due date assignment policy and dispatching policy…etc) which are characterized by assessable parameters. Several tools and performance indicators are operational for the performance analysis of manufacturing systems. Two parameters that are often used are: throughput (the number of lots processed per time unit), mean flow time (the average time an order spends in the system). Throughputs as well as mean flow time are descriptive performance indicators that are they quantify the performance of the system. They do not explain why the performance is the way it is, nor do they assist in finding solutions to improve the performance. Therefore, the combination used for the arrangement of these elements should be adjusted to determine and to increase the performance of a manufacturing system.

In this thesis, average flow time is considered as the target "system performance indicator". The main objective for a generic manufacturing system is to decrease average flow time. Adjusting the flexibility can accomplish it by avoiding congestion and increasing system efficiency. At this instant, a fundamental research question arises about the adjustment of the flexibility. What kind/type/amount of flexibility makes a system better? The effects of flexibility on manufacturing performance and the possible answers were investigated by several researchers (A brief review can be found in Baykasoğlu and Özbakır, 2008). But, to our knowledge, there is no consensus about the effects of flexibility on the different performance measurements and characteristics of these effects.

For the performance prediction of manufacturing systems, typically discrete event simulation models or analytical queuing models are used. Both model types have their own specific advantages and disadvantages. Analytical models are computationally fast, but it is difficult to include many shop-floor realities in the model. The gap between model assumptions and shop floor reality is often considered too large (Fowler and Rose 2004, Shanthikumar et al. 2007). If one would be able to aggregate the shop-floor realities and the processing into a single distribution for each workstation, and then be able to actually measure this aggregate distribution from simple shop-floor events such as lot arrivals and departures, then this may provide an opportunity to bridge this gap. Also for simulation models aggregation of shop-floor realities into a single workstation would be advantageous: a simulation model would require less input data, while the model becomes computationally cheaper since only one distribution per workstation is induced.

For this purpose, a hypothetical job-shop system is modeled using SIMAN simulation language and the modeled system has been reconfigured using different scenarios. Information about this system and the scenarios can be found in the next sub-section.

1.3 A Brief Description of the System

This thesis specifically intended to find effects of flexibility in job shop manufacturing. For this purpose, a hypothetical system with six machines and ten types of jobs at most with the six different operation types has been considered. Twelve scenarios are developed under four different cases (with/without transportation, with/without additional processing time), four levels of flexibility, two different machine selection rules and three types of dispatching rules. Brief descriptions of these factors are as listed below. Details of the scenarios and the factors can be found in Chapter 4.

1) ***Flexibility:*** Flexibility considered here as being able to build different types of products in the same plant/production facility/machine at the same time

a) Specialization (null flexibility, dedication),

b) Two level flexibility (any machine can perform two different types of operations),

c) Three level flexibility (any machine can perform three different types of operations),

d) Chain (any machine can perform operations which can be routed to two neighboring machines)

e) Full flexibility (any machine can perform all types of operations).

2) ***Shop utilization level:***

a) Average shop utilization 70% (low).

b) Average shop utilization 90% (high).

3) ***Dispatching rules*:**

Jobs are dispatched according to:

a) FSFS (Minimum system entrance time, first)

b) FCFS (Minimum machine queue entrance time, first)

c) MAPT (Minimum average processing time, first)

4) **Transportation time:**

a) System with no transportation time.

b) System with transportation time.

5) Different processing time:

a) Processing time of an operation does not change whether it is performed in the actual machine (machine used in the base case) or in the alternative machine. In literature, this state is called as "machine independent"

b) Processing time of an operation increases if the operation is performed in the alternative machine. In literature, this state is called as "machine dependent"

6) Jockeying:

a) Systems where jockeying is allowed

Jockeying here refers to the movements of operations which have the option of one queue to another when several machines, each having a separate and distinct queue available (Tarabia, 2007).

i. When alternative machine is idle

ii. When alternative machine is idle and there is no operation routed to the idle machine

b) Systems where jockeying is not allowed

7) Machine Selection Rule:

a) Systems where operations are routed according to SEARCH1

b) Systems where operations are routed according to SEARCH2 (Search1 and search2 are parameters created for this thesis)

For the levels mentioned above, approximately 640 versions of simulation models are developed and run. Characterization of these levels is presented in Table 1.2. Details of the above mentioned scenarios will be given in Chapter "4".

Table 1.2 Scenarios and the corresponding factors

FACTORS	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12
With\Without Transportation	2	2	2	2	2	2	2	2	1	1	1	1
With\Without Additional Processing Time	2	2	2	2	2	2	2	2	2	2	2	2
Machine Selection Rule (1-2)	2	2	2	2	2	2	2	2	2	2	2	2
Dispatching Rules (FSFS-FCFS-MAPT)	1	1	1	1	1	1	1	1	1	1	1	1
With\Without Jockeying	1	1	1	1	1	1	1	1	1	1	1	1
Flexibility Levels (Two,Three, Chain, Full)	4	4	4	4	4	4	4	4	4	4	4	4
Utilization Levels (Low- High)	2	2	2	2	2	2	2	2	2	2	2	2
TOTALS (640)	64	64	64	64	64	64	64	64	32	32	32	32

1.4 Organization of the Thesis

This thesis is divided into six chapters. Chapter 1 has provided an overview of the problem studied, research objectives and approaches, and performance measures of interests. In chapter 2, the background knowledge about simulation and the manufacturing is given. Chapter 3 reviews and summarizes the relevant literature in the area of flexibility. Chapter 4 describes the proposed models and the scenarios for the experimentation. It begins with the overview of the cases and factors. Then it describes 12 scenarios which are run with SIMAN, simulation language. In chapter 5, results of the simulation models and effects of flexibility is discussed. Finally, Chapter 6 summarizes the research results and contributions, and then provides recommendations for future research.

1.5 Conclusion

Effects of flexibility on manufacturing performance and the possible questions and the answers about flexibility were investigated. In this introduction section, the fundamental research questions, the need for this thesis and general flow of thesis is discussed. In the next chapter, the background knowledge about simulation and manufacturing is presented.

CHAPTER 2- BACKGROUND KNOWLEDGE

2.1 Introduction

This chapter provides background information, which will be used in later chapters. As mentioned before, the main target of this thesis to gain insight about effects of different levels of flexibility in job shop manufacturing system. Hence, basic elements of simulation and manufacturing are first introduced in Section 2.2 and in Section 2.3, respectively. The model designed for this thesis is discussed in Chapter 4. Therefore, fundamental concepts are given in this chapter of the thesis. This chapter does not include flexibility in details, since it is given in a separate chapter (Chapter 3).

2.2 Fundamental Concepts of Simulation

In a gradually more competitive world, simulation has become a very widely used tool for developing new systems and reconfiguring the existing systems. In a broad sense, simulation is methods and applications to imitate real systems. Simulation is the process of designing a model of a real system and conducting experiments with the model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system (Pegden et al., 1995). As it can be understood from the definition, the term "model" and "system" are the two basic components of the simulation.

2.2.1 Systems and models

System (from Latin "*systēma"*, in turn from Greek "*σύστημα* systēma") is a set of interacting or interdependent entities, real or abstract, forming an integrated whole (http://en.wikipedia.org/wiki/System). Any integrated formation can establish a system like manufacturing facilities, hospitals, schools, and restaurants… etc. A system includes components, parts, and subsystems that undertake a task or procedure.

On the other hand, model is the representation of a group of objects or ideas in some form other than the entity itself (Pegden et al., 1995). Models are akin to systems however, they are easier than the systems they represent.

Models are used for predicting the effects of changes on the system. Therefore, a model must have a realistic approximation to the system. For this purpose, main parameters and the futures of the system should be carefully reflected in the model. For the easiness of the usage and experimentation of the model, it is mostly preferred to construct clear and simple models.

In some cases, it might be possible to experiment the actual systems. However in many cases, it's too difficult, costly, or totally impossible to succeed. Therefore, models are generally easier and less costly manner of experimenting. "What would happen in the system, if that condition occurs?" question can be resolved more easily by using models. There are different modeling methods available each with their own strengths and weaknesses. One of the most useful and widely used methods of modeling is simulation

Simulation modeling can be thought as an experiment or an applied method where it is desired to describe the behavior of the systems, construct theories or hypotheses that account for the observed behavior and use the model to predict future behavior (Pegden et al., 1995). Simulation can be performed in various ways like by hand, by using general purpose language, by using simulation languages…etc. In the recent years, simulation modeling and analysis have been enhanced significantly by increasingly powerful computational platforms (Bodner and McGinni, 2002).

2.2.2 Types of simulation models

There are various ways to classify simulation models. In this section, different classifications of Pegden et al. (1995)'s, simulation models are given.

Iconic and symbolic models: Some models evoke a physical replica or scale model of the system (Kelton et al., 2001). These types of models are called as iconic model. Iconic simulation models (usually called simulator) generally look likes the real system (i.e. driving simulators, flight simulators). Other type of model is called symbolic. Symbolic simulation models capture the properties and characteristics of the real system in mathematical or symbolic form. Kelton et al. (2001) named these models as logical (mathematical) and defined this type of model as a set of approximations and assumptions, both structural and quantitative, about the way the system does or will work.

According to type of computer used to execute the model: analog, digital and hybrid: An *analog computer* is a form of computer that uses *continuous* physical phenomena such as electrical, mechanical, or hydraulic quantities to model the problem being solved (http://en.wikipedia.org/wiki/Analog_computer). Analog computers are faster than digital ones. However, digital computers, measuring discrete values of 0 and 1 and carry out mathematical calculation on them, have greater accuracy than analogs. The third type of computers are called hybrid computers, comprise features of analog computers and digital computers.

Deterministic and stochastic models: Deterministic simulation models are constructed for situations where the model parameters are assumed to be predictable. In this type of models, it is assumed in advance that there is solely one possible and known result for each alternative. In contrast to deterministic model, a stochastic (random) simulation model aims to capture the important random components of the system. Stochastic models are based on probability distributions of outcomes. The random variations are typically created by the fluctuations through the historic data.

Dynamic and static models: Static simulation models represent the behavior of a system at a single point of time. Static simulation models give snapshots of the system and time does not play a role. On the other hand, dynamic simulation models mimic the behavior of the system through the time. Therefore, time is the most crucial component of dynamic simulation models.

Discrete, continuous, and combined models: In discrete event simulation (DES) models change of the system status, occur at separated points in time. In DES, the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system (Robinson, 2004). Discrete-event simulation is one of the most widely used methods to study, model, analyze, design and improve manufacturing systems (Bodner and McGinni, 2002).

However, in continuous simulation models, system status changes continuously. In some situations, some part of the system changes continuously whereas other parts are changed discrete time interval. This type of simulation model is called as combined simulation model.

2.2.3 Components of a discrete event simulation model

A typical DES should have some certain components. The definitions and properties of these components are as follow:

a) **Clock:** Simulation must keep track of the current simulation time. Any kind of time unit (minutes, hours, etc.) can be used however all parameters should be defined in terms of the same units for running the model consistently. In DES, the clock skips to the next event start time as the simulation proceeds.

b) **Events List:** DES must include at least one simulation events list. These lists are named as *pending event set* since it includes the events which have not been activated yet. Events are traced by the type and the time at which they occur.

c) **Random-Number Generators:** The simulation models require creation of random variables of several types depending on the coded system. For this purpose, *"Pseudo random number generators"* are used.

d) **Statistics:** The simulation models trace the statistics of the interested system properties.

e) **Ending Condition:** Theoretically, a DES can be run everlastingly. However, the executer of the simulation must determine a termination point or event for the simulation model. Typical ending conditions are like: "at time t" or "processing n number of events" or etc.

2.2.4 Simulation process

In every simulation study, the following procedure can be traced. The following procedure was extracted based on the steps proposed by Shannon (1998) and Banks (1999).

1) ***Problem Definition:*** This stage is the first step in simulation and is perhaps the most critical. If this stage is not properly conducted, the entire modeling

process fails. The problem definition stage consists of identifying a research problem, objectives, and hypotheses. The nature of the research problem will directly influence the nature of the research design. The problem definition stage is common to all models.

2) ***System Definition:*** This stage includes definition of entities, objects, rules, assumptions, boundaries and restrictions of the system.

3) ***Conceptual Model Formulation:*** This stage includes setting of the initial visual model which represents the general flow of the system. This can be succeeded using pseudo codes or any other kind of graphical representation.

4) ***Preliminary Experimental Design:*** This stage includes selection of levels and factors to be experimented. This stage also includes the determination of type of output (statistical measures, performance criteria, etc.)

5) ***Input Data Preparation:*** This stage includes the identification, gathering, and standardization of the input data which are required by the model.

6) ***Model Translation:*** This stage includes the codification of the conceptualized model by an appropriate simulation language.

7) ***Verification and Validation:*** Verification stage includes the checking out the simulation model whether it is a reflection of the conceptual model or not. However, validation stage includes the checking out the conceptual model whether it is an accurate representation of the real system or not (output analysis).

8) ***Final Experimental Design:*** This stage includes the design of an experiment which yields the required information and the determination of how each of the tests runs specified in the experimental design is to be executed.

9) ***Experimentation:*** This stage includes the execution of the simulation in order to obtain the required data and carry out sensitivity analysis.

10) ***Analysis and Interpretation:*** This stage includes analysis of the output and drawing conclusions from these outputs.

11) ***Implementation and documentation:*** This is the last step in simulation and it includes the announcement of the results, putting the results to use and documenting the model outputs.

2.2.5 Simulation using SIMAN

SIMAN is a world-wide accepted simulation tool for manufacturing problems (Pegden et al., 1995). SIMAN is a traditional simulation language with many built-in capabilities dedicated to the manufacturing processes.

The description of the simulated problem in SIMAN can be given by the following three files (Nacsa, 1995):

- *The Model Frame* describes the model of the simulated system, so it should be independent from the actual process plans and orders. Model is functional description of the system's components (Pegden et al., 1995).

- *The Experimental Frame* defines the environment of the simulation, plenty of statements of the model (layouts, stations, entity attributes, etc.).

- *Graphical Layout (Cinema)* with mappings to the special statements of the model to support on-line animation during the simulation run.

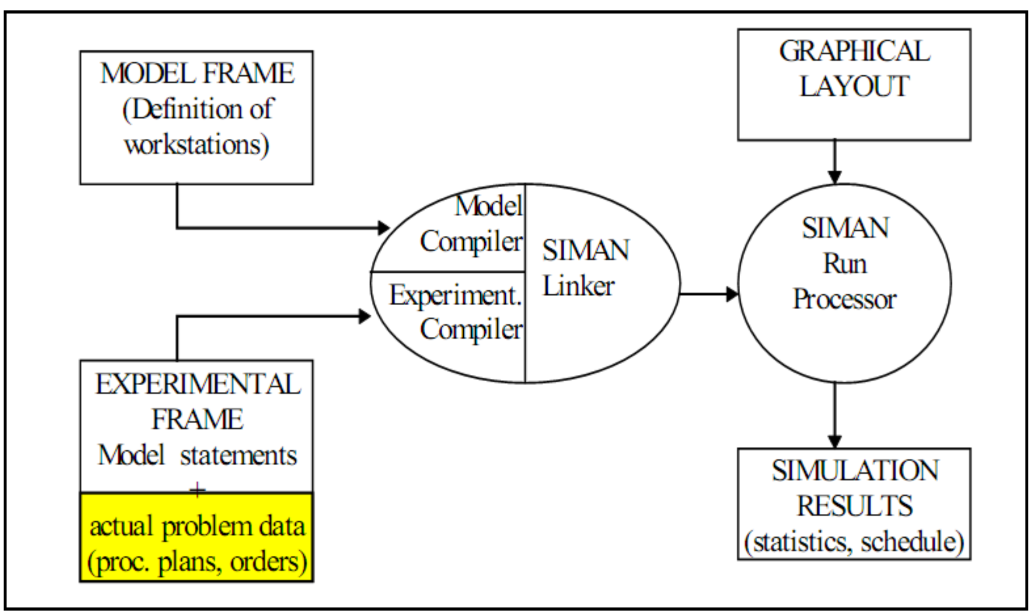

Figure 2.1 Structure of the SIMAN simulation tool

In SIMAN simulation language, “entity” term symbolizes the people, objects, or products of which movement through the system changes the state of the system.

In a system, there may be various kinds of entities and each kind has specific characteristics which is called attributes. In SIMAN, entities are dynamic. They arrive to the system and depart from the system and therefore, the number of entities in the system changes both of these two events. In SIMAN, the sequences of activities through which the entities move are called as process. Process are static and activated by entities (Pegden et al., 1995)

2.2.6 Advantages and disadvantages of simulation

All modeling methods have their own advantages and disadvantages which are specific to content they have. Simulation models have as well some advantages and disadvantages.

Advantages

- New strategies, organization structures, control policies and etc. can be experimented without interrupting the ongoing operations.
- New design issues or physical layouts can be investigated and reconfigured before implementation.
- Some new phenomena and hypothesis can be tested on the phenomena interested.
- Time span can be extended or shortened to understand long run results.
- Factors and levels of parameters and variables can be analyzed.
- Bottlenecks and unexpected phenomena in the system can be found easily.

Disadvantages

- Model building requires special knowledge and expertise.
- Simulation analysis can be time consuming.

- Interpreting results and drawing conclusions also require special knowledge and expertise.

- Execution of simulation models can sometimes be costly where analytical models can give results that are more straightforward.

Although it has some advantages and disadvantages, simulation is a useful and powerful tool when designing and analyzing manufacturing systems, determining ordering policies for an inventory system, analyzing layout of a production system…etc.

2.3 Some Fundamental Concepts of Manufacturing

Manufacturing is the use of tools and labor to make things for use or sale. The term may refer to a range of human activity, from handicraft to high tech, but is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale (http://en.wikipedia.org/wiki/Manufacturing). This transformation process is the welfare signification of nations. The policies developed on manufacturing by the governments determine the level of efficiency for that nation. Level of manufacturing determines the employment rate, average income and many other economic indicators. Manufacturing policies can be established national wide and companywide. Companywide policies usually include improvement of inner parameters of manufacturing. There are certain efforts to improve these inner parameters of manufacturing. Cumulative knowledge used for the improvement has created a common vocabulary for manufacturing. In this section some fundamental concepts from this common vocabulary is presented.

2.3.1 Classification of manufacturing systems

Volume and variety of products and the flow structure of the processes are generally used to classify the manufacturing systems. These factors naturally have heavily effects on the layout of facility, usage and the flow of resources, technology decisions, and work methods. When characterized by its flow structure, a process broadly can be classified either as a *job shop* or a *flow shop* (http://www.netmba.com/operations/process/structure/). Job shops are typically small manufacturing operations that handle specialized manufacturing processes such as small customer orders or small batch jobs (http://en.wikipedia.org/wiki/Job_shop). In a flow shop, each job has exactly one operation performed by each of the machines and all jobs go through these machines in the same order.

Manufacturing systems can be further categorized into five classes according to process structure as follows:

- Project type: It is suitable for the products that are too large in volume or too heavy to move and therefore the inputs are brought to the project location as they are needed. Aircraft production is an example of this type. Final assembly of an aircraft is performed in a fixed location and all subassemblies are brought into final assembly location.

- Job shop: It is suitable for low volume and high variety of products since job shops can be designed more flexible (Details about job shop is given in the following section)

- Batch process: It is similar to a job shop, except that the sequence of activities tends to be in a line and it is less flexible. In a batch process, dominant flows can be identified (http://www.netmba.com/operations/process/structure/)

- Assembly line: It is like a batch process, an *assembly line* processes work in fixed sequence. However, the assembly line connects the activities and paces them (http://www.netmba.com/operations/process/structure/)

- Continuous flow: Like the assembly line, a *continuous flow* process has a fixed pace and fixed sequence of activities. (http://www.netmba.com/operations/process/structure/)

2.3.2 Job shop

A job shop is a facility that produces goods according to prespecified process plans, under several domain-dependent and commonsense constraints (Uckun et al., 1993).

The most important part of a job shop is that "it processes small batches of many different products" (Barash, 1980). In job shop manufacturing environment, processing requirements for each job consist of a group of ordered tasks where each of them to be performed on a different machine.

Ordered tasks, determine the route of a job in the job shop. Since there might be lots of jobs processed by the shop, there will lots of routings which are not particularly grouped. These routes are created by the jobs received from the other machines; or similarly jobs may be routed to next work centers or they may be disposed from the shop if completed. This variety of routings makes "work flow" a very sophisticated issue. Therefore, production control gets harder and it is often structured based on *"queue management system"*. According to *"queue management system"* approach, job shop is a combination of queues where each work center is defined as server.

2.3.3 Components of a job shop

A classical job shop environment may include the following components:

a) **Operations**; series of acts especially involved in a particular form of work jobs.

b) **Jobs**; a group of operations which builds up a particular order. The word "order" can be used with the meaning of "job".

c) **Events**; any kind of incident which corresponds to the movement of jobs in the shop

d) **Machines**; the instruments which executes and completes the operations

e) **Workers**; a kind of resource which uses the machines to operate

f) **Queues;** a series of entities waiting in line to be processed

g) **Routes;** a path or pattern that orders trace and it includes the corresponding machines

h) **Bill of Materials (BOM)**; a detailed list of materials and components that make up product.

i) **Arrival time**; the time at which the job arrives to the system

j) **Processing time;** the time it takes to complete perform an operation for a particular job.

k) **Due date;** an established date about the completion of an order

l) **Dispatching rule;** Selection of a job from a queue when the machine becomes idle.

m) **Schedule;** is time based order of jobs to be processed by the machines.

n) **Performance measures;** is a criteria or a group of criteria which are used to evaluate value of outputs

2.3.4 Types of job shop

Bitran et al. (1983) classified job shop in terms of the time environment, the job arrival process, the machine configuration, the operation flow process.

a) The time environment: deterministic and stochastic

In deterministic job shop, all variables and parameters like processing time, interarrival times are all known in advance. On the contrary, in stochastic job shops, all these variable and parameters are randomly distributed. However, in some cases, both types can exist together.

b) The job arrival process: static and dynamic

All the jobs are known and ready to be processed in static type of job arrival, however, in dynamic case, arrivals occur randomly, and therefore it is not possible to know how many entities will be processed. Dynamic job shops are complex systems for which future conditions cannot be anticipated by analyzing only current performance (Onur and Fabrycky, 1987).

c) The machine configuration: one stage and n stage

This type of classification includes the number of machines used in job shop. "*n-stage*" refers to use of *n* different types of machines in the shop. If there are identical machines, then they are grouped and served at the same center. This state is called as "*parallel machine*" configuration.

d) The operation flow process: pure flow shop and pure job shop

If all jobs follow the same route, it is called as pure flow shop on the other hand, if all jobs have their own route, then it is called as pure job shop. Pure job shop has also two types. Closed job shops include jobs which have a unique fixed routing and open job shops include arbitrary routings.

2.3.5 Shop floor control

Shop floor is an integral part of any manufacturing system (Mbaya, 2000). Shop floor is a dynamic environment where unexpected events continuously occur, and impose changes to the planned activities (Hyun and He 2001). For more dynamic and variable contexts such as job shop, manufacturing shop floor control (SFC) becomes more important. SFC, as defined in (Melnyk et al., 1985) consists of all activities directly responsible for managing the transformation of planned orders into a set of outputs. It is still negotiable when the SFC stages start whether it starts from acceptance or planning. Sha and Liu (2005) claims that, there are basically two types of SFC strategies for the wafer) function (Sabuncuoglu and Karapınar, 1999) which is also referred to as input sequencing (Hutchison, 1991), input/output control (Onur and Fabrycky, 1987), controlled release (Wight, 1970), input control (Baker 1984). The second type of SFC strategy is the dispatching strategy. Vig and Dooley (1992) categorized dispatching rules as random, static, and dynamic. Random dispatching (priority) rules are arbitrary disregarding both job and shop information. Static priority rules calculate priority of a job based purely on the factors inherent in the job itself, rather than on its current timeliness of progress through the shop (http://www.glossaryofmanufacturing.com/s.html). However, dynamic priority rules depend on the actual evolution of the system therefore; they require continuous updating of job priorities.

2.3.6 Performance indicators of manufacturing systems

There are different factors which are very crucial to manufacturing systems. These factors determine to performance of the systems via adding value to the system which they are a part of. These factors are mostly the statistics belonging to outputs. Therefore, performance measures are obtained using long-run results. These indicators can be modified and thereby their numbers can be increased. Some of the definitions of these indicators from literature are as described flows:

Average flow time (AFT); (mean flow time) is an average over the flow time for each of the measured flows. It is also a widely used measure for the responsiveness of the system. The formula for AFT is as given below:

$$\boldsymbol{AFT = \sum_{n=1}^{N} FT_n / N} \qquad \textbf{(2.1)}$$

where;

$FT_n: Actual\ flow\ time\ of\ job\ n$

$N: number\ of\ jobs\ completed$

As mentioned before flow time is the average time an order spends in the system. The flow time formula is given as follows (Baykasoğlu et al., 2007).

$$F_i = \sum_{j \in S\{i\}} \left(s_{ij} + m_{ij} + w_{ij} + p_{ij} \right) \qquad (2.2)$$

where;

i: job type,

j: machine number,

s_{ij}: set-up time for job i at machine j,

m_{ij}: transportation time necessary for job i moving from machine j to the next machine on its route,

w_{ij}: queue waiting time for job i in machine j,

p_{ij}: actual processing time of job i in machine j,

S{i}: the set of machines which are placed on job i's route.

Some factors of a shop like utilization of each machine, queue waiting times are varying instantaneously and this variety cause flow time fluctuations (Baykasoğlu et al., 2008).

Average tardiness; gives a measure of how late each job was on average without giving information on critical outliers that are likely to result in severe customer dissatisfaction (Ashby and Uzsoy, 1995).

Coefficient of variation (CV) of inter-departure times; is a measure of the regularity of output (Glassey and Resende, 1988).

Delay factor; defined as the ratio of throughput time to processing time (Eilon, 1976).

Early costs; may include the opportunity cost of capital, excess holding costs, or simply the cost of having excess work in the shop (Rohleder and Scudder, 1993).

Facility idle time; is the time between a machine completing the processing of a job and the arrival of the next job for processing (Eilon, 1976).

Holding cost; reflects the actual time-weighted work completed on the unfinished jobs (Work in process inventory), than their due dates (finished goods inventory) (Philipoom et al., 1993).

Job waiting time; is the time elapsed from the moment of a job arriving until its processing on a machine begins; this quantity is based on all the jobs completed during a simulation run (Eilon, 1976).

Lateness; is the difference between completion dates and due date (Shimoyashiro et al., 1984).

Performance rate; The ratio of finished jobs to total jobs on the due date (Shimoyashiro et al., 1984).

Lateness variance (LC); is the variability of the lateness criteria. The lower the variance, the better performance is said to be (Udo, 1994). Lateness penalty is the measure for tardiness (Bobrowski and Mabert, 1988).

Maximum lateness; gives a measure of the worst due date performance (Ashby and Uzsoy, 1995).

Mean absolute deviation of lateness (MAD); is an important performance metric in practical applications because it measures how close to their due dates jobs are completed (i.e., the just-in-time philosophy) (Sabuncuoglu and Karapınar, 2000).

Mean job lateness (MJL); is a mean of the difference between when a job is completed and when it is due. Lateness of a job is negative if the job is completed before its due-date and positive if the job is completed after its due-date (Udo, 1994).

Measure of shop load; included in this category were measures which dealt with average load observed on the shop floor (Melnyk and Ragatz, 1989).

Missed due date time; is the discrepancy the actual job completion date and its due date (Eilon, 1976).

Percentage of tardy jobs (PTJ); is a ratio of tardy jobs to the total number of completed jobs for a given run (Udo, 1994). Measures how many jobs missed their due dates but gives no indication of how late they were (Ashby and Uzsoy, 1995). Percent tardy is used to measure the percent of jobs finished after their due dates among all finished jobs (Sabuncuoğlu and Karapınar, 2000).

Queue length; is the number of jobs waiting to be processed measured at the time when a machine is free to accept the next job (Eilon, 1976).

Root mean square tardiness; differentiates system in which few jobs are very tardy from systems in which many jobs are slightly tardy (Philipoom et al., 1993).

Tardiness; is the difference between job completion date and its due date determines the magnitude of tardiness (Onur and Fabrycky, 1987).

Tardy costs; could include the costs of price discounting, expediting, and lost customer goodwill (Rohleder and Scudder, 1993). Jobs that complete their final operation after their due date are tardy and subjected to a penalty (Onur and Fabrycky, 1987).

Throughput time; is the time taken from the arrival of a job to the completion of its processing (Eilon, 1976).

2.4 Machine Sharing and Chaining in Manufacturing Systems

The need to share manufacturing resources, such as machines, arises in environments where either part demands or the available processing capacity are subject to variability (Benjaafar, 1995; Jordan and Gravesi, 1995). Machine sharing can be defined as the capability of a group of machines in a manufacturing system to share the production of a set of different part types so that a part type in the set can be indiscriminately allocated to any machine in the group (Benjaafar, 1996). Benjaafar (1996) also explained that machine sharing requires flexible part routing capabilities, allowing parts to be directed to any one of the shared machines, and sharing and\or duplication of some of the auxiliary resource. In related literature, previous studies focused on two scenarios which are pooling and specialization. In pooling, machines are set into functional pools, where each pool is associated with a set of operations, whereas in specialization each machine is dedicated to a single operation type. Pooling is frequently employed in flexible manufacturing systems (FMS), cellular manufacturing systems (CMS), job shops. Specialization is more common in dedicated flow lines where a sufficiently high volume of a single part type is being manufactured (Jordan and Graves, 1995). Some researchers (Stecke and Solberg, 1985; Stecke and Kim, 1989; Dallery and Stecke, 1990) investigated the subject of resource pooling in closed queuing network models of FMS and revealed that resource pooling increases the system throughput. In opening queue network models, some authors (such as Benjaafar, 1995; Calabrese, 1992; Smith and Whitt, 1981) found that part waiting times and WIP inventory can be reduced significantly by increasing pooling. However, Smith and Whitt (1981), show that in a system where rare customers have long service times, a pooling can be made arbitrary worse than specialization. Benjaafar (1996) claimed that machine sharing can be beneficial, the benefits are conditioned and limited by a number of system operating parameters such as setup times, part mix variety, system utilization, and batch sizes. He added that for systems with small setups, the reduction in flow times and WIP can be significant. On the other hand, for systems with high setup times, machine sharing can lead to lower production rates and higher congestion levels. Similar conclusion is also explained by Buzacott (1996) who considers a variety of pooling scenarios. The author explained that when the service times of different customer classes are not identical in distribution, pooling can lead to longer queuing delays. He also added that sensitive to service time variability, the size of demand from each class, and the routing policy are the factors which cause difference in performance between different pooling scenarios.

It is well known that sharing resource often is performed with additional investment (e.g. flexible material handling, programmable machines, flexible workforce) or higher operating costs (e.g. more frequent setups, increased material handling, increased control complexity), therefore increased resource sharing could result in a tradeoff between performance and cost. Sheikzadeh et al. (1998) focused on a sharing strategy that combines the benefits of both pooling and specialization. This strategy is referred as machine chaining. Sheikzadeh et al. (1998) show that chain systems, with homogenous demand and service times, achieve most of the benefits of total pooling.

The concept of a chain was introduced by Jordan and Graves (1995). They employed chaining in the context of process flexibility for a single-stage manufacturing system with random demand. Graves and Tomlin (2003) extended the Jordan and Graves (1995)'s system to multistage manufacturing systems. Another study employing chaining was performed by Hopp et al. (2004) who investigated serial production systems operating under a CONWIP protocol with queuing models of flexible workers. They reveled 2-skill chaining structure possesses strong capacity balancing and variability buffering properties.

In a chained configuration, each operation (or customer) can be routed to one of two neighboring machines (or servers) and each machine can process operations from two neighboring classes. Chaining may capture the benefits of full flexibility without requiring every machine to process every party type. Because the number of part types that are processed on any resource is limited to two in a changing configuration. This characteristic is important because additional flexibility often comes at the cost of either additional investment or high operating overhead. Sheikzadeh et al. (1998) indicated that by increasing the scope of manufacturing resource, the routing flexibility of products is also increased.

The treatment of flexibility in this thesis can address issues mentioned in literature as routing flexibility and machine flexibility.

2.5 Conclusion

In this chapter of the thesis, fundamental concepts of simulation and the manufacturing are introduced. It includes the terms which will be widely used through the later chapters of this thesis. Therefore, this chapter can be perceived as a glossary chapter for the simulation and the manufacturing. This chapter is expected to create benefits especially for the new researchers in this area. It is also suggested for the readers to read the flexibility chapter (Chapter 3) where flexibility and its literature are detailfully discussed.

CHAPTER 3- AN OVERVIEW OF FLEXIBILITY

3.1 Introduction

The rapid and turbulent changes in the markets of today have resulted in constantly changing businesses to meet new customer requirements. These changes in the customer requirements put pressure on the manufacturing companies to modify their manufacturing philosophies. Therefore, it has been necessary to comprise increasing flexibility and visionary adaptation of market policies. In consequence of this change in the market, flexibility as well received more notice from the academic world. Therefore, the literature on manufacturing flexibility has been the richest among all engineering systems. Numerous papers have discussed the different aspects of flexibility within manufacturing systems and included several definitions, classifications, measurements and the need for flexibility. In this chapter, different definitions of flexibility, its classification/types and the existing literature on is presented.

3.2 Definitions

"Flexibility" term originated from the Latin word "bendable" (Baykasoğlu, 2008). Flexibility, as a concept of the theory, was first introduced by Stigler (1939) who studied flexibility in terms of the slope of short run cost curves. In the field of engineering systems design, it refers to designs that can adapt when external changes occur. Flexibility has been defined differently in many fields of engineering, architecture, biology, economics, etc. In the context of engineering design, one can define flexibility as the ability of a system to respond to potential internal or external changes affecting its value delivery, in a timely and cost-effective manner. Thus, flexibility for an engineering system is the ease with which the system can respond to uncertainty in a manner to sustain or increase its value delivery. It should be noted that uncertainty is a key element in the definition of flexibility. Uncertainty can create both risks and opportunities in a system, and it is with the existence of uncertainty that flexibility becomes valuable (http://en.wikipedia.org/wiki/Uncertainty).

The definitions of manufacturing flexibility found in literature either directly refer to the firm's context or derive from general definitions of flexibility born in other disciplines (such as biological-evolutionary one, the anthropological one, that of the theory of systems, etc.) (De Toni and Tonchia, 1998). Some definitions of flexibility in literature has been gathered and listed in Table 3.1.

Table 3.1 Definitions of flexibility

Author, Year	Definition (Flexibility…)
Koopman (1964)	… is the set of remaining alternatives after the initial choice had been revealed.
Eppink (1978)	… is a buffer for the effects of a changing environment.
Zelenovich (1982)	… is the ability of a manufacturing system to adapt to changes in environmental conditions and in process requirements.
Slack (1983)	… is namely the range of states a system can adopt, the cost of moving from one state to another, and the time which was necessary to move from one state to another.
Gerwin (1983)	… is the adaptive response to uncertainties.
Slack (1987)	… is the range of possible states; … is the time needed to move from one state to another; … is the cost required to change the state.
Clark et al. (1988)	… is along with cost, quality and service is an important aspect of manufacturing strategy.
Sethi and Sethi (1990)	… is a complex, multi dimensional, and hard-to-capture concept.
Upton (1995)	… is the ability to change or react with little penalty in time, effort, cost or performance
Correa (1994)	… in manufacturing has been defined as a characteristic of the interface between a system and its external environment.
Sager (1994)	… refers to future choices among satisfactory alternatives, and that flexibility implies adjustments in accordance with principles and criteria.
Sanchez (1995)	… is the ability of an organization to undertake planning
Volberda (1997)	… is rapidly respond to change.

Table 3.1 Definitions of flexibility cont.

De Toni and Tonchia (1998)	… can be viewed as a filter, buffering the system from external perturbations. Flexibility thus functions as an absorber of uncertainty
Hitt et al. (1998)	… has been promoted as a critical element of organizational performance where it has been promoted as a means of gaining and sustaining a competitive advantage.
Tsubone and Horikawa (1999)	… is the ability of a system to adapt quickly to any changes in relevant factors such as product, process, workload, or machine failure.
Bahrami and Stuart (2000)	… is to absorb shocks and bounce back after a disaster.
Golden and Powell (2000)	… is adapt to chaining circumstances.
Grewal and Tansuhaj (2001)	… is to build excess resources.
Moses (2003)	… is the ability to add new nodes and connect to existing nodes using alternate paths, thereby increasing the original functionality of the system.
Iravani et al. (2005)	… is a very general concept that is often viewed as a firm's ability to match production to market demand in the face of uncertainty and variability. The notion of flexibility is also closely linked to the firm's ability to provide niche and customized products to the consumer.
Martin (2006)	… is a broad concept that can refer to operational issues such as manufacturing flexibility, or to strategic decisions such as alterations in the organization's product-market combinations.

As shown in the Table 3.1 there isn't a unique definition for flexibility that remains same for all circumstances since flexibility is a multi dimensional concept and has many different forms. Reasons for difficulties of understanding flexibility are explained by some authors (such as Swamidass, 1988; Chung and Chen, 1990; Bernardo and Mohamed, 1992) as follows; "the use of flexibility terms with scopes which overlap, the use of flexibility terms which have different meanings and, the use of flexibility terms which are aggregates of others". Sushi (2001) demystified flexibility in terms of what is and what is not. These statements are given in Table 3.2.

Table 3.2 What is/is not flexibility

FLEXIBILITY IS NOT \ DOES NOT	a destinations	***BUT***	a journey
	a one-time phenomenon		a process of continuous change
	shifting to extremes		dynamically balancing them
	mean wild freedom		the rights with duties
	mean lack of convictions		courage to face the reality
	changing your side as per convenience		evolving your value system
	demanding time for action		generating spontaneity and agility
	remain shuttling within the system		to get liberated
	to create chaos		bring to a natural organic order out of it
	a stress raiser		a stress reliever
	creating ambiguity		capturing it
	creating waste		rather minimizing it
	run away from values		bring spirituality into them
	succumbing to causal		to generate enlightment

Unfortunately, there is no agreement about the classification of “Flexibility”. Therefore, in the manufacturing literature, many authors classify flexibility by using their own way; however, there are also some similarities between the definitions.

Nilchaiani (2005) explained that there are six crucial elements in defining and classifying flexibility. These are;

1) Boundary of the system to be studied

2) Aspects of system to which flexibility is applied

3) Time windows in which flexibility is observed in the system

4) The uncertain and probabilistic nature of the future of the system

5) The degree of access to the system in order to apply the option or flexibility

6) Responses or the system to change through changes from the owner’s, designer’s, operator’s and user’s perspective in the value delivery

De Toni and Tonchia (1998) grouped the origin and definitions of flexibility as given in Table 3.3.

Table 3.3 Origin and application of the definitions of flexibility

		Application of the definition	
		Other disciplines	**Firm context**
Origin of the definition	Other disciplines	•As a characteristic of the interface between a system and its environment •As a degree of homeostatic control and dynamic efficiency •As a capability of adaptation or change	Range of states reachable and time for moving (determined by demand variety and uncertainty)
	Firm context	—	•Low costs for changing (economic approach) •Changing 'without disorganization' (organizational approach) •Volume, mix, product, process (operational approach) •Competitive priorities

3.3 Flexibility, Variability and Uncertainty

As being closely linked to environmental changes, Evans (1991) believed that flexibility composed of a number of ''senses'' including adaptability, agility, corrigibility, elasticity, hedging, liquidity, malleability, plasticity, resilience, robustness, and versatility.

Correa (1994) classified changes, which develops the flexibility, into two categories as being planned and unplanned changes. According to this classification, unplanned changes occur independently of an organization's willpower but to which the organization has to adapt, whereas planned changes happen as a result of the organization's conscious managerial decisions, which are taken to alter some aspect of the organization or its relation with the environment (Correa, 1994). However, most of the researchers, investigating flexibility on manufacturing, deal with unplanned change. In this section, the term "changes" refers to the unplanned changes.

Main attributes of changes in a system are uncertainties and variations. Correa (1994) suggested that flexibility is mainly needed in order to cope with intrinsic uncertainties and the variability of outputs (Correa, 1994). As known previously, origin of variability and uncertainty is situation specific; therefore, it is not possible in advance to predict situations that might be faced by manufacturing companies.

Many authors proposed various factors as the source\origin\nature of the changes. In the most basic form, turbulent environment and changing in customer demand are the two main sources of changes (Kara and Kayis, 2004). It should also be noticed that there is an obvious difference between the approaches that are being focused on, the sources of change and the origin of change.

According to Palaniswami's (1994) view, products, manufacturing processes, planning and control, human resources, and the relations with the suppliers are the five factors which originate changes in a manufacturing system.

Kara and Kayis, (2004) defined uncertainty as a driving force that management must learn to cope with it whether it is based in product markets or in the manufacturing process. Uncertainty is a complex concept, which has received different approaches in literature. The most controversial point appears to be a discussion on whether the measurement of uncertainty is the adequacy of either perceived or objective approaches (Swamidass and Newell, 1987). The objective measures of uncertainty are indexes for uncertainty based on attributes of the environment. At the same time the value of these attributes are dependent on the previous knowledge and cognitive process of uncertainty for the estimator.

In order to understand the interactions and relations among the environmental uncertainty and flexibility needs, several conceptual frameworks have been developed (e.g: Gerwin, 1993; Tincknell and Radcliffe, 1996) in the literature.

Cheng et al. (1997) investigated environmental uncertainty and classified them in two different forms. These forms are the marketing function perspective and the manufacturing function perspective. According to Cheng et al. (1997), marketing flexibility (product, volume…etc.) is structured against the dynamical conditions of the market, while manufacturing based flexibility (machine, material handling, process …etc.) is structured against the inherent within manufacturing resources and the production management.

Swamidass and Newell (1987) claims that environmental uncertainty influences manufacturing flexibility and business performance is influenced by the manufacturing flexibility

Tombak and DeMeyer (1988), propose that flexibility required for an organization increases in response to both internal and external uncertainties.

Prabhaker et al. (1995) claimed that flexibility does not only influence manufacturing strategy, but it also affects the marketing and corporate strategy.

As mentioned above, variability is the most important reason for manufacturing companies to call for flexibility. De Toni and Tonchia (1998) defined variability as the flexibility of offering a variety of products and carrying out different manufacturing processes. Correa (1994) explained that output variability of a manufacturing system has two dimensions. The first dimension is related to the actual variety of outputs and the second one is related to the variation of the system's outputs over time in terms of volume, part or product variation, mix and timing.

Griffiths et al. (2000) separated causes of variation in demand into two classes. First, one is consumer-led change (true demand) and second is company-led change (induced variation).

Changes faced by the system -product, process, etc.- are the most important cause of uncertainty or variation. These changes can be originated from either inside or outside of a system. Therefore, as indicated by Buzacott (1982), in order to estimate flexibility level of a manufacturing system (need for flexibility), nature of the changes must be analyzed.

In literature, there are various reasons request (need) for flexibility. Different authors listed different reasons for flexibility. In this part of the thesis, several views on the need for flexibility are investigated.

As indicated by Gerwin (1987), the basic reason of need for flexibility in a manufacturing environment is to cope with uncertainty. Chen and Everatt (1991) divided the causes for flexibility into two groups: environmental uncertainties with regard to marketing, and uncertainties with regard to the manufacturing process. Similarly, Correa (1994) indicated that *environmental uncertainty,* (i.e. caused by machine breakdowns, demand and supply… etc.), and *variability of the products and process* are the two main factors or request for flexibility. Miller et al. (1992) investigated request for flexibility on different perspective. According to them request for flexibility comes from customer.

Palaniswami (1994) listed five factors for request for flexibility: These factors are;

a) Product

b) Manufacturing process

c) Planning and control

d) Human resources

e) Relations with supplier

According to Suarez et al. (1991; 1995; 1996) product strategy, consumer demand, competitor's behavior, product life cycle, and end product characteristics are the five factors which affect the need for flexibility.

Market related factors: According to Chen et al. (1992) increased product diversity, short product life cycle and an increase in buyer concentration are the three main sources of flexibility needs on the view of marketing perspective. A similar but detailed classification was made by De Toni and Tonchia (1998). These authors defined market related need for flexibility as follows:

- the variability of the demand (random or seasonal);
- shorter life cycles of the products and technologies;
- wider range of products;
- increased customization;
- shorter delivery times.

Tombak and DeMeyer, (1988) demonstrated that need for flexibility mounts as process or market uncertainties increase. Chen et al. (1992) additionally listed three sources of manufacturing related need for flexibility as:

(1) Focused manufacturing.

(2) Manufacturing technology innovation.

(3) Unexpected competitors.

Other authors (such as Correa, 1994 and Gerwin, 1993) list various factors for manufacturing related need for flexibility:

- uncertainty with respect to machine downtime;
- uncertainty of whether the material input meets the standards of the process;
- changes with regard to delivery times of raw materials;
- variations in workforce.

3.4 Classification of Flexibility

In literature, there are various taxonomies for flexibility (Mandelbaum, 1978; Buzacott, 1982; Zelenovic, 1982; Browne et al., 1984; Jaikumar, 1986; Swamidass, 1988; Sethi and Sethi, 1990; Hyun and Ahn, 1993; Tsubone and Matsuura, 1995). As indicated by Sethi and Sethi (1990) flexibility is a complex, multi-dimensional, and hard to capture concept. For this reason, authors use some variables of flexibility in order to classify it. In this part of the thesis types of flexibility in manufacturing will be presented.

Mandelbaum (1978) defines characterized flexibility into two forms: action flexibility which is ‘‘the capacity for taking new action to meet new circumstances’’, and state flexibility which is ‘‘the capacity to continue functioning effectively despite changes in the environment’’.

Buzacott (1982) classified flexibility as job flexibility and machine flexibility. Job flexibility, which can be achieved either at the machine or at the system level, is the ability of the system to cope with changes in the jobs to be processed by the system, whereas machine flexibility is the ability of the system to cope with changes and disturbances at the machine and workstations.

Another classification is made by Zelenovic (1982). According to the author, design adequacy -is similar to the Buzacott's term of job flexibility- and adaptation flexibility, which relates to reducing times for setup changes between jobs and leads to smaller batch sizes. The author was the first to reflect on short-term or adaptation flexibility, as well as medium to long term flexibility.

Browne et al. (1984)'s classification of flexibility is one of the most used classification. In this classification, eight different types of flexibility are considered which are machine flexibility, product flexibility, process flexibility, operation flexibility, routing flexibility, volume flexibility, expansion flexibility, and production flexibility. Skinner (1985) classified flexibility as process, product, and production volume flexibility. Barad and Sipper (1988) add one dimension which is called as transfer flexibility, to the Brown et al.'s classification. In this classification transfer, flexibility refers to the ability to process parts using different machines. These authors also subsumed nine types of flexibility into two groups as short term flexibility (machine flexibility, process flexibility, transfer flexibility, routing flexibility, operation flexibility and volume flexibility) and long term flexibility (product flexibility, production flexibility and expansion flexibility)

Taymaz (1989) analyzed flexibility considering hierarchical structure of flexibility. The author investigated types of flexibility following these three levels.

a) Component level flexibility, which are determined a priori by design and can be compared without any reference to production

b) Operations level flexibility, which must be evaluated for some define production characteristics

c) System level flexibility, can be thought as overall production flexibility

Similar to Barad and Sipper (1988), Sethi and Sethi (1990) adds three types of flexibility to the Browne et al. (1984)'s classification which are material handling flexibility, program flexibility and market flexibility.

Slack (1987) classified flexibility in terms of range and response. In this classification range flexibility refers to the total envelope of capacity or range of states which the manufacturing system is capable of achieving (i.e. short- term flexibility) and response flexibility refers to the ease the ease, in terms of time and/or cost, with which changes can be made within the capability envelope, (i.e. long-term flexibility).

Azzone and Bertele (1987) classified flexibility as production flexibility, product flexibility, operational or technological flexibility, mix flexibility, volume flexibility and expansion flexibility.

Lynch and Cross (1991) considered two components of flexibility namely internal and external. External refers to meeting customer requirements, while internal refers to meeting the customer requirements in an efficient manner.

Suarez et al. (1991) take into consideration four dimensions of flexibility which are volume flexibility, mix flexibility, new product flexibility, and delivery flexibility. In 1992, Parthasarthy and Sethi grouped Suarez et al. (1991)'s classification as speed flexibility and scope flexibility.

Some authors classified flexibility into three groups: strategic (long term flexibility), tactical (mid-term) or operational (short-term) (Gustavsson, 1984; Jaikumar, 1986; Das, 1991; Gerwin and Kolodny, 1992). Strategic flexibility is defined by Hyun and Ahn (1992) as how well a firm addresses and adapts its strategic decisions to unexpected changes in competitive environment. Second type of flexibility is about the specific performance features of manufacturing such as machine utilization, work-in-process inventory, and efficiency. Third type is concerned with unpredictable and sporadic problems like machine breakdowns, minor design changes, unreliable raw material supplies, and demand variations encountered during day-to-day manufacturing operations.

Swamidass (1988) on the other hand makes a distinction between *machine-level* and *plant-level* flexibility: the former is exclusively technological, where as the latter also takes into account the firm's skills, the procedures adopted, managerial systems, etc.

Dixon et al. (1990) classified flexibility into four groups. These are;

- Flexibility associated to quality (relative to the materials and relative to output
- Flexibility associated to the product (launching new products, changing pre-existing ones)
- Flexibility associated to service (deliveries, volume, mix)
- Flexibility associated to cost (flexibility in the use of resource)

Chen et al. (1992) subsumed flexibility into three groups. First, one is *production flexibility* including machine, process, routing, material handling and programming flexibility. Second, one is *marketing flexibility* including product, volume, mix and expansion flexibility. Last one is *infrastructural flexibility* including flexibility of an organization.

Bartezzaghi and Turco (1989) explained that there are four types of flexibility as follows: *product flexibility, volume flexibility, mix flexibility* and *promptness* which mean the ability to vary delivery dates and\or internal planning)

Benjaafar and Ramakrishn (1996) classified flexibility as product related flexibility, (including operation flexibility, sequencing flexibility, processing flexibility), process related flexibility (including processor flexibility, mix flexibility, volume, layout and component flexibility).

De Toni and Tonchia (1998) believed that, four different classification logics can be found, although often the existing taxonomies presented are the result of mixed logics. These authors categorized manufacturing flexibility as: horizontal (by phase), vertical (hierarchical), temporal and by the object of variation. In this classification, horizontal flexibility refers to the single manufacturing stage and in a wider sense, to the all phases that constitute the value chain. However, vertical refers to the degree of the details of the analyzed state. Temporal flexibility includes flexibility just for a moment which indicates the short term flexibility (Merchant, 1983). The term "state/object of variation" refers corresponding variation of variables (mix, volume and etc.) to the other variables in the system. This classification is the most frequent classification in the literature.

As indicated above, in the literature many authors suggested different classification for flexibility in manufacturing. According to Oke (2005) there are at least three level of confusion in to the theory framework. These are as follows:

- Different names have been used to refer to the same type of flexibility.
- Failure to differentiate flexibility (the ability of a manufacturing system to flex across a range of states such that it can return to its exact original state) and change capability (ability to alter state “permanently” from one configuration to another quickly and easily).
- Failure to differentiate how flexibility is perceived externally by the market, how it is characterized at the manufacturing system level and the actual tools and techniques used to deliver it.
- The term “Flexible Manufacturing System” is often used (usually in its shortened form “FMS”) to describe a very specific piece of technology used in the engineering industry to machine individual components from metal blanks, castings, etc. The characteristics of this technology are such that taxonomies developed in relation to such systems are not easily transferable to manufacturing systems in general (Parker and Wirth, 1999).

Oke (2005) encompassed types of flexibility listed on literature into three categories and then separated the lower level flexibilities into three sub groups. Oke’s classification is given at Table 3.4.

Table 3.4 Oke’s classification of flexibility

Generic Factor	**System Flexibility**	**Fundamental Factor**	**Shared Factor**
Supply Chains	New Product	NPD Process	Product Modularity
Process Technology	Mix	Changeover Time	
Information Technology	Volume	Employment Terms	

Different definitions of flexibility for its type are given as follows:

1) Machine Flexibility: The ease of change to processing a given set of part types (Browne et al., 1984). In other words, it is the capacity of a machine to accommodate changes (Son and Park, 1987). Numeric control, easily accessible programs, automated part loading, and tool changing devices, size of the tool magazines are the technological source of machine flexibility. These equipment lead to shorter setup, better controls, faster production and reduction of throughput time. Machine flexibility allows smaller batch sizes, resulting in shorter manufacturing lead times, higher machine utilization and lower inventory level.

2) Product Flexibility: The ability to modify the resources of the firm in order to launch a new product (Azzone and Bertele, 1989).

3) Process Flexibility: The ability to build different types of products in the same manufacturing plant or on the same production line at the same time (Browne et al., 1984; Sethi and Sethi, 1990). Process flexibility also gives the ability to change volumes of products produced in response to demand changes.

4) Operational Flexibility: The ability to interchange ordering of operations on a part (Browne et al., 1984). In other words, it is the ability of producing a part in different ways.

5) Routing Flexibility: The ability of a manufacturing system to provide multiple alternate routes to produce a set of parts/products economically and efficiently and thereby to allow the system to finish the production tasks without experiencing a fatal degeneration of the system performance, especially when internal (e.g., machine break down) and/or external (e.g., rush orders) disturbances occur (on the measurement of routing flexibility). Routing flexibility is a function of machine flexibility and operation flexibility. By employing identical machines and versatility material handling system are improved the routing flexibility. Sethi and Sethi (1990) recognized routing flexibility as a fundamental characteristic of a manufacturing system's overall flexibility, as it enhances a system for the easier scheduling of parts by better balancing the machine loads and allows the system to produce a given set of part types or part families without interruption. Routing flexibility gives the system the capability to continue producing a given set of parts despite machine breakdown.

6) Volume Flexibility: The ability to vary production with no detrimental effect on efficiency and quality (Suarez et al., 1996).

7) Expansion Flexibility: The ability to easily add capability and capacity. This is determined by the dimensions in terms of capacity that system can reach. The capacity must be available at the right time periods so that the production can be completed in time. Insufficient capacity will quickly lead to deteriorating delivery performance and escalating work in process inventories. On the other hand, excess capacity is an expense.

8) Production Flexibility: The ability of the system to produce new products (Azzone and Bertele, 1987).

9) Job Flexibility: The ability of the system to cope with changes in the jobs to be processed by the system (Buzocotto, 1982).

10) Mix Flexibility: The adaptability of the manufacturing system to changes in product mix (Son and Park, 1987). According to Upton (1995), less experienced operators were more flexible in their ability to make changes quickly between products.

11) Supplier Flexibility: The ability of the supplier of parts and raw materials to cater to the requirements of the firm, in terms of *last* minute changes in quantity, timing, and mix of raw material.

12) Equipment Flexibility: The ability of the equipment to handle a range of operation.

13) Labor Flexibility: The ability of the workers to handle a range of task.

14) Material Handling Flexibility: The ability of the material handling system to efficiently link the different machine centers in the production system.

15) Input Quality Flexibility: The ability of the production system to accommodate a range of input qualities and conform to a range of tolerances.

16) New Product and Modification Flexibility: The ability to introduce new products and model of the existing products.

17) Delivery Flexibility: The ability to shorten or lengthen delivery times.

18) Structural Flexibility: The ability provided by system's structure of multi capability sources, to reallocate production to respond to changes in demand or in source capacity (Iravani et al., 2005; Iravani et al., 2007).

19) Changeover Flexibility: The ability to quickly substitute new products for those currently being offered is required in the manufacturing process (Gerwin, 1993).

20) Modification Flexibility: The ability of a manufacturing process to implement minor design changes in a given product (Gerwin, 1993).

21) Programme Flexibility: The ability of a system to run virtually unattended for a long enough period.

22) Market Flexibility: The ease with which manufacturing system can adapt to a changing market environment.

3.5 Measurement of Flexibility

Similar to the case for the types of flexibility, several studies have performed for measuring flexibility (Kulatilaka, 1988; Brill and Mandelbaum, 1990; Gupta and Somers, 1992; Roll and Arzi, 1992; Das and Nagendra, 1993; Gupta, 1993; Das, 1996; Stockton and Bateman, 1995;Baykasoğlu, 2008). Unfortunately, there is still no acceptable measurement for measuring the different types of flexibility. Gupta (1993) claims that there is a ''lack of universal acceptance of any one scheme'' because of the nature of flexibility, its usage and its variety to particular to situations. Later, Narain et al. (2000) summarized the reasons of difficulty on measuring flexibility as follows:

1) Flexibility is a measure of the potential rather than performance.
2) Flexibility has multiple dimensions.

3) Coherent detailed classification of manufacturing flexibility.

4) The domain of flexibility is difficult to determine a priority.

5) Flexibility has to be user- or situation- specific, making it hard to develop any universal measure.

Although it has been recognized as a difficult issue, some efforts have continued to measure flexibility. Buzacott (1982) proposed a measurement method for job and machine flexibility. In his method, "*the set of all jobs that cannot be processed by the system* with *the probability that such a job in fact will be required to be processed in the future for measuring job flexibility*". He employed the ratio of expected production rate with disturbance to the expected production rate without disturbance for measuring machine flexibility.

Son and Park (1987) have also declared four types of flexibility measures (equipment, process, product, and demand flexibility) for a particular period. By using these partial flexibility measures total flexibility measure defined as reciprocal of the sum of the reciprocals of the individual flexibilities.

Kumar (1987) suggested a measure based on information theory, derived from thermodynamics. The measure is structured on the "Markovian Analysis" of the interrelationship between machines in the manufacturing system. However, this approach is usually criticized for being random and arbitrary.

In another study, Son and Park (1990) employed four non-conventional costs (namely; set-up, waiting, idle, and inventory cost) to describe flexibility in manufacturing.

In 1991, Abdel-Malek and Wolf proposed a measurement in order to rank different "Flexible Manufacturing Systems" (FMS) based on their inheriting flexibility. In 1994, they extended their work and developed a novel index that also includes the technological "obsolescence and life cycle cost" of the FMS in the evaluation process in order to competing designs (Abdel-Malek and Wolf, 1994).

In order to measure the flexibility of a system, Pyoun and Choi (1994) and Pyoun et al. (1995) differentiated "potential flexibility" from "realizable flexibility". They stressed on the development of a procedure for quantifying the realizable flexibility in monetary terms.

Some authors (Zelenovich, 1982; Gustavsson, 1984; Kochikar and Narendran, 1992; Chen and Chung, 1996) measured flexibility on the basis of physical characteristics of the system. But these measurements are considered insufficient, since flexibility is the integration of several other factors.

De Toni and Tonchia (1998) separated measurement of flexibility into three groups; direct measurement of flexibility, indirect measurement of flexibility and synthetic measurement of flexibility. Direct measures include objective and subjective measurement since objective measurements include personal judgments of the evaluator. Indirect measures include the measurements where the flexibility inherently arises from the characteristics of the manufacturing system. In the second category performance related flexibility is considered. These groups make up the branches of measurement functions. The author's classification of measurement of flexibility is given in Figure 3.1.

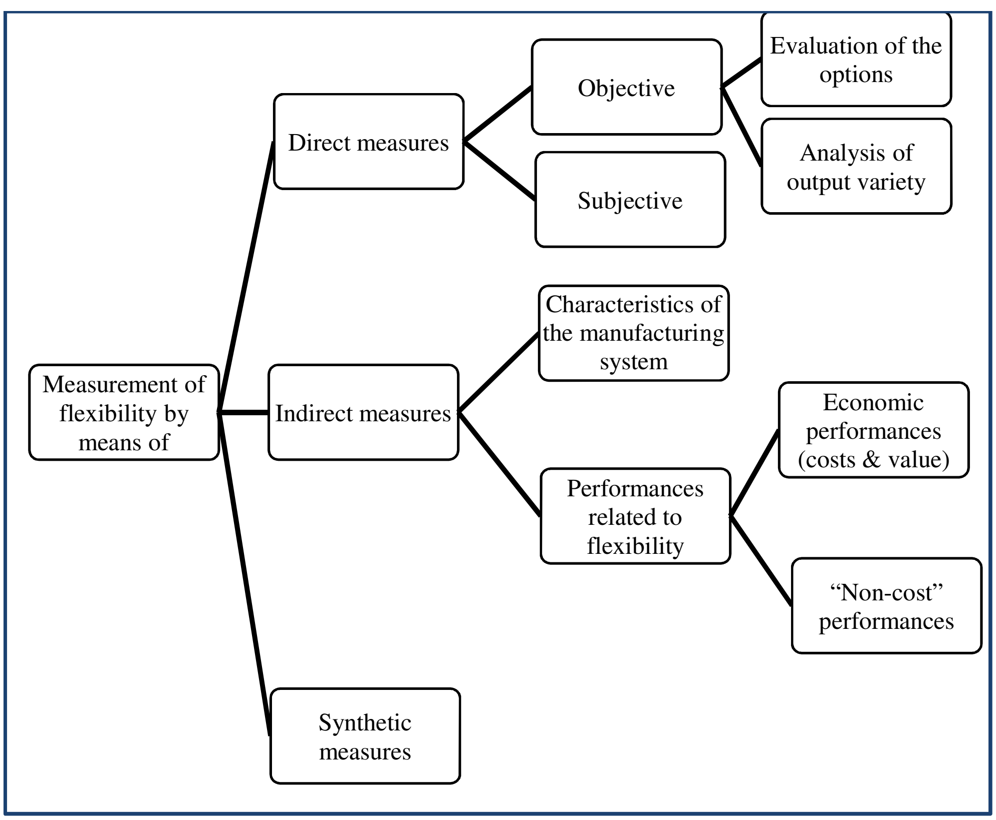

Figure 3.1 DeToni and Tonchia's (1998) classification of flexibility

In the literature, some authors broadly classified measurement of flexibility as being qualitative and quantitative (Brill and Mandelbaum, 1989; Sarker et al., 1994). Qualitative measurement is measuring flexibility by using general terms. At the other hand, quantitative measurement is measuring flexibility in terms of specific manufacturing issues. In the literature, many techniques are employed for quantitative measures of flexibility whereas many of them are theoretical and generally focused on specific flexibility.

According to Gupta and Goyal (1989) quantitative measures of flexibility in the literature can be classified into six groups. They are:

1) Measures based on economic consequence: Financial analysis (Chandra and Tombak, 1992), value based (Ramasesh and Jayakumar, 1991; Son and Park, 1987; Ramasesh and Jayakumar, 1991).

2) Measures based on performance criteria: Empirical data analysis (Dixon, 1992).

3) Multidimensional approach: Path modeling (Swamidass and Newell, 1987), contingency theoretic (Germain, 1989).

4) Petri-nets approach (Kochikar and Narendran, 1992).

5) Information theoretic approach (Yao, 1985).

6) Decision theoretic approach. (Mandelbaum and Buzacott, 1990).

Sarker et al. (1994) considered manufacturing flexibility at the system level and classified the research in this area as: aggregate and attribute. In this classification, "aggregate term" refers to integration of flexibility measures of individual parts of the system into single manufacturing system flexibility. Attribute refers construction of a measure of manufacturing flexibility based on parameters selected from a cross section of those functions of the manufacturing system which contribute to flexibility. In other words, aggregate approach is focused on the identification of the relationships between the flexibility types, whereas attribute approach is focused on the identification of parameters and factors which are independent from flexibility types.

Son and Park (1987)'s measure of flexibility integrated some individual measures to a number therefore it is categorized in the aggregate approach. Similarly, Abdel-Malek and Wolf (1991) introduced a measure of flexibility which parameterizes the averages' of several types of flexibility and then convert these values to an index value. For that reason, their flexibility measure falls in the same category. At the other hand, Hutchinson and Sinha (1989)'s measure of flexibility, which focuses on relationships among the uncertainty and flexibility, fall in the attribute approach.

Some critics have also risen for the attribute approaches since they are thought as theoretical. To avoid these critics, Lim (1987) developed a novel aggregate approach where managements were interviewed to ask the definition of flexibility. Gerwin (1987) succeeded further and he proposed a methodology for systematically identifying factors which affects the flexibility. Sethi and Sethi (1990) have also added novel factors to the existing ones and tested them in the companies. Gupta and Somers (1992) performed a factor analysis approach to uncover the speculations about these factors. Then, they have summarized their findings within "9 principal types of flexibility" title.

At the similar times, Ramasesh and Jayakumar (1991) proposed a new notion of aggregated flexibility where the joint effect of all types of flexibilities that exist in the manufacturing system is considered.

Gupta and Buzacott (1989) claimed that value of flexibility can change over the time and therefore it may be required to use a number to represent its real value. Upon this claim, a stochastic mathematical programming model is proposed by Jaikumar, (1986) to define this value. The proposed model employs machine, material, labor and volume flexibility to build an aggregated flexibility.

3.6 Effects of the Flexibility on Performance of Manufacturing Systems

As mentioned before, manufacturing flexibility provides an opportunity to adjust to changing environmental conditions. In the literature, there are considerable amount of researches that recognized manufacturing flexibility as a competitive priority of the organization. The relationship between manufacturing flexibility and manufacturing performance began to be investigated in early 1980s.

Mishra and Pandey (1989) developed a simulation based scheduling algorithm for the performance evaluation of a batch job-shop flexible manufacturing system. They employed maximum makespan and average machine utilization as the performance indicator. Morito et al. (1991) analyzed a flexible manufacturing system with a simulation model to show the effect of flexibility on manufacturing performance. According to some researchers (Price et al., 1998; Newmann et al., 1992), manufacturing flexibility is a critical sign to manufacturing performance. However, there is no consensus about the relationship between manufacturing flexibility and manufacturing performance.

Some researchers have found a positive relationship between manufacturing flexibility and manufacturing performance (Gerwin, 1987; Olhager, 1993). However, others (Bengtson, 2001) have argued that increased manufacturing flexibility does not necessarily improve manufacturing performance.

Sethi and Sethi 1990 indicated that the routing flexibility helps in the scheduling of jobs in very efficient manner.

Das and Nagendra (1993) found that machine flexibility, was significantly related to performance at the FMS only sub-system level. They also found that product mix flexibility was positively correlated with manufacturing performance.

Watts et al. (1993) and D'Souza (2006) found a positive relationship between manufacturing flexibility and the organization's ability to increase on-time deliveries.

Suarez et al. (1996) claimed that there is no relationship between manufacturing flexibility and quality. Conversely, some others (Galbraith, 1993;Tombak and De Meyer, 1988; Upton, 1994; D'Souza, 2006) have argued that increases in manufacturing flexibility should lead to better quality.

Caprihan and Wadhwa (1997) have presented a framework based on a Taguchi experimental design in order to study the impact of varying levels of routing flexibility. They concluded that an increase in routing flexibility is not always beneficial. Albino and Garavelli (1998) declined that, as the resource dependability decreases, routing flexibility can be effectively used to increase productivity, in particular adopting the limited flexibility configuration.

Wadwa and Bhagwat (1998) have studied the effect of various forms of decision and information delays on the makespan performance at different levels of flexibility in an semi computerized flexible manufacturing (SCFM) system. They showed the makespan performance deteriorates with an increase in decision delays, and this deterioration is higher at higher levels of flexibility. In other words, they claimed that while in general it is advantageous to have more flexibility, the advantage of having more flexibility decreases with an increase in sequencing decision delays.

Nagarur and Azeem (1999) studied to observe the effect of component commonality and machine flexibility in a manufacturing system. They showed that flexibility improves the performance and the effect of flexibility is more pronounced in the context of unexpected changes like breakdowns.

Mohamed et al. (2001) studied the relationship between the degree of machine flexibility and the level of system performance. Makespan, routing flexibility, capacity flexibility, and inventory effects are employed as performance measure. Their research results indicated that changes in the machine flexibility affect some measures more than others. They added that, as the workload on the FMS increases, the differences in the performance between two FMSs (with different degrees of machine flexibility) increase.

Chan et al. (2007) presented a simulation study in order to investigate the need of modeling of the physical and operating parameters of flexible manufacturing system along with flexibility. These parameters are analyzed under Taguchi's method. They showed that the expected benefits from increasing the levels of flexibility and a superior control strategy may not be achieved if the physical and operating parameters of alternative machines have variations. They added that Taguchi's method analysis indicates that relative percentage contribution of variations in physical and operating parameters of alternative resources should be negligible or minimum in the performance of FMS.

Baykasoğlu and Özbakır (2008) investigated the effects of machine and process plan flexibilities on job shop scheduling performance. They found out that the effect of "machine flexibility" on the job shop performance is more than the other factors for all problem sizes. Using different dispatching rules in scheduling always increase the job shop performance. And they concluded that after a certain machine flexibility level, the speed of performance improvement declines dramatically.

3.7 Conclusion

In this part of the thesis, several different researches/papers about the flexibility have been discussed. All these searches have a common idea about the strategic value of flexibility. However, it is not possible to claim that there are common classification and measurement schemes. Existing studies require reconfiguration and rethinking for creating proper classification and measurement schemes.

It is known that, if well configured, flexibility can achieve several benefits. However the question is how can flexibility well configured to obtain the all benefits from flexibility. This thesis also investigates this question and sets several simulation models to measure these effects. Since flexibility has a strategic focus on creating important benefits like resource utilization and decreasing average flowtime; there are certain needs for further studies.

CHAPTER 4- SYSTEM DEFINITION

4.1 Introduction

Simulation modeling and analysis is the process of creating and experimenting with a computerized mathematical model of a physical system. As stated before the physical system described in this thesis is a "job shop" manufacturing facility. Usually "average throughput rate" is considered as the performance criteria for system with finite buffers. However, for infinite buffer systems, the throughput rate is constant and simply corresponds to the overall arrival rate to the system. Therefore, for systems with infinite buffers, "average flow time" is considered as performance criteria. In this respect, the experimentations are structured to measure effects of the different levels of flexibility on the average flow time. The main objective is gaining insight into the levels of flexibility and its effects on average flow time on job shop.

The simulation model issued in this thesis provides job shop managers with a tool that effectively analyzes their current operations and the impact of alternative manufacturing scenarios. The simulation results can be obtained quickly and accurately, thereby providing the justification required for implementing managerial decisions.

Simulation models developed in this thesis represent a hypothetical job shop with six machines. There are six different type of operations defined. In this chapter, details of the system, assumptions, and the scenarios are discussed. The experimental results obtained from simulation of a hypothetical job shop under various shop conditions are discussed in Chapter 5.

4.2 Experimental Conditions

Simulation models are the models which have been run under different scenarios. Each scenario specifically named as experiment has different levels of parameters. However, the specification of the parameter set with which to run these simulations is a quite hard issue. Criticism can easily be found regarding to the procedure and the selected parameters. Since it is difficult to justify why to choose one specification of parameters, especially some theoretical assumptions are defined prior to experiment. In simulation models, theoretical assumptions are often embedded in procedural details. If an assumption is entirely and exclusively represented in a procedural aspect, then it should be indicated before the model is explained.

For the models developed in this thesis, there are also some assumptions regarding the system. Initial assumptions of the simulation models run in this thesis are as follows:

a) Assumptions about the "Shop Environment"

Machine limited job shops; labor is assumed to be always available and waiting time occurs only when a machine is busy.

b) Assumptions about the "Machines"

b1) Each machine is continuously available without any shifts and without any temporary unavailability such as breakdown or maintenance.

b2) There are six different types of machines and there is only one unit of each machine type.

b3) All the machines are not identical originally.

b4) Each machine maintains a separated queue for all flexibility levels.

b5) Machines posses the capability of operating more than one type of operation. Types of operation performed by a machine depends on the flexibility level (details will be discussed through this Chapter).

b6) Each machine can handle at most one operation at a time.

c) Assumptions about the "Jobs"

c1) Jobs are strictly ordered sequences of operations without assembly.

c2) Jobs are neither split nor combined.

c3) There is no scrap loss.

c4) There are 10 different types of jobs.

c5) Probabilities of the arrival of job types to the system are equal (10%).

c6) Jobs arrive to the system randomly with interarrival times that are exponentially distributed with a mean 2.5 and 3.25 for two different shop utilization levels.

c7) There is no "entrance gate". Jobs enter to the first machines without any time delay.

c8) A job leaves the system after completing its all operations from the same exit gate.

c9) Job leave the system with time delay solely depends on the distance between its last machine and the exit gate.

c10) Number of operations of a job varies between 4 and 8. Table 4.1 presents the corresponding operations of job types and routes.

Table 4.1 Corresponding operations of the job types and the sequences

Job Type	# of Operations	Sequence of Operations
1	4	1 2 1 5
2	4	2 3 6 2
3	4	3 5 1 6
4	5	4 2 3 2 6
5	5	5 1 4 5 6
6	5	1 4 2 5 3
7	6	6 3 1 5 4 6
8	6	2 4 3 1 5 1
9	7	6 2 4 2 5 3 1
10	8	3 1 5 4 6 1 3 4

d) ***Assumptions about*** **the *"Operations"***

d1) There are six different types of operations.

d2) Operation preemption is not allowed. (Once started, an operation must be completed before another operation be started on the same machine)

d3) Setup time is ignored

d4) Processing time of each operation is randomly generated from uniform distribution.

d5) Transportation time between machines is deterministic and solely depends on the distance between stations.

d6) Any operation type can exist on a job. More than ones same type of consecutive operations on the same job are prohibited.

d7) The sequence of operations of a job cannot be changed.

d8) Operations have the flexibility of being processed by more than machine.

e) ***Assumptions about*** **"Control Policy"**

e1) In order to identify reasonable operation-machine assignment, the specification of a control policy is required. Machine selection rule and dispatching rule are the two components of the control policy.

e2) Control policies are applied at each decision point (machine selection and job selection).

e3) Arrival of a job to the shop or completion of an operation by a machine is the two events that trigger the decision point.

f) Other Assumptions

f1) All jobs are accepted, there is no job acceptance/rejection stage

f2) Jobs are released to the shop as soon as they arrive; therefore, there is no order review release (ORR) policy.

f3) Work in process (WIP) buffers have unlimited capacities.

f4) Inserted idle time is not allowed. A machine will not remain idle for waiting for a particular operation to arrive. If there are other operations already available and waiting are processed without considering the routed job. This assumption is released in scenario 9, scenario 10 scenario 11, scenario 12.

4.3 System Considerations

In this thesis effects of flexibility level in job shop is investigated under various;

- Flexibility levels,
- Shop utilization levels,
- Machine selection (routing) rules.

All these variables are accepted as system parameters. Details about these levels of the above mentioned parameters are given in the "Components of the System" part.

4.4 Components of the System

In this thesis, specialization is accepted as base case.

1) ***Flexibility level:*** In this thesis, flexibility levels are changed with respect to number of different operations performed by a machine. Four flexibility levels are employed and named as FL1, FL2, FL3, and FL4.

   a. FL1: Each machine can perform two different operations. This configuration is given in Figure 4.1.
   b. FL2: Each machine can perform three different operations. This configuration is given in Figure 4.2.
   c. FL3: Chained configuration which is given in Figure 4.3. It is assumed that each operation type "i" can be processed by machine "i" and machine "i-1", as the alternative machine for operation type i. Notice for an operation type i=1, machine 6 is its alternative.
   d. FL4: Each machine can perform all types of operations. This configuration is given in Figure 4.4.

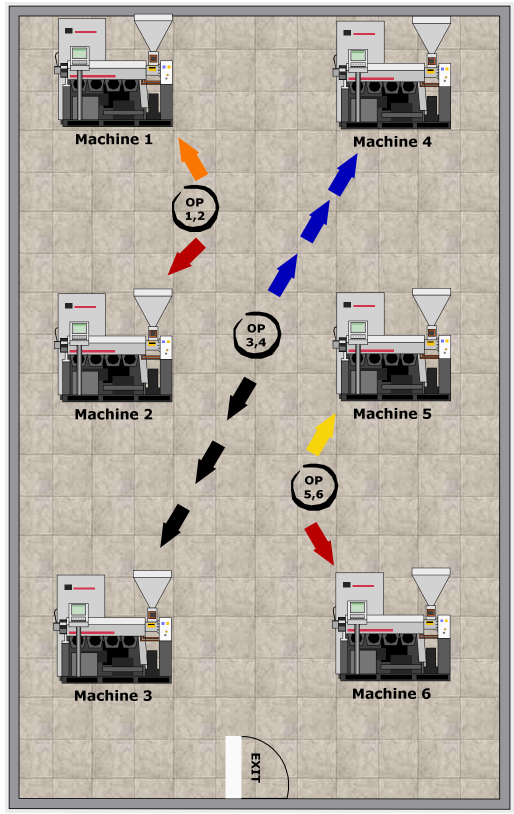

Figure 4.1 Configuration for FL 1

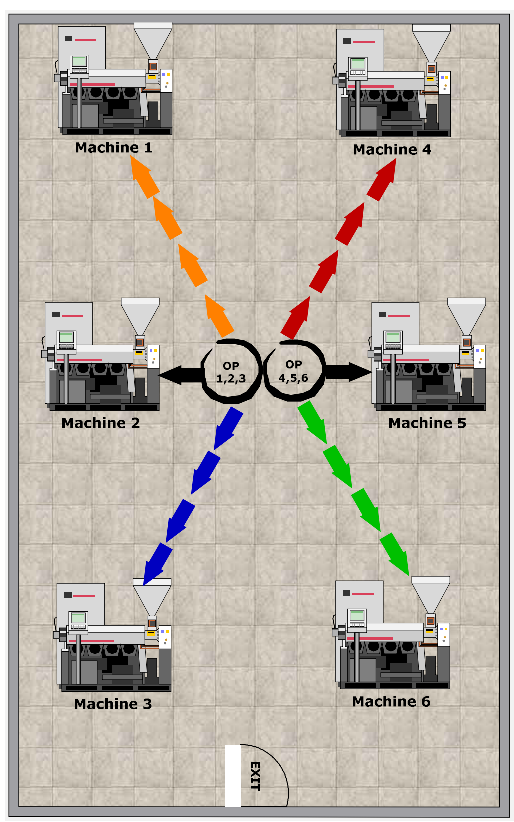

Figure 4.2 Configuration for FL 2

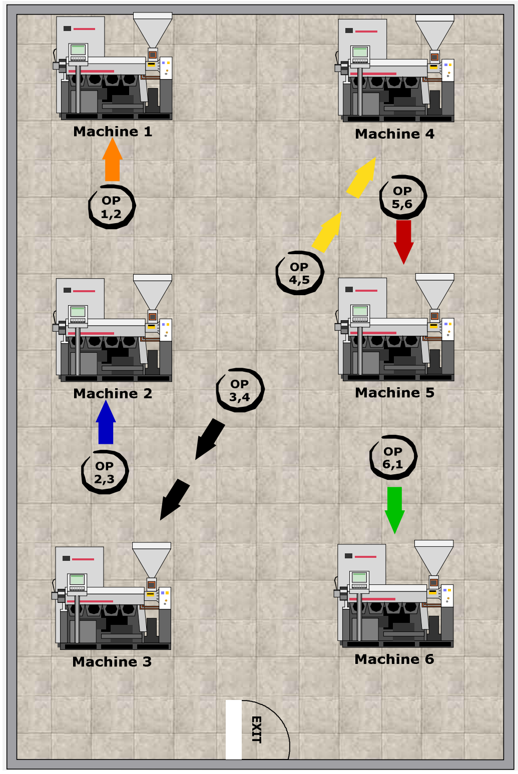

Figure 4.3 Configuration for FL 3

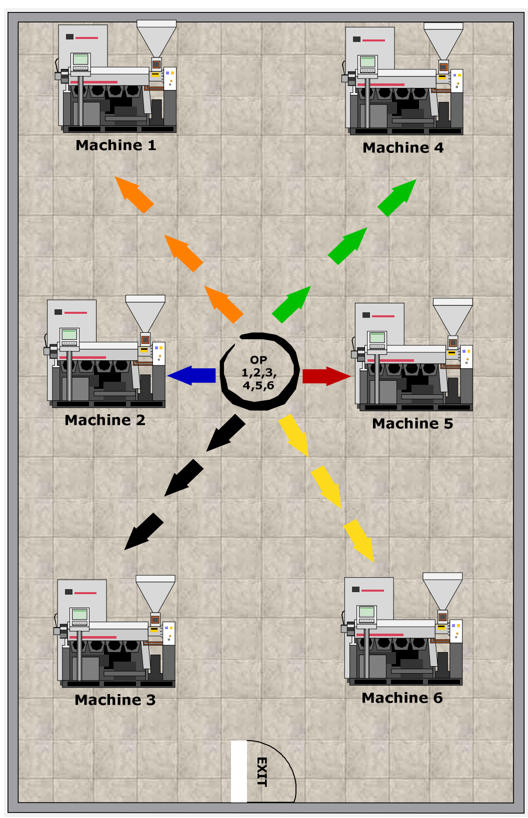

Figure 4.4 Configuration for FL 4

A unified scheme for representing various flexibility levels is presented (Sheikhzadeh et al., 1998).

Let $M = \{M_1, M_2, \dots., M_m\}$ be the set of *m* machines in the system and $O = \{O_1, O_2, \dots., O_n\}$ be the set of *n* operation types. Possible operation-machine assignments are denoted by a *m x n* matrix $A = [a_{ij}]$. The elements of the matrix A, the values of a_{ij}, are the indicator variables such that

$$a_{ij} = \begin{cases} 1, if\ operation\ i\ can\ be\ assigned\ to\ machine\ j; \\ 0, otherwise \end{cases}$$

We define a set $M(i)$ of machines associated with each part type i, such that this operation can be assigned to any one of the machines in the set $M(i)$:

$M(i) = \{M_{i(1)}, M_{i(2)}, \dots., M_{i(m_i)}\}$,

where $m_i = \sum_{j=1}^{m} a_{ij}$ is the size of set M(*i*), and *i*(*k*) denotes the index of the *k*th machine assigned to operation *i*.

It is assumed that, each operation type eventually is assigned to at least one machine. Therefore, $m_i = |M(i)|$ is at least 1, for every operation type.

Similar to M(i), O(j) be the set of operation types can be assigned to machine j as follows:

$$O(j) = \{O_{j(1)}, O_{j(2)}, \dots., O_{j(n_j)}\}$$

where $n_j = \sum_{i=1}^{n} a_{ij}$ is the size of set O(*j*), and *j*(*k*) denotes the index of the k^{th} operation type assigned to machine *j*.

It is assumed that, each machine is capable of processing at least one operation type. Therefore, $n_j = |O(j)|$ is at least 1, for every machine j.

Definition 1. $\alpha_{kj} = |O(k) \cap O(j)|$ is a measure of the degree of operation assignment overlap between any two machines *k* and *j*.

Definition 2. $\beta_{ir} = |M(i) \cap M(r)|$ is a measure of the machine sharing between any two operation types *i* and *r*.

Definition 3. Machines can be organized into groups such that no operation in the operation set O can be assigned more than one such group; each such group is called a *machine partition.*

Definition 4. If, for every k, j, i, and r belonging to the same machine partition, $\alpha_{kj} = \beta_{ir} = 1$, then such operation-machine assignment is called *chaining*. Chaining is possible only when the number of machines within a machine partition is equal to the number of operation types assigned to it.

Definition 5. For a given set of machines, *M*, the relative length of the chain corresponding to a machine partition is defined as the ratio of the number of machines in the partition to the size of the set *M*.

In addition *l* denotes the number of machine partition; it can be at least 1 or at most m.

In this thesis, number of different machines and number of different operation types in the system is 6. Therefore,

$M = \{M_1, M_2, M_3, M_4, M_5, M_6\}$ the set of 6 machines in the system (*m*=6)

$O = \{O_1, O_2, O_3, O_4, O_5, O_6\}$ the set of 6 operation types in the system (*n*=6)

Possible operation-machine assignment $A = [a_{ij}]$ changes with respect to flexibility level. Now, based on the preceding formulas and definitions, following calculations can be performed for each flexibility level including base case.

Base Case: Operation machine assignment matrix for B.C. is;

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

M(i) for each operation type is given as follows;

Operation Type (i)	***M(i)***	$\boldsymbol{m_i}$
1	$M(1) = \{M_{1(1)}\}$	1
2	$M(2) = \{M_{2(2)}\}$	1
3	$M(3) = \{M_{3(3)}\}$	1
4	$M(4) = \{M_{4(4)}\}$	1
5	$M(5) = \{M_{5(5)}\}$	1
6	$M(6) = \{M_{6(6)}\}$	1

O(j) for each machine is given as follows;

Machine Type (j)	***O(j)***	$\boldsymbol{n_j}$
1	$O(1) = \{O_{1(1)}\}$	1
2	$O(2) = \{O_{2(2)}\}$	1
3	$O(3) = \{O_{3(3)}\}$	1
4	$O(4) = \{O_{4(4)}\}$	1
5	$O(5) = \{O_{5(5)}\}$	1
6	$O(6) = \{O_{6(6)}\}$	1

$l = m$ and $\alpha_{kj} = \beta_{ir} = 0; \quad \forall i, j, k, r$

Each machine forms a separate partition of the set *M*.

FL1: Operation machine assignment matrix for FL1 is;

$$A = \begin{bmatrix} 1\ 1\ 0\ 0\ 0\ 0 \\ 1\ 1\ 0\ 0\ 0\ 0 \\ 0\ 0\ 1\ 1\ 0\ 0 \\ 0\ 0\ 1\ 1\ 0\ 0 \\ 0\ 0\ 0\ 0\ 1\ 1 \\ 0\ 0\ 0\ 0\ 1\ 1 \end{bmatrix}$$

M(i) for each operation type is given as follows;

Operation Type (i)	***M(i)***	$\boldsymbol{m_i}$
1	$M(1) = \{M_{1(1)}, M_{1(2)},\}$	2
2	$M(2) = \{M_{2(1)}, M_{2(2)},\}$	2
3	$M(3) = \{M_{3(3)}, M_{3(4)},\}$	2
4	$M(4) = \{M_{4(3)}, M_{4(4)},\}$	2
5	$M(5) = \{M_{5(5)}, M_{5(6)},\}$	2
6	$M(6) = \{M_{6(5)}, M_{6(6)},\}$	2

O(j) for each machine is given as follows;

Machine Type (j)	***O(j)***	$\boldsymbol{n_j}$
1	$O(1) = \{O_{1(1)}, O_{1(2)}\}$	2
2	$O(2) = \{O_{2(1)}, O_{2(2)}\}$	2
3	$O(3) = \{O_{3(3)}, O_{3(4)}\}$	2
4	$O(4) = \{O_{4(3)} O_{4(4)}\}$	2
5	$O(5) = \{O_{5(5)}, O_{5(6)}\}$	2
6	$O(6) = \{O_{6(5)}, O_{6(6)}\}$	2

$\alpha_{kj} = \beta_{ir}$=2 $\forall\ i, j, k, t\ \in same\ machine\ partition$

Two of six machines form a separate partition, *l*=3

FL2: Operation machine assignment matrix for FL2 is;

$$A = \begin{bmatrix} 1\ 1\ 1\ 0\ 0\ 0 \\ 1\ 1\ 1\ 0\ 0\ 0 \\ 1\ 1\ 1\ 0\ 0\ 0 \\ 0\ 0\ 0\ 1\ 1\ 1 \\ 0\ 0\ 0\ 1\ 1\ 1 \\ 0\ 0\ 0\ 1\ 1\ 1 \end{bmatrix}$$

M(i) for each operation type is given as follows;

Operation Type (i)	***M(i)***	$\boldsymbol{m_i}$
1	$M(1) = \{M_{1(1)}, M_{1(2)}, M_{1(3)},\}$	3
2	$M(2) = \{M_{2(1)}, M_{2(2)}, M_{2(3)}\}$	3
3	$M(3) = \{M_{3(1)}, M_{3(2)}, M_{3(3)}\}$	3
4	$M(4) = \{M_{4(4)}, M_{4(5)}, M_{4(6)}\}$	3
5	$M(5) = \{M_{5(4)}, M_{5(5)}, M_{5(6)}\}$	3
6	$M(6) = \{M_{6(4)}, M_{6(5)}, M_{6(6)}\}$	3

O(j) for each machine is given as follows;

Machine Type (j)	***O(j)***	$\boldsymbol{n_j}$
1	$O(1) = \{O_{1(1)}, O_{1(2)}, O_{1(3)}\}$	3
2	$O(2) = \{O_{2(1)}, O_{2(2)}, O_{2(3)}\}$	3
3	$O(3) = \{O_{3(1)}, O_{3(2)}, O_{3(3)}\}$	3
4	$O(4) = \{O_{4(4)}, O_{4(5)}, O_{4(6)}\}$	3
5	$O(5) = \{O_{5(4)}, O_{5(5)}, O_{5(6)}\}$	3
6	$O(6) = \{O_{6(4)}, O_{6(5)}, O_{6(6)}\}$	3

$\alpha_{kj} = \beta_{ir}$=3 $\forall\ i, j, k, t\ \in same\ machine\ partition$

Three of six machines form a separate partition, *l*=2

FL3: Operation machine assignment matrix for FL3 is;

$$A = \begin{bmatrix} 1\ 0\ 0\ 0\ 0\ 1 \\ 1\ 1\ 0\ 0\ 0\ 0 \\ 0\ 1\ 1\ 0\ 0\ 0 \\ 0\ 0\ 1\ 1\ 00 \\ 0\ 0\ 0\ 1\ 1\ 0 \\ 0\ 0\ 0\ 0\ 1\ 1 \end{bmatrix}$$

M(i) for each operation type is given as follows;

Operation Type (i)	***M(i)***	$\boldsymbol{m_i}$
1	$M(1) = \{M_{1(1)}, M_{1(6)}\}$	2
2	$M(2) = \{M_{2(1)}, M_{2(2)}\}$	2
3	$M(3) = \{M_{3(2)}, M_{3(3)}\}$	2
4	$M(4) = \{M_{4(3)}, M_{4(4)}\}$	2
5	$M(5) = \{M_{5(4)}, M_{5(5)}\}$	2
6	$M(6) = \{M_{6(5)}, M_{6(6)}\}$	2

O(j) for each machine is given as follows;

Machine Type (j)	***O(j)***	$\boldsymbol{n_j}$
1	$O(1) = \{O_{1(1)}, O_{1(2)}\}$	2
2	$O(2) = \{O_{2(2)}, O_{2(3)}\}$	2
3	$O(3) = \{O_{3(3)}, O_{3(4)}\}$	2
4	$O(4) = \{O_{4(4)}, O_{4(5)}\}$	2
5	$O(5) = \{O_{5(5)}, O_{5(6)}\}$	2
6	$O(6) = \{O_{6(1)}, O_{6(6)}\}$	2

$\alpha_{kj} = \beta_{ir}$=1 $\forall\ i, j, k, t\ \in same\ machine\ partition$

FL4: Operation machine assignment matrix for FL4 is;

$$A = \begin{bmatrix} 1\ 1\ 1\ 1\ 1\ 1 \\ 1\ 1\ 1\ 1\ 11 \\ 1\ 1\ 1\ 1\ 1\ 1 \\ 1\ 1\ 1\ 1\ 11 \\ 1\ 1\ 1\ 1\ 1\ 1 \\ 1\ 1\ 1\ 1\ 1\ 1 \end{bmatrix}$$

M(i) for each operation type is given as follows;

Operation Type (i)	***M(i)***	$\boldsymbol{m_i}$
1	$M(1)=\{M_{1(1)},M_{1(2)},M_{1(3)},M_{1(4)},M_{1(5)}M_{1(6)}\}$	6
2	$M(2)=\{M_{2(1)},M_{2(2)},M_{2(3)},M_{2(4)},M_{2(5)}M_{2(6)}\}$	6
3	$M(3)=\{M_{3(1)},M_{3(2)},M_{3(3)},M_{3(4)},M_{3(5)}M_{3(6)}\}$	6
4	$M(4)=\{M_{4(1)},M_{4(2)},M_{4(3)},M_{4(4)},M_{4(5)}M_{4(6)}\}$	6
5	$M(5)=\{M_{5(1)},M_{5(2)},M_{5(3)},M_{5(4)},M_{5(5)}M_{5(6)}\}$	6
6	$M(6)=\{M_{6(1)},M_{6(2)},M_{6(3)},M_{6(4)},M_{6(5)}M_{6(6)}\}$	6

O(j) for each machine is given as follows;

Machine Type (j)	***O(j)***	$\boldsymbol{n_j}$
1	$O(1)=\{O_{1(1)},O_{1(2)},O_{1(3)},O_{1(4)},O_{1(5)},O_{1(6)}\}$	6
2	$O(2)=\{O_{2(1)},O_{2(2)},O_{2(3)},O_{2(4)},O_{2(5)},O_{2(6)}\}$	6
3	$O(3)=\{O_{3(1)},O_{3(2)},O_{3(3)},O_{3(4)},O_{3(5)},O_{3(6)}\}$	6
4	$O(4)=\{O_{4(1)},O_{4(2)},O_{4(3)},O_{4(4)},O_{4(5)},O_{4(6)}\}$	6
5	$O(5)=\{O_{5(1)},O_{5(2)},O_{5(3)},O_{5(4)},O_{5(5)},O_{5(6)}\}$	6
6	$O(6)=\{O_{6(1)},O_{6(2)},O_{6(3)},O_{6(4)},O_{6(5)},O_{6(6)}\}$	6

$\alpha_{kj}=\beta_{ir}=6 \quad \forall\, i,j,k,t$

These configurations for FL1, FL2, FL3 and FL4 are also presented schematically in Figure 4.5 (Baykasoğlu and Unutmaz, 2008).

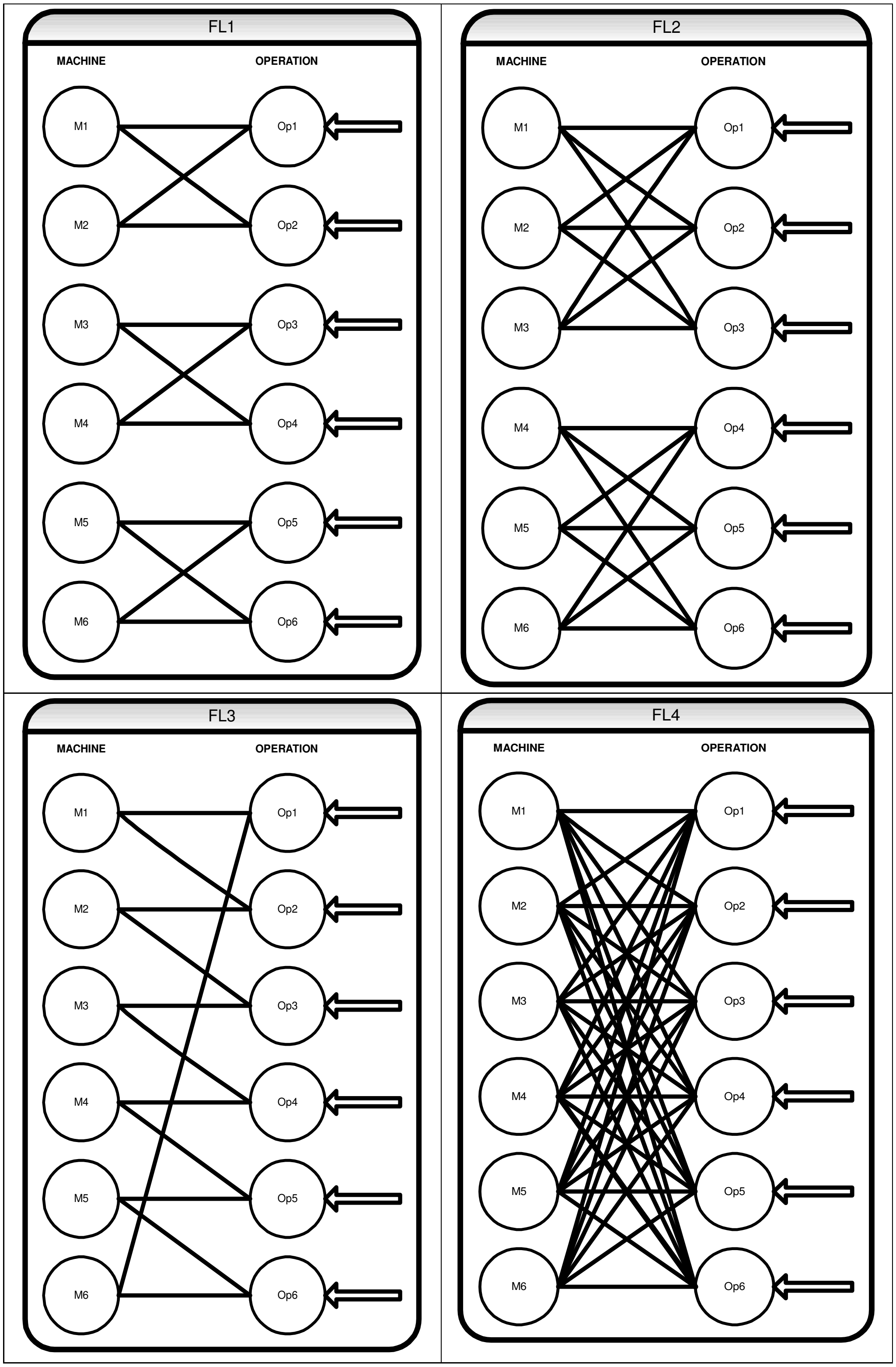

Figure 4.5 Schematic presentation of flexibility levels.

2) ***Shop utilization level:*** *utilization* is defined as percentage of time a resource is busy servicing user requests (http://www.codeplex.com). In this thesis, two levels of shop utilization (70% and 90%) is employed with respect to base case. Shop utilization levels are set by changing arrival rate. Two shop utilization levels are achieved by changing mean of interaarrival times.

3) ***Machine selection rule (MSR):*** Two different formulas are employed in order to decide which machine is selected. They are named as SEARCH1 and SEARCH2 respectively. One of these formulas is employed for each alternative machine and the machine giving the minimum value is selected.

    a. ***SEARCH1***=(Number of jobs waited in machine queue * Average processing time of last 10 operations performed at this machine)+ Remaining processing time of operation working at this machine + Transportation time between previous machine and this machine

    b. ***SEARCH2***=(Number of operations waited in machine queue * Average processing time of last 10 operations performed at this machine)+ Remaining processing time of operation working at this machine + Transportation time between previous machine and this machine

In SEARCH2 number of operations waited in the machine queue is calculated by using the following routine.

```
Job number =1
  CONTROL1 IF Job number < NQ(M)
                  CONTROL2   IF operation number +1 <=total operation
                                          IF operation number + 1 ϵ M
                                               Potential operation =potential operation +1
                                               Operation number = operation number +1
                                             GOTO CONTROL2
                                          ELSE
                                                 Job number = Job number +1
                                               GOTO CONTROL1
                                          ENDIF
                               ELSE
                               Job number = Job number +1
                               GOTO CONTROL1
                               ENDIF
                  ENDIF
```

In the above pseudo code “job number”, “potential operation”, “M” and “NQ” are variables referred to rank of the job waited in the queue, order of the current operation of the job, number of operations can be performed at this machine, machine and number of jobs waited in the machine queue respectively. “Operation number” and “total operation” are attributes referred to operation number of waited in the queue and, total number of operation of the job respectively.

Each of these factors, mentioned above, is reconfigured with following cases.

Case 1: Transportation time between machines is assumed to be zero.

Case 2: Transportation time between neighbor machines is assumed to be 8 minutes. Layout design is presented in Figure 4.1, 4.2, 4.3, and 4.4.

Case 3: Processing time of an operation does not change whether it is performed in the actual machine (machine used in the base case) or in the alternative machine.

Case 4: Processing time of an operation increases if the operation is performed in the alternative machine. In literature, this state is called as “machine dependent”

The processing time of the each operation considered in this thesis is as presented in Table 4.2

Table 4.2 Corresponding process times for the operations (hours)

Operation	**Case 1 & Case 3** **Case 2 & Case 3**	**Case 1 & Case 4** **Case 2 & Case 4**
Op 1	Uni (1.80, 2.25)	Uni (1.89, 2.36)
Op 2	Uni (2.35, 2.85)	Uni (2.47, 2.99)
Op 3	Uni (2.35, 2.85)	Uni (2.47, 2.99)
Op 4	Uni (2.35, 2.85)	Uni (2.47, 2.99)
Op 5	Uni (2.35, 2.85)	Uni (2.47, 2.99)
Op 6	Uni (3.15, 3.25)	Uni (3.31, 3.41)

Scenarios are developed for each cases and each level of the factors under three dispatching rules. These are;

1) First-in-system-first served (FSFS): When the machine becomes idle, the job in queue with the earliest shop arrival date is selected first.

2) First come first served (FCFS): When the machine becomes idle, the operation in queue with the earliest queue arrival date is selected first. Here the term operation is used instead of job because when an operation of a job is performed at the same machine, it does not change the current machine.

3) Minimum average processing time (MAPT): When the machine becomes idle, the job in queue with the minimum average processing is selected first.

For the second and the third dispatching rules, FSFS is used as a tie break.

4.5 Scenarios

It is known that, in simulation analysis, warm ups are set to avoid misleading results. In this thesis, models are terminated after 18000 jobs are completed. Therefore; the duration required for completing 1800 jobs (10 % of all jobs) are not included in the statistics of the results since it has been treated as warm-up periods for each model. All models are run using 25 replications in order to minimize variability in results. In addition, common random numbers (CRM) are used to provide the same experimental condition across the runs for each scenario.

The selection of the machine for the first operation of each job is the same for all scenarios whereas MSR changes. The selection process is given as follows:

When a job enters to the system, it searches among the alternative machines of the first operation by using one of MSR. Then a machine is selected.

1) IF the selected machine is idle, then the operation is processed as soon as it enters to the system.
2) IF the selected machine is not idle (i.e. there is an operation processing at this machine), then the operation enters to the queue of this machine.

Scenario1

Operations are dispatched according to FSFS.

Jockeying between alternative machine's queues is not allowed.

When an operation of a job is finished, first of all it is checked whether it is the last operation of this job or not.

1) IF it is the last operation, then this job leaves the system.

2) IF it is not the last operation, then it is checked whether it can be processed at the current machine or not.

2a) IF it can be processed at the current machine, then it is controlled whether there is any job that is waiting for this machine with arrival time to the system is smaller than its.

2a1) IF there is any job whose system arrival time is smaller than its, then the job with minimum system arrival time is processed.

Current job, for processing the next operation, searches among the alternative machines by using one of MSR. It selects either a different machine or the current machine.

2a1i) IF current machine is selected again, then next operation of this job passes to the same machine's queue.

2a1ii) IF different machine is selected, then this job is routed to the selected machine in order to process the next operation.

2a2) IF there is not any job whose system arrival time is smaller than the current operation, next operation of the current job is processed at the same machine

2b) IF it cannot be processed, then current job searches among the alternative machines by using one of MSR. It is routed to the selected machine in order to process the next operation.

2b1) IF there is any job waiting for current machine, then the job having the minimum system arrival time is processed at current machine.

2b2) IF there is not any job waiting for this machine, nothing is performed.

Whenever an operation ends, all machines queue's are searched sequentially.

1) IF the searched machine is idle and its queue is not empty, then the job having the minimum system arrival time is selected for processing on this machine.

2) IF the searched machine is not idle or the searched machine is idle but there is not a job waiting on its queue nothing is performed.

This search process continues until last machine is controlled.

Scenario1 is programmed under four flexibility level, two shop utilization level, two machine selection rule. In other words, it is programmed for 16 (4*2*2) different factors. In addition, all these programs are run for case 1, case 2, case 3, and case 4. Namely 64 (4*16) programs are developed and run in order to compare different flexibility levels under various conditions.

Besides, this scenario is programmed for specialized job shop conditions (since there is no alternative machines, MSR is not employed) under two shop utilization levels. These two programs are run for case 1 and case 2. (4 programs are added) In other words, for this scenario totally ***68*** (64 + 4) programs are developed and run.

Scenario2

Operations are dispatched according to FCFS.

Jockeying between alternative machine's queues is not allowed.

When an operation of a job is finished, first of all it is checked whether it is the last operation of this job or not.

1) IF it is the last operation, then this job leaves the system.

2) IF it is not the last operation, then it is checked whether it can be processed at the current machine or not.

- **2a)** IF it can be processed at the current machine, next operation of the current job is processed at the same machine.
- **2b)** IF it cannot be processed, then current job searches among the alternative machines by using one of MSR. It is routed to the selected machine in order to process the next operation.

2b1) IF there is any operation waiting for current machine, then the operation having the minimum machine arrival time is processed at current machine.

2b2) IF there is not any job waiting for this machine, nothing is performed.

Whenever an operation ends, all machines queue's are searched sequentially.

1) IF the searched machine is idle and its queue is not empty, then the operation having the minimum machine arrival time is selected for processing on this machine.

2) IF the searched machine is not idle or the searched machine is idle but there is not a job waiting on its queue nothing is performed.

This search process continues until last machine is controlled.

Similar to scenario 1, for this scenario totally ***68*** (64 + 4) programs are developed and run.

Scenario 3

Operations are dispatched according to MAPT.

Jockeying between alternative machines' queues is not allowed.

When an operation of a job is finished, first of all it is checked whether it is the last operation of this job or not.

1) IF it is the last operation, then this job leaves the system

2) IF it is not the last operation, then it is checked whether it can be processed at the current machine or not.

2a) IF it can be processed at the current machine, then it is controlled whether there is any operation whose average processing time at this machine is smaller than its.

2a1) IF there is any operation whose average processing time at this machine is smaller than its, then the operation with minimum machine arrival time is processed.

Current job, for processing the next operation, searches among the alternative machines by using one of MSR. It selects either a different machine or the current machine.

2a1i) IF current machine is selected again, then next operation of this job passes to the same machine's queue.

2a1ii) IF different machine is selected, then this job is routed to the selected machine in order to process the next operation.

2a2) IF there is not any operation whose average processing time at this machine is smaller than the current operation, next operation of the current job is processed at the same machine

2b) IF it cannot be processed, then current job searches among the alternative machines by using one of MSR. It is routed to the selected machine in order to process the next operation.

2b1) IF there is any operation waiting for current machine, then the operation having the minimum average processing time is processed at current machine.

2b2) IF there is not any job waiting for this machine, nothing is performed.

Whenever an operation ends, all machines queue's are searched sequentially.

1) IF the searched machine is idle and its queue is not empty, then the operation having the minimum average processing time at this machine is selected for processing on this machine.

2) IF the searched machine is not idle or the searched machine is idle but there is not a job waiting on its queue nothing is performed.

This search process continues until last machine is controlled.

Dissimilar to scenario 1 and scenario 2, for this scenario totally ***64*** programs are developed and run. For specialized job shop, using this scenario is worthless. Because each machine can only processes one type of operation in specialized job shop. Therefore, average processing time of each operation waiting at the same machine's queue is indifferent and this scenario behaves as it is in scenario 1 (*Since FSFS is used as a tie break*).

Scenario 4

This scenario is very similar to scenario 3. However, in this scenario possible consecutive operation /operations of the same job is/are allowed to be processed at the same machine without interruption. In other words, there is no need to search the current machine's queue.

Similar to scenario 3, for this scenario totally ***64*** programs are developed and run.

Scenario 5

Operations are dispatched according to FSFS.

The difference between scenario 1 and scenario 5 is allowance of jockeying between alternative machine's queues. In the literature of Queue Theory, "jockeying" refers to the movements of customers who have the option of switching from one line to another when several servers, each having a separate and distinct waiting line, are available (Koenigsberg, 1966). Jockeying is quite common in many queue systems. Most of the people jockeying for years (i.e. switching lines in auto license offices and supermarkets) when faced by long queues in order to reduce total time spent in the system. Jockeying can be employed in manufacturing systems. In these systems, operations or jobs can be moved from one queue to another. No matter which type of system is studied, jockeying can only occur when the customer\operation\job have more than one alternative queues.

In the literature, some researchers (Disney and Mitchell, 1971; Kao and Li, 1990; Zhao, 1990) have studied the jockeying problem by considering models with Markovian inputs. Some authors (such as Zhao and Grassmann, 1995; Tarabia, 2007) have compared the results for jockeying and non-jockeying models, and they revealed that significant improvement of the system performance has been achieved for the jockeying model. To our knowledge, researchers studying the manufacturing systems assumed that jockeying among queues is not allowed. Distinct from the existing studies, in this thesis, jockeying is employed in order to see the effect of it in flexible job shop manufacturing systems.

When an operation of a job is finished, the same procedure employed in scenario 1 is repeated.

Whenever an operation ends, all machines queue's are searched sequentially.

1) IF the searched machine is idle and its queue is not empty, then the job having the minimum system arrival time is selected for processing on this machine.

2) IF the searched machine is not idle, nothing is performed.

3) IF the searched machine is idle and its queue is empty, then the nearest queue which can perform the same operation is sought. Seeking process continues until a machine queue having any job for processing is found or all the alternatives are dead.

  3a) IF any job is found among the alternatives, then the job with minimum system arrival time is routed to the idle machine.

  3b) IF there are more than one machine having the same distance to the idle machine, the job with the minimum system arrival time among these machines is routed to the idle machine.

  3c) IF alternatives are dead, nothing is performed.

This search process continues until last machine is controlled.

Similar to scenario 4 and scenario 5, totally 64 programs are developed and run for this scenario. Again, for specialized job shop, using this scenario is worthless. Because in specialized job shop there is no alternative queue, therefore jockeying can not be performed.

Scenario 6

Operations are dispatched according to FCFS.

The difference between scenario 2 and scenario 6 is allowance of jockeying between alternative machine's queues.

When an operation of a job is finished, the same procedure employed in scenario 2 is repeated.

Whenever an operation ends, all machines queue's are searched sequentially.

1) IF the searched machine is idle and its queue is not empty, then the operation having the minimum machine arrival time is selected for processing on this machine.

2) IF the searched machine is not idle, nothing is performed.

3) IF the searched machine is idle and its queue is empty, then the nearest machine's queue which can perform the same operation is sought. Seeking process continues until a machine queue having any job for processing is found or all the alternatives are dead.

  3a) IF any job is found among the alternatives, then the operation with minimum machine arrival time is routed to the idle machine.

  3b) IF there are more than one machine having the same distance to the idle machine, the operation with the minimum machine arrival time among these machines is routed to the idle machine.

  3c) IF alternatives are dead, nothing is performed.

This search process continues until last machine is controlled.

Similar to scenario 4, scenario 5, totally 64 programs are developed and run for this scenario.

Scenario 7

Operations are dispatched according to MAPT.

The difference between scenario 3 and scenario 7 is allowance of jockeying between alternative machine's queues.

When an operation of a job is finished, the same procedure employed in scenario 2 is repeated.

Whenever an operation ends, all machines queue's are searched sequentially.

1) IF the searched machine is idle and its queue is not empty, then the operation having the minimum average processing time at this machine is selected for processing on this machine.

2) IF the searched machine is not idle, nothing is performed.

3) IF the searched machine is idle and its queue is empty, then the nearest machine's queue which can perform the same operation is sought. Seeking process continues until a machine queue having any job for processing is found or all the alternatives are dead.

3a) IF any job is found among the alternatives, then the operation with minimum average processing time is routed to the idle machine.

3b) IF there are more than one machine having the same distance to the idle machine, the operation with the minimum machine arrival time among these machines is routed to the idle machine.

3c) IF alternatives are dead, nothing is performed.

This search process continues until last machine is controlled.

Similar to scenario 5, and scenario 6, 64 programs are developed and run for this scenario.

Scenario 8

Scenario 4 is reconfigured using the same jockeying procedure in scenario 7. Totally, 64 programs are developed and run.

Scenario 9 and Scenario 10, 11,12

Scenario 9 is similar to scenario 5, scenario 10 is similar to scenario 6, scenario 11 is similar to scenario 7 and scenario 12 is similar to scenario 8. Differences between these scenarios are as listed below.

In Scenario 5, 6, 7, 8 jockeying is allowed when the selected machine is idle and its queue is empty, however, in scenario 9,10,11,12 in addition to these conditions there should be no routed job to the idle machine. Scenarios 9,10,11,12 have not been run for CASE1, since all transportation times are zero and thereby there is no time gap for job routing.

Scenario 9, scenario 10, scenario 11, scenario 12 are programmed under four flexibility level, two shop utilization level, and two machine selection rule. In other words, each of these scenarios are programmed for 16 (4*2*2) different factors. In addition, these scenarios with 16 factors are run for case 2 & case 3 and case 2 & case 4. Totally 128 (16*4*2) programs are run for all of these scenarios.

SIMAN code for scenario 9 for case 2 and 4, search 1, FL2 and 90% shop utilization can be found in Appendix A.

SIMAN code for scenario 10 for case 2 and 4, search 1, FL2 and 90% shop utilization can be found in Appendix B.

SIMAN code for scenario 12 for case 2 and 4, search 1, FL2 and 90% shop utilization can be found in Appendix C.

4.6 Conclusion

In this section details of twelve scenarios are presented. In addition four flexibility levels, specification state; dispatching rules and the machines selection rules are discussed.

CHAPTER 5- RESULTS AND DISCUSSION

5.1 Introduction

As stated before, this thesis is structured to measure of effects of flexibility on average flow time. In this part of the thesis, results of simulation experiments are discussed.

5.2 Results via Scenarios

In this section, the results of the experiments are discussed for 10 scenarios.

Scenario 1

The details about scenario 1 can be found in Chapter 4. As it can be seen from Table 5.1, full flexibility (FL4) always gives the minimum AFT for 70% shop utilization level. In addition, in each case search 2 gives better result than search 1. FL2 is also the second best in each case and search condition.

For 90% shop utilization, different results are obtained. Except two combinations (case 1 and 4, case 2 and 4 with search 1), FL4 gives the best result. However, FL3 gives the best result in the indicated situations. Difference between FL4 and FL3 becomes smaller with transportation. Dissimilar to 70% shop utilization, FL3 gives the second best result. In addition, the gap between AFT gets smaller when the processing times are machine dependent.

In summary, full flexibility has the least average flow time for the combinations of Case 1 and Case 3; Case 2 and Case 3. The average flow times for full flexibility is always better then FL1 and FL2 configurations. However, for a few cases, there exists a slight difference between the chained configuration and fully flexible configuration. At other hand, all kind of flexibility configurations have always better values compared to base case.

Table 5.1 The average flow times for scenario 1

		Case1 and Case3		Case1 and Case4		Case2 and Case3		Case2 and Case4	
		Search1	**Search2**	**Search1**	**Search2**	**Search1**	**Search2**	**Search1**	**Search2**
70%	**Base Case**	27.576	27.576	27.576	27.576	28.593	27.576	27.576	27.576
	FL1	20.420	20.404	21.604	21.610	21.547	23.402	22.732	22.702
	FL2	18.484	18.311	19.814	19.649	19.411	19.142	20.749	20.474
	FL3	19.333	19.105	20.351	20.106	20.461	20.218	21.463	21.205
	FL4	16.094	15.405	17.289	16.475	16.268	15.575	17.458	16.644
90%	**Base Case**	80.511	80.511	80.511	80.511	81.607	81.607	81.607	81.607
	FL1	48.491	48.734	67.360	67.527	49.815	49.946	68.521	68.790
	FL2	39.307	39.417	59.169	59.232	40.396	40.368	60.225	60.221
	FL3	35.546	35.154	44.841	44.552	36.788	36.400	46.135	45.875
	FL4	28.149	26.769	46.029	44.496	28.314	26.933	46.194	44.660

As it can be seen from Figure 5.1 and Figure 5.2 the effects of flexibility is much more for the 90% shop utilization level.

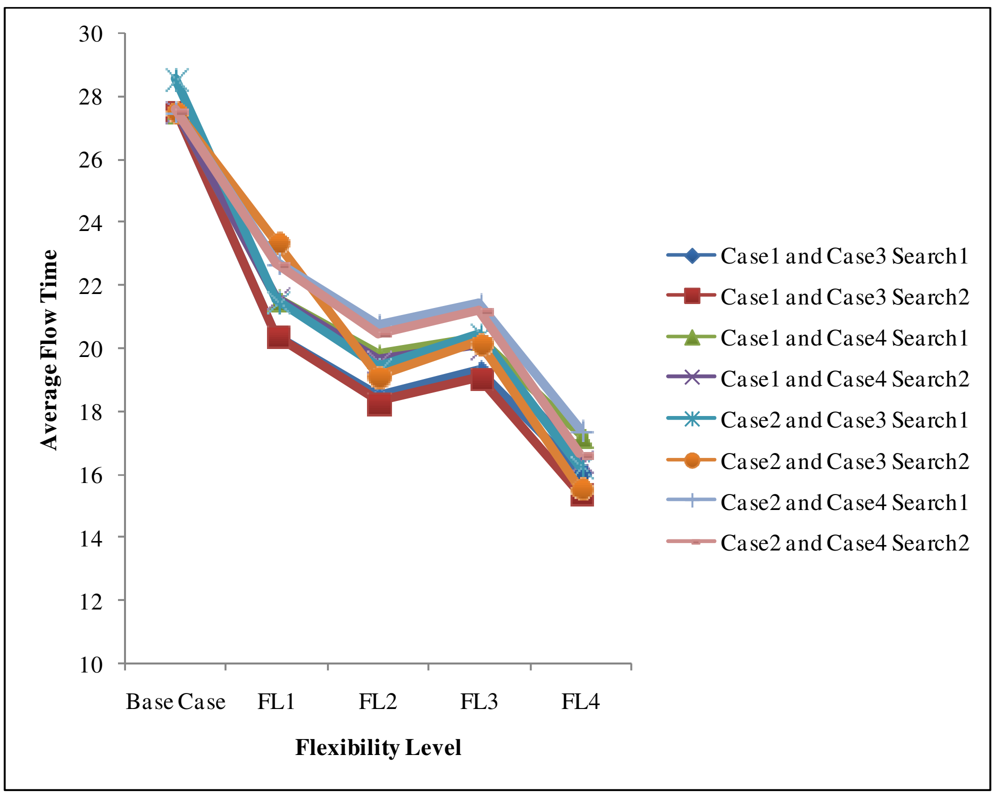

Figure 5.1 The average flow times for 70% shop utilization for scenario 1

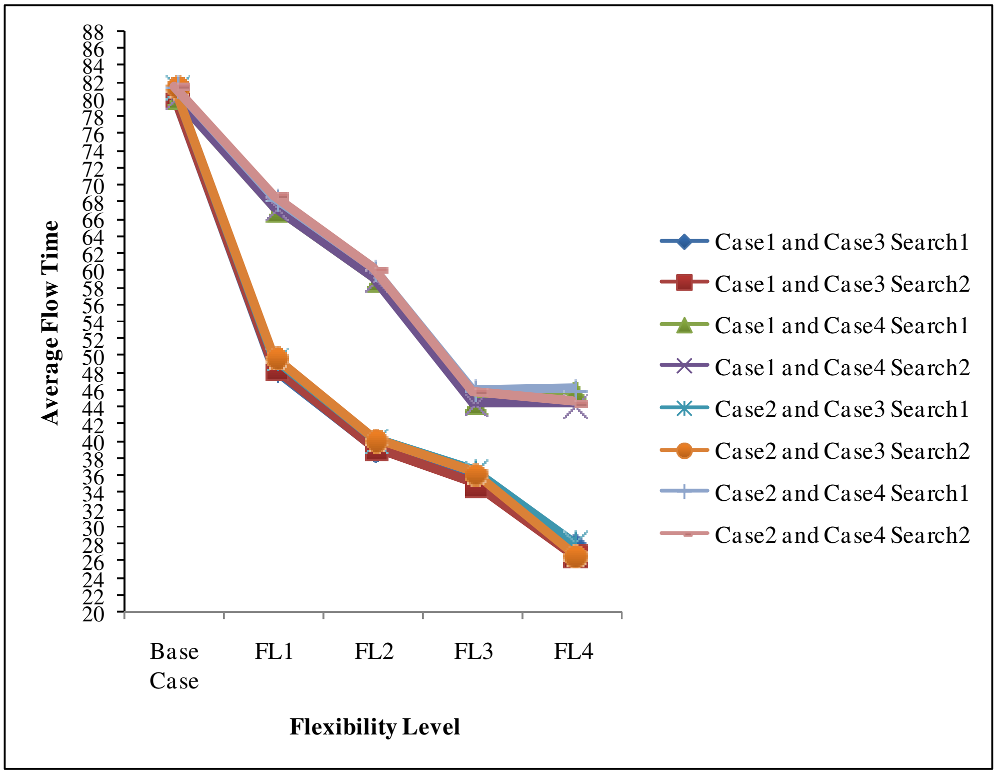

Figure 5.2 The average flow times for 90% shop utilization for scenario 1

Scenario 2

The details about scenario 2 can be found in Chapter 4. As it can be seen from Table 5.2, similar to scenario 1, for 70% shop utilization level FL4 gives the minimum AFT value and FL2 follows it. Like 70% shop utilization level; FL4 is the best configuration in 90% shop utilization without any exception.

In addition, it can be easily seen from Table 5.1 and Table 5.2, AFT value does not change for FL4 for both of the shop utilization levels. In scenario 1 and 2, jobs do not need to leave their machines until they have completed their all operations, since machines can only capture the operations minimum system arrival time/machine arrival time where it is impossible to have an early comer in the queue.

However in the other levels of flexibility (FL1-FL2-FL3), all operations of a job may not be completed in the same machine and there may be some machine switches. Thereby; the order of operations with respect to machine arrival times are not the same with the order of the jobs with respect to the system arrival times.

Consequently, an early comer to the system looses it advantage and may have longer average flow times when compared to Scenario1.

Table 5.2 The average flow times for scenario 2

		Case1 and Case3		Case1 and Case4		Case2 and Case3		Case2 and Case4	
		Search1	Search2	Search1	Search2	Search1	Search2	Search1	Search2
70%	Base Case	28.341	28.341	28.341	28.341	29.330	29.330	29.330	29.330
	FL1	21.195	20.997	22.517	22.309	22.335	22.139	23.664	23.437
	FL2	19.090	18.587	20.589	20.001	20.067	19.506	21.582	20.941
	FL3	19.872	19.466	20.970	20.528	20.981	20.596	22.086	21.661
	FL4	16.094	15.405	17.690	16.475	16.268	15.575	17.458	16.644
90%	Base Case	85.976	85.976	85.976	85.976	86.904	86.904	86.904	86.904
	FL1	55.339	55.068	78.190	77.773	56.679	56.305	79.380	79.035
	FL2	44.801	43.599	70.812	68.147	46.038	44.659	71.955	69.194
	FL3	40.589	39.857	53.234	52.588	41.758	41.022	54.443	53.804
	FL4	28.149	26.769	46.029	44.496	28.314	26.934	46.194	44.660

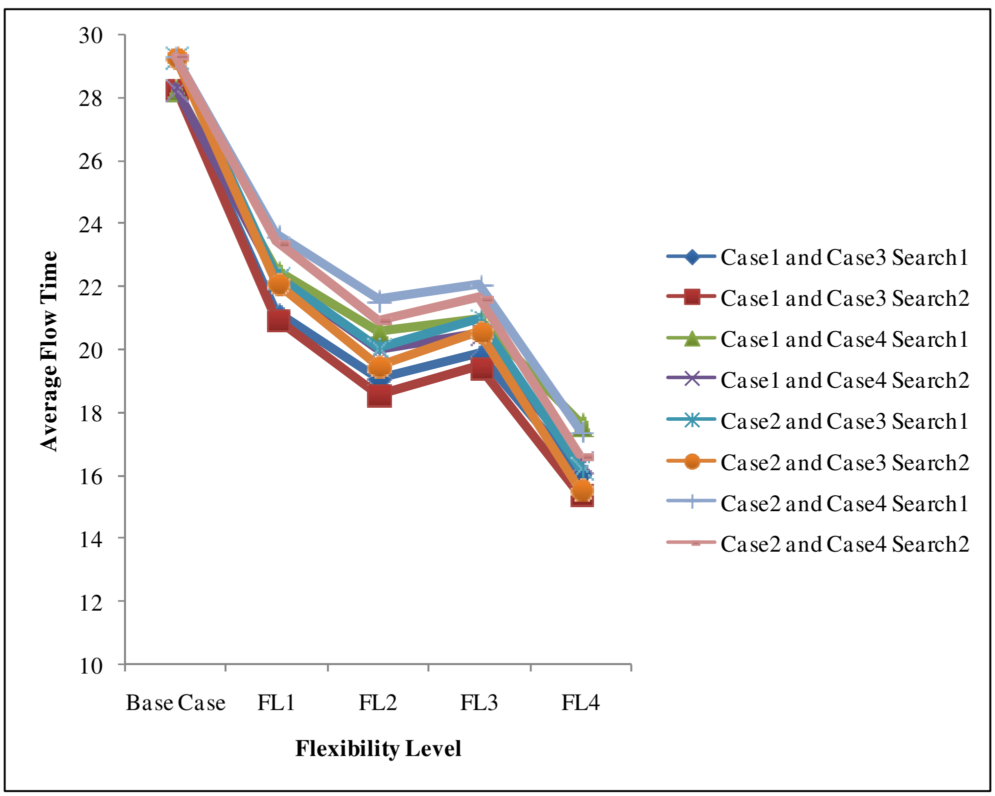

Figure 5.3 The average flow times for 70% shop utilization for scenario 2

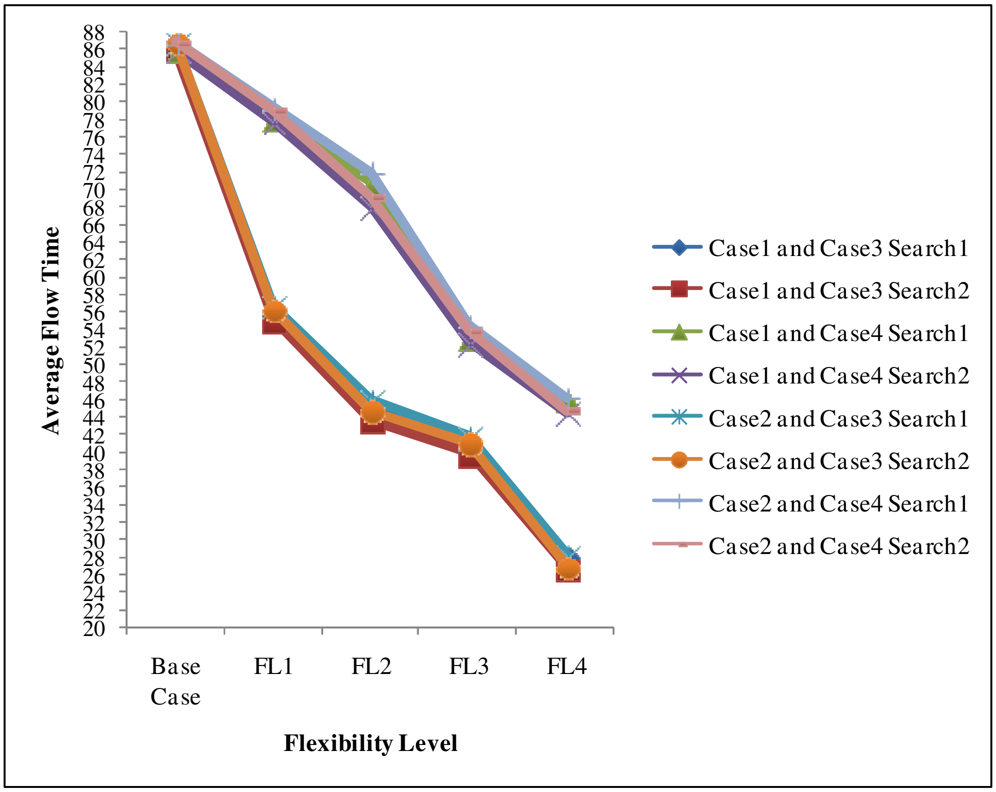

Figure 5.4 The average flow times for 90% shop utilization for scenario 2

Scenario 3

The details about scenario 3 can be found in Chapter 4. As it can be seen from Table 5.5 and Figure 5.6; similar to scenario 1 and scenario 2, FL4 is the best under each case and each search rule for 70% shop utilization. In addition, FL2 is the second best.

However the average flow time for 90% shop utilization level**,** situation, is a bit complex. In this scenario, dispatching rule is MAPT and therefore, an early comer has no advantage unless it has operations with smaller processing time. As a consequence, a job processed in a certain machine, does not guarantee to process its next operation on the same machine. Moreover, a job having an operation with high processing time (like any job having operation type 6 for the experiment defined in this thesis), is always waited at the end of queues. This state is not repeated for 70% shop utilization level, since the system is not crowded as in the 90% and average queues lengths are relatively small. Therefore, system with 70% shop utilization level overcomes most of the handicaps arising from the dispatching rule, “MAPT”. Because of the reasons, all explained above, the system behavior is not as expected. Generalizing the results would be nonsense since there is high spread among the replications. The deviations from the expectations can be explained with the inconsistency between the search mechanism and the dispatching rule. Search mechanisms let the operations to select the machines/machine queues with smaller number of jobs (Search 1)/operations (Search 2) waiting. However, machines seize the jobs having the operation with minimum processing time. The jobs loads are not distributed in balance and system lose its stability. This problematic state is widely appears in full flexibility, because the different operation may be on the same queue. However; as the level of flexibility decreases, probability of similar operations to stay on the same queue increases.

Table 5.3 The average flow times for scenario 3

		Case1 and Case3		**Case1 and Case4**		**Case2 and Case3**		**Case2 and Case4**	
		Search1	**Search2**	**Search1**	**Search2**	**Search1**	**Search2**	**Search1**	**Search2**
70%	**Base Case**	27.576	27.576	27.576	27.576	28.593	28.593	28.593	28.593
	FL1	20.626	20.611	21.930	21.696	21.734	21.806	23.049	23.018
	FL2	18.717	18.652	20.204	20.221	19.647	19.571	21.154	21.046
	FL3	19.356	19.146	20.386	20.205	20.467	20.256	21.483	21.288
	FL4	16.530	16.472	17.959	17.244	16.759	16.659	18.210	17.430
90%	**Base Case**	80.511	80.511	80.511	80.511	81.607	81.607	81.607	81.607
	FL1	50.761	50.766	71.810	73.069	51.940	53.640	73.311	74.231
	FL2	43.631	43.971	68.737	68.751	44.692	44.781	69.647	69.707
	FL3	36.765	36.489	47.781	48.111	37.928	37.727	49.024	49.296
	FL4	38.602	32.933	75.685	60.758	38.869	40.744	75.776	60.815

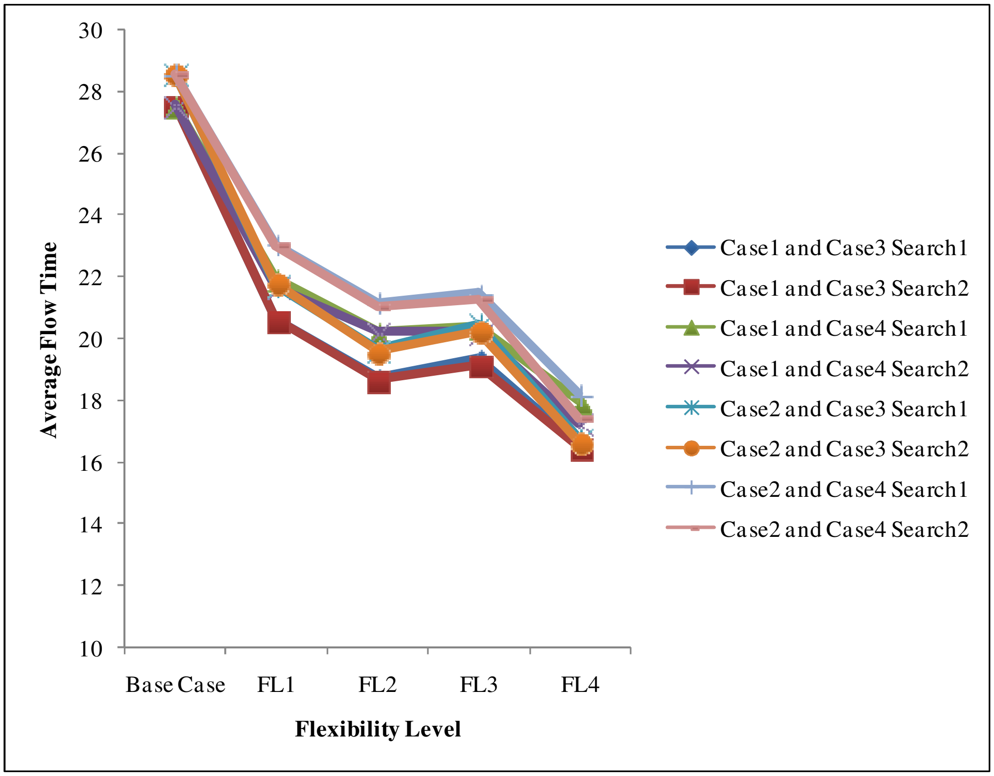

Figure 5.5 The average flow times for 70% shop utilization for scenario 3

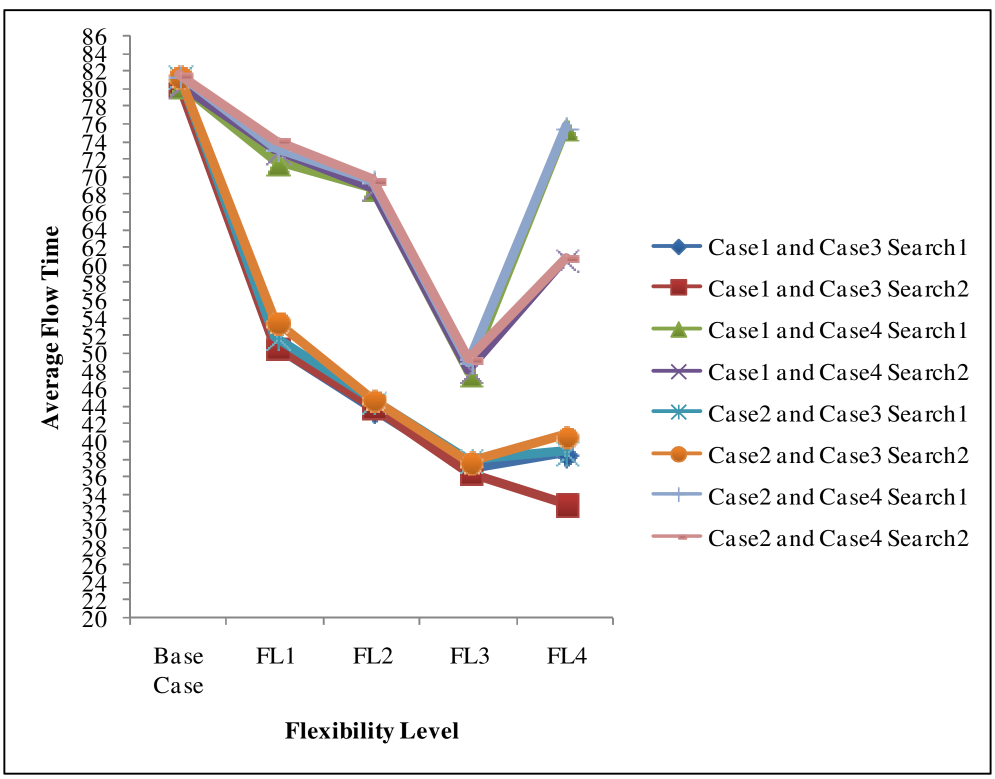

Figure 5.6 The average flow times for 90% shop utilization for scenario 3

Scenario 4

The details about scenario 6 can be found in Chapter 4. As it can be seen from Table 5.6, similar to above investigated scenarios, FL4 is the best under each case and each search rule for 70% shop utilization. In addition, FL2 is the second best. It should be noticed that, however, in FL2 level, each machine is capable of performing three different operations, whereas in FL3 each machine is capable of performing two different operations; they have approximately same AFT values. This state indicates that, chain configuration (FL3) is capable of performing at least as the FL2 does for 70% shop utilization level.

Although this scenario uses the same dispatching rule as scenario 3, the dilemma is removed for 90% shop utilization and therefore FL4 is always the best. In this scenario, it is not allowed for jobs to leave the machine unless they have an operation which cannot be performed at the current machine except FL4. This state creates advantages for FL4 when compared to scenario 3. All of the operations of jobs waiting on the queue will be performed at the same machine and it is reasonable for them to wait. However, in FL1 level, all of the consecutive operations of a job cannot be completed at the same machine (please check Table 4.1) and thereby jobs will naturally change their machines. For that reason, many operations of the jobs waiting at queue unreasonably (remember the assumption that a job's operations cannot be distributed to different machines at the same time). This leads increase in AFT for FL1 with 90% shop utilization in this scenario. As the number of consecutive operations of a job which can be performed by the same machine increases, the difference of AFT values of scenario 3 and scenario 4 gets smaller. In this scenario, chained configuration is always the second best.

Table 5.4 The average flow times for scenario 4

		Case1 and Case3		Case1 and Case4		Case2 and Case3		Case2 and Case4	
		Search1	Search2	Search1	Search2	Search1	Search2	Search1	Search2
70%	**Base Case**	27.576	27.576	27.576	27.576	28.593	28.593	28.593	28.593
	FL1	20.933	20.789	22.265	22.127	22.048	21.906	23.408	23.251
	FL2	18.967	18.548	20.441	20.034	19.928	19.437	21.348	20.926
	FL3	19.618	19.234	20.725	20.333	20.718	20.350	21.399	21.437
	FL4	16.097	15.410	17.288	16.485	16.267	15.580	17.457	16.654
90%	**Base Case**	80.511	80.511	80.511	80.511	81.607	81.607	81.607	81.607
	FL1	52.641	52.593	74.807	74.708	53.881	53.896	76.079	76.012
	FL2	43.033	43.061	67.985	68.605	44.256	44.028	69.021	69.301
	FL3	37.421	36.869	49.295	48.777	38.583	38.088	50.501	50.015
	FL4	28.176	26.901	46.221	44.787	28.340	27.045	46.385	44.949

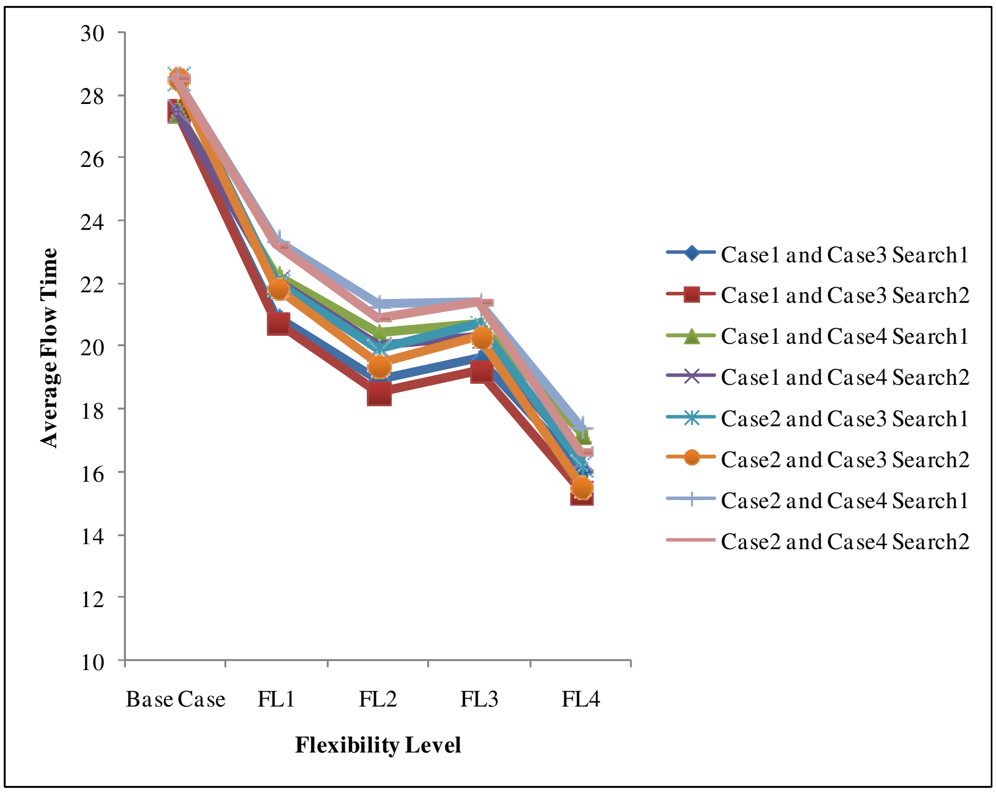

Figure 5.7 The average flow times for 70% shop utilization for scenario 4

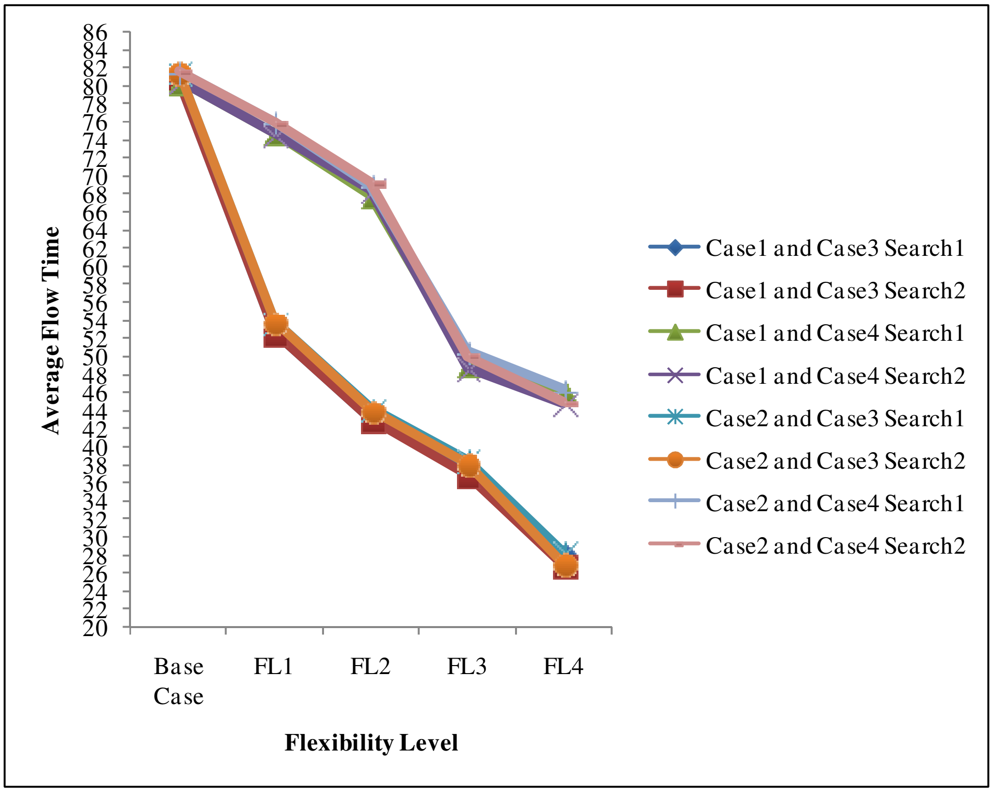

Figure 5.8 The average flow times for 90% shop utilization for scenario 4

Scenario 5

The details about scenario 5 can be found in Chapter 4. Remember that scenario 5 is same with the scenario 1, however; scenario 5 allows for jockeying. Therefore, all commends for scenario 1 is valid for scenario 5. Allowance of jockeying has created some improvements for AFT. AFT values decreases or remained same for all of the states. Amount of the improvement becomes apparent for FL4. Since all operations can be performed by all of the machines, a job waiting at queue can be routed to another machine with a higher probability for both shop utilization level.

Another advance with jockeying is the reduction differences of AFT values obtained for search1 and search2 rules. In scenario 5, the differences of AFT values for search 1 and search 2 gets smaller relative to scenario 1. This state can be explained with the precision of search rules. Search 1 rule, is structured on the jobs waiting at the queue and search 2 is based on the total operations waiting at the queue. Inherently, search 1 rule is less precise for determining the job loads of machines. Therefore, in scenario 1, differences of AFT values are relatively large. However, scenario 5 allows jockeying and the jobs can switch their queues and as a consequence, the precision handicap for search 1 is released.

Table 5.5 The average flow times for scenario 5

		Case1 and Case3		Case1 and Case4		Case2 and Case3		Case2 and Case4	
		Search1	Search2	Search1	Search2	Search1	Search2	Search1	Search2
70%	Base Case	27.576	27.576	27.576	27.576	28.593	28.593	28.593	28.593
	FL1	20.314	20.401	21.479	21.589	21.255	21.300	22.432	22.494
	FL2	18.131	18.302	19.432	19.633	18.873	18.951	20.174	20.264
	FL3	19.014	18.989	20.000	19.972	19.967	19.934	20.946	20.891
	FL4	15.401	15.401	16.472	16.470	15.623	15.573	16.702	16.642
90%	Base Case	80.511	80.511	80.511	80.511	81.607	81.607	81.607	81.607
	FL1	48.490	48.697	67.227	67.395	49.464	49.716	68.357	68.411
	FL2	38.816	39.373	58.634	59.344	39.710	40.130	59.350	60.049
	FL3	34.638	34.576	43.780	43.866	35.758	35.651	44.983	45.004
	FL4	26.754	26.758	44.448	44.456	27.073	26.928	44.770	44.633

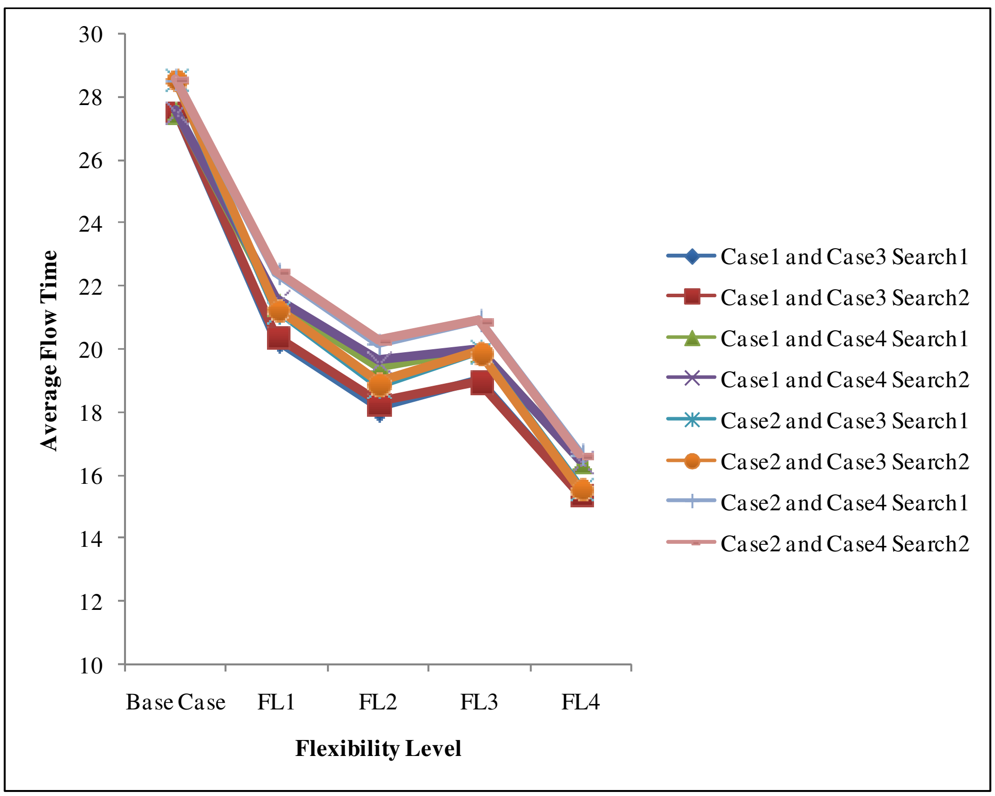

Figure 5.9 The average flow times for 70% shop utilization for scenario 5

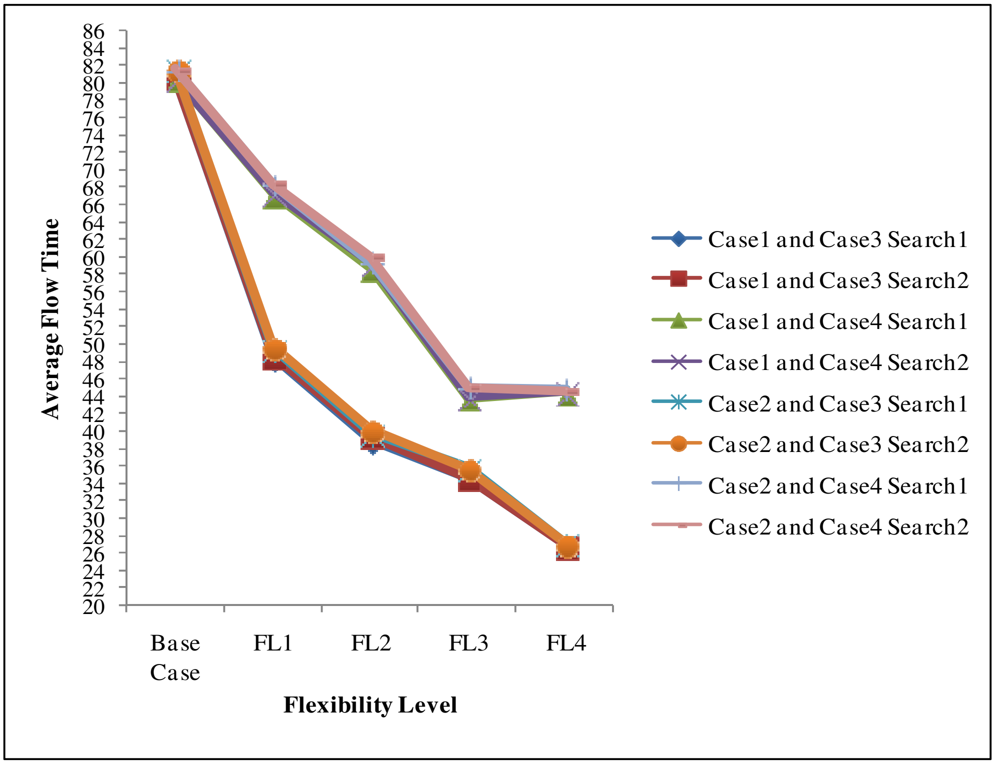

Figure 5.10 The average flow times for 90% shop utilization for scenario 5

Scenario 6

The details about scenario 6 can be found in Chapter 4. Remember that scenario 6 is same with the scenario 2, however; scenario 6 allows for jockeying. Therefore, all commends for scenario 2 is valid for scenario 6. The two improvements obtained with jockeying for scenario 5, does the same effect.

Table 5.6 The average flow times for scenario 6

		Case1 and Case3		Case1 and Case4		Case2 and Case3		Case2 and Case4	
		Search1	**Search2**	**Search1**	**Search2**	**Search1**	**Search2**	**Search1**	**Search2**
70%	**Base Case**	28.341	28.341	28.341	28.341	29.330	29.330	29.330	29.330
	FL1	20.996	20.993	22.305	22.308	21.955	21.910	23.272	23.223
	FL2	18.576	18.583	19.994	19.997	19.351	19.254	20.774	20.670
	FL3	19.453	19.428	20.521	20.496	20.373	20.332	21.437	21.386
	FL4	15.400	15.401	16.472	16.470	15.619	15.573	16.698	16.642
90%	**Base Case**	85.976	85.976	85.976	85.976	86.904	86.904	86.904	86.904
	FL1	55.096	55.044	78.111	77.722	56.137	56.061	78.978	79.073
	FL2	43.594	43.591	68.099	68.056	44.563	44.349	69.095	68.870
	FL3	39.724	39.719	52.395	52.471	40.769	40.646	53.363	53.380
	FL4	26.757	26.758	44.457	44.456	27.070	26.928	44.750	44.632

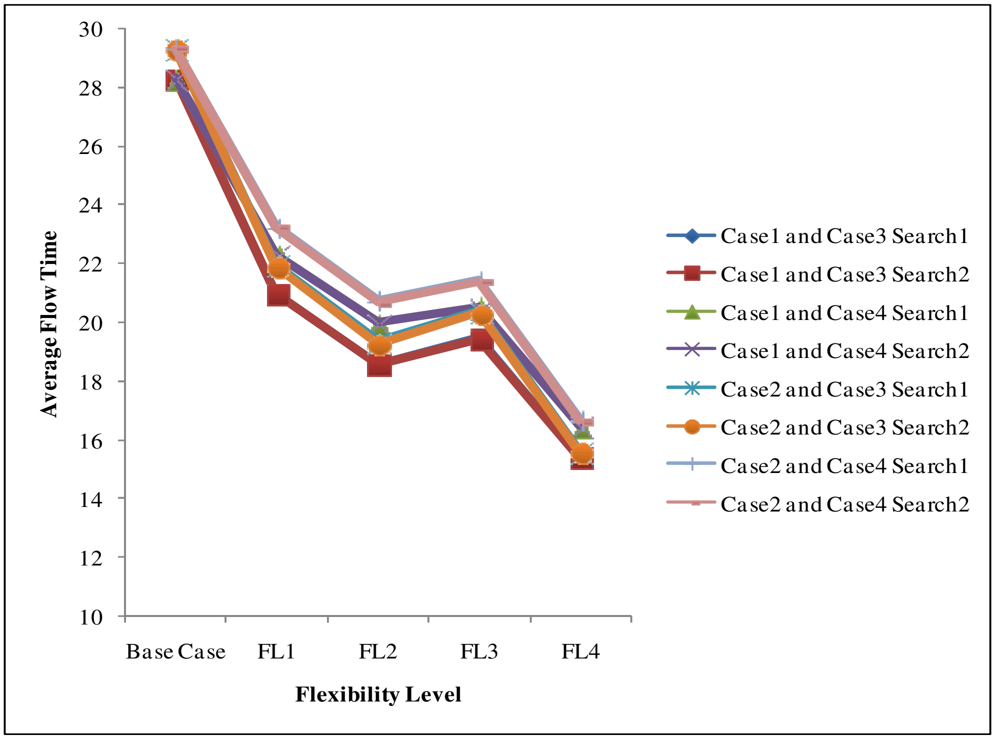

Figure 5.11 The average flow times for 70% shop utilization for scenario 6

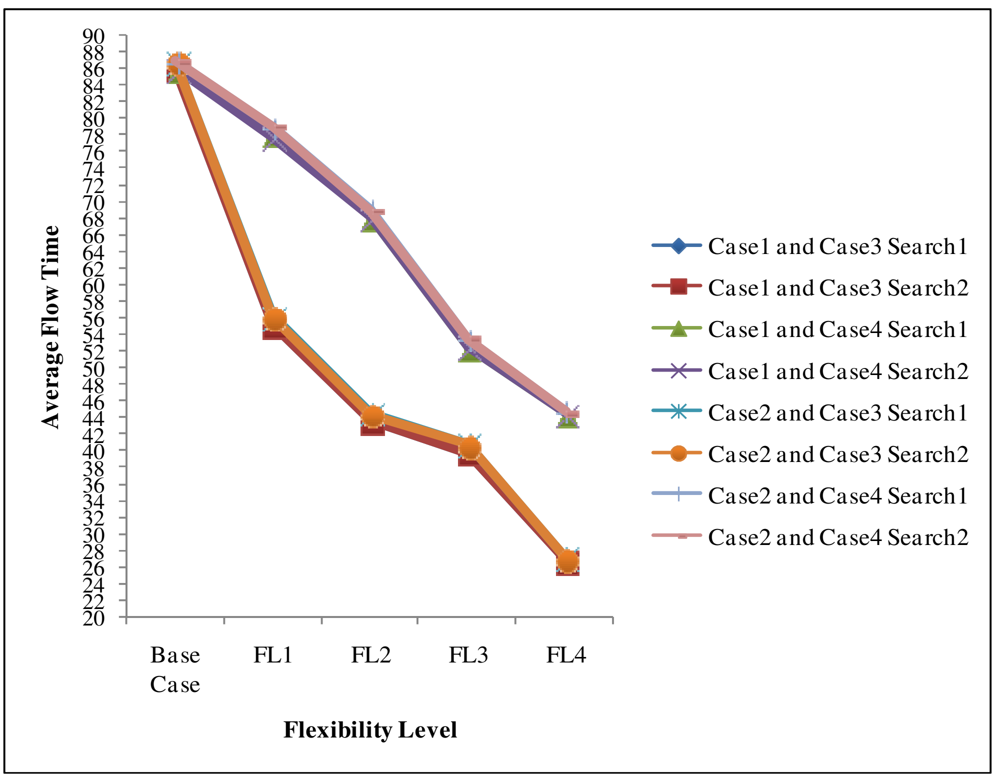

Figure 5.12 The average flow times for 90% shop utilization for scenario 6

Scenario 7

The details about scenario 7 can be found in Chapter 4. Remember that scenario 7 is same with the scenario 3, however; scenario 7 allows for jockeying. As it was highlighted in scenario 3, the deviations from the expectations were explained with the inconsistency between the search mechanism and the dispatching rule. Allowance for jockeying in this scenario has also created improvements for 70% shop utilization level. However, the improvements for 90% shop utilization level are not consistent. Remember that, the deviations of AFT values among the replications mentioned in scenario 3 were causing instabilities. Therefore, it is not a surprise that the improvements obtained with jockeying are consistent.

Table 5.7 The average flow times for scenario 7

		Case1 and Case3		**Case1 and Case4**		**Case2 and Case3**		**Case2 and Case4**	
		Search1	**Search2**	**Search1**	**Search2**	**Search1**	**Search2**	**Search1**	**Search2**
70%	**Base Case**	27.576	27.576	27.576	27.576	28.593	28.593	28.593	28.593
	FL1	20.536	20.605	21.845	21.929	21.469	21.496	22.781	22.830
	FL2	18.473	18.646	19.940	20.182	19.195	19.273	20.666	20.839
	FL3	19.056	19.042	20.077	20.067	20.003	19.971	20.987	20.976
	FL4	15.924	16.407	17.276	17.220	16.158	16.591	17.527	18.139
90%	**Base Case**	80.511	80.511	80.511	80.511	81.607	81.607	81.607	81.607
	FL1	50.538	50.752	71.990	73.067	52.953	51.603	72.991	73.904
	FL2	43.179	43.836	68.123	69.613	44.881	44.511	68.996	69.665
	FL3	36.825	35.983	46.881	47.396	37.880	36.988	47.971	48.418
	FL4	36.967	32.914	73.621	79.021	37.585	40.599	73.905	79.111

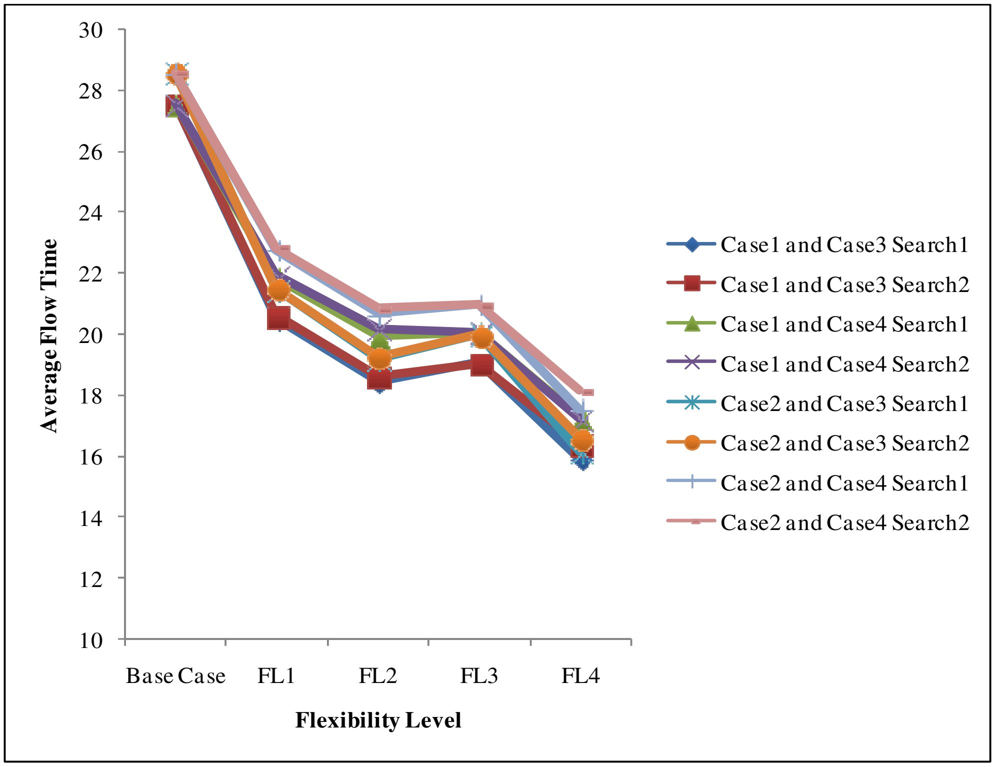

Figure 5.13 The average flow times for 70% shop utilization for scenario 7

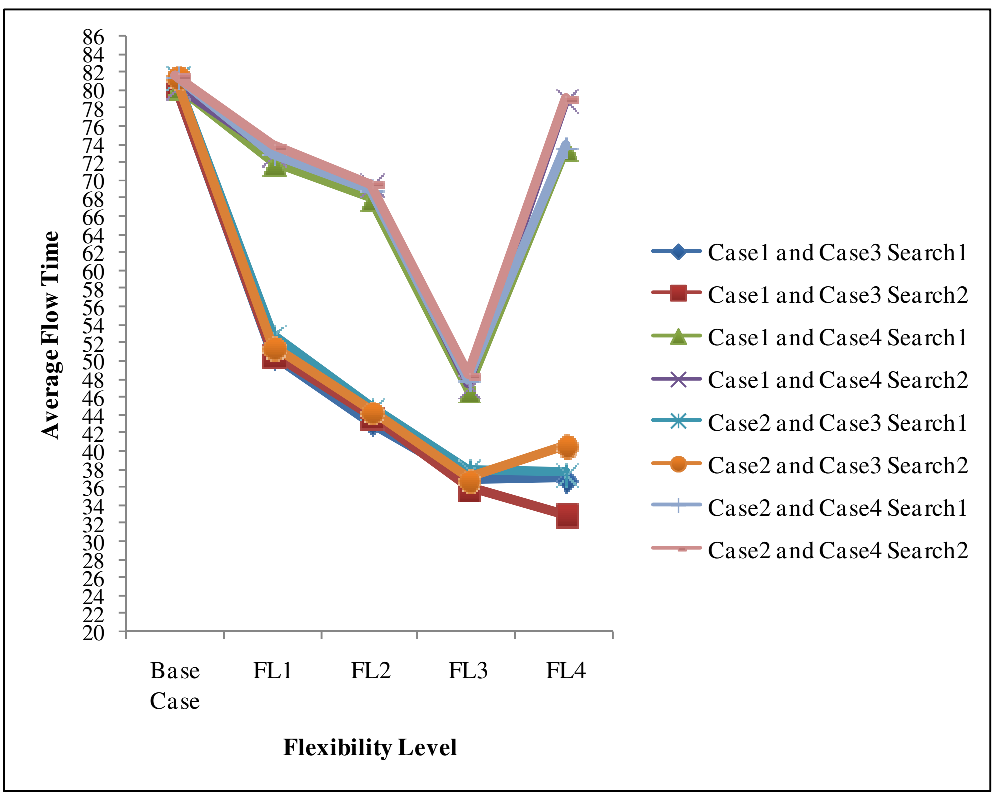

Figure 5.14 The average flow times for 90% shop utilization for scenario 7

Scenario 8

The details about scenario 8 can be found in Chapter 4. Remember that scenario 8 is same with the scenario 4, however; scenario 4 allows for jockeying. Therefore, all commends for scenario 4 is valid for scenario 8. The two improvements obtained with jockeying for scenario 5 and scenario 6, do the same effect. Remember the similarity between scenario 3 and scenario 4. Therefore, there is also similarity between scenario 7 and scenario 8. However, as indicated in scenario 4, all mentioned problems for scenario 7 are released since it is not allowed for jobs to leave the machine. For more details, it is suggested for readers to go "analysis section" for scenario 4.

Table 5.8 The average flow times for scenario 8

		Case1 and Case3		Case1 and Case4		Case2 and Case3		Case2 and Case4	
		Search1	Search2	Search1	Search2	Search1	Search2	Search1	Search2
70%	**Base Case**	27.576	27.576	27.576	27.576	28.593	28.593	28.593	28.593
	FL1	20.732	20.773	22.063	22.108	21.679	21.679	23.010	23.009
	FL2	18.403	18.529	19.826	19.957	19.160	19.161	20.576	20.649
	FL3	19.154	19.109	20.200	20.161	20.097	20.040	21.132	21.061
	FL4	15.400	15.406	16.470	16.479	15.619	15.578	16.698	16.651
90%	**Base Case**	80.511	80.511	80.511	80.511	81.607	81.607	81.607	81.607
	FL1	52.468	52.493	74.583	75.020	53.338	53.505	75.855	75.720
	FL2	42.257	43.029	67.030	68.594	43.149	43.722	67.679	69.148
	FL3	36.268	36.253	48.254	47.925	37.314	37.254	48.996	48.952
	FL4	26.791	26.865	44.618	44.766	27.096	27.042	44.951	44.925

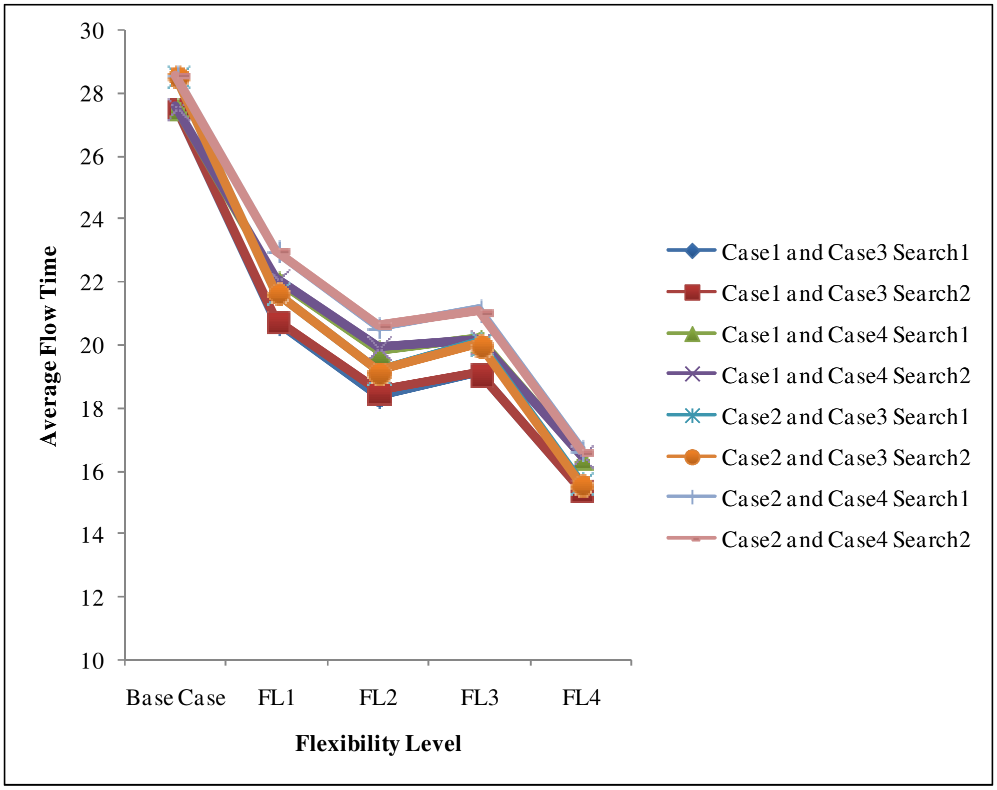

Figure 5.15 The average flow times for 70% shop utilization for scenario 8

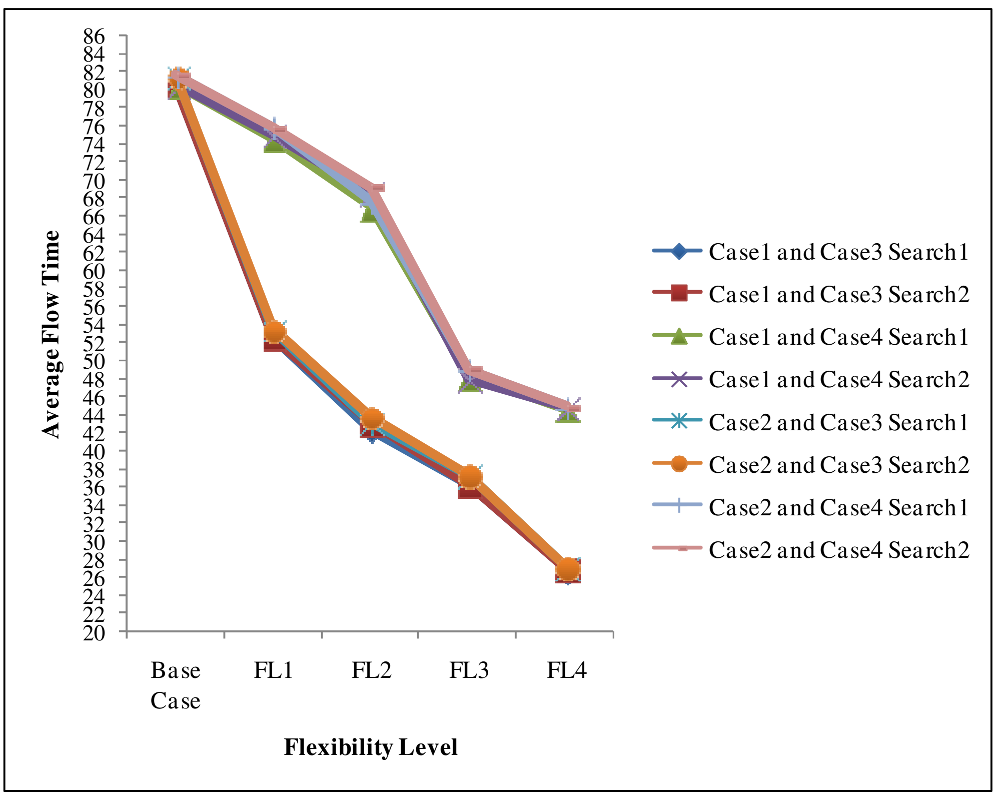

Figure 5.16 The average flow times for 90% shop utilization for scenario 8

Scenario 9

The details about scenario 9 can be found in Chapter 4. Scenario 9 is a different version of scenario 5 and thereby scenario 1. Scenario 9 also includes jockeying however, conditions required for jockeying is a bit different. In this scenario, a job does not leave its queue if there is an already routed job to the candidate idle machine. Therefore, this system is proactive about the state of the idle machine. Therefore, results are consistently better or equal to the results given in scenario 5. As it can be seen from Table 5.9, AFT values are better but they do not create significant improvements.

Table 5.9 The average flow times for scenario 9

		Case2 and Case3		Case2 and Case4	
		Search1	**Search2**	**Search1**	**Search2**
70%	**Base Case**	28.593	28.593	28.593	28.593
	FL1	21.246	21.301	22.425	22.486
	FL2	18.861	18.942	20.165	20.259
	FL3	19.959	19.924	20.939	20.883
	FL4	15.618	15.573	16.698	16.642
90%	**Base Case**	81.607	81.607	81.607	81.607
	FL1	49.398	49.645	68.321	68.347
	FL2	39.659	40.062	59.515	59.978
	FL3	35.732	35.650	44.984	44.993
	FL4	27.054	26.928	44.713	44.634

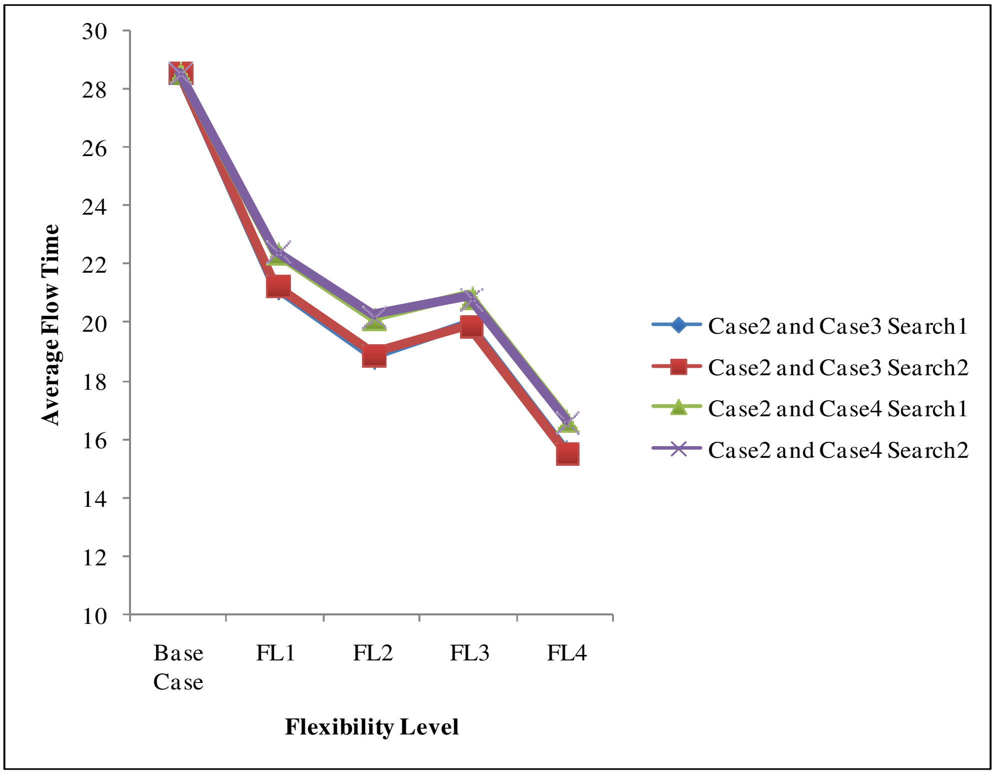

Figure 5.17 The average flow times for 70% shop utilization for scenario 9

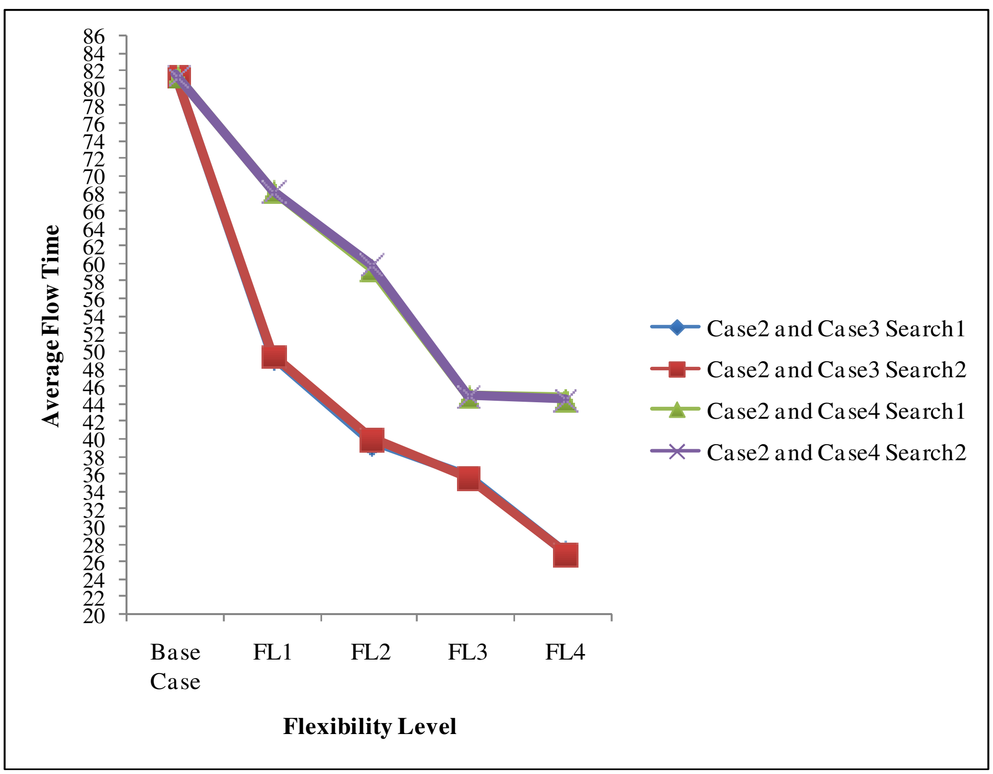

Figure 5.18 The average flow times for 90% shop utilization for scenario 9

Scenario 10

The details about scenario 10 can be found in Chapter 4. Scenario 10 is a different version of scenario 6 and thereby scenario 2. Scenario 10 also includes jockeying however, conditions required for jockeying is different as mentioned in scenario 9. In this scenario, AFT values are consistently better or equal to the results given in scenario 6. As it can be seen from Table 5.10, AFT values are better but they do not create significant improvements.

Table 5.10 The average flow times for scenario 10

		Case2 and Case3		**Case2 and Case4**	
		Search1	**Search2**	**Search1**	**Search2**
70%	**Base Case**	29.330	29.330	29.330	29.330
	FL1	21.945	21.908	23.258	23.219
	FL2	19.337	19.247	20.758	20.666
	FL3	20.371	20.320	21.428	21.374
	FL4	15.615	15.573	16.690	16.642
90%	**Base Case**	86.904	86.904	86.904	86.904
	FL1	56.118	56.056	78.812	78.938
	FL2	44.539	44.354	69.039	68.771
	FL3	40.768	40.649	53.382	53.341
	FL4	27.055	26.928	44.746	44.632

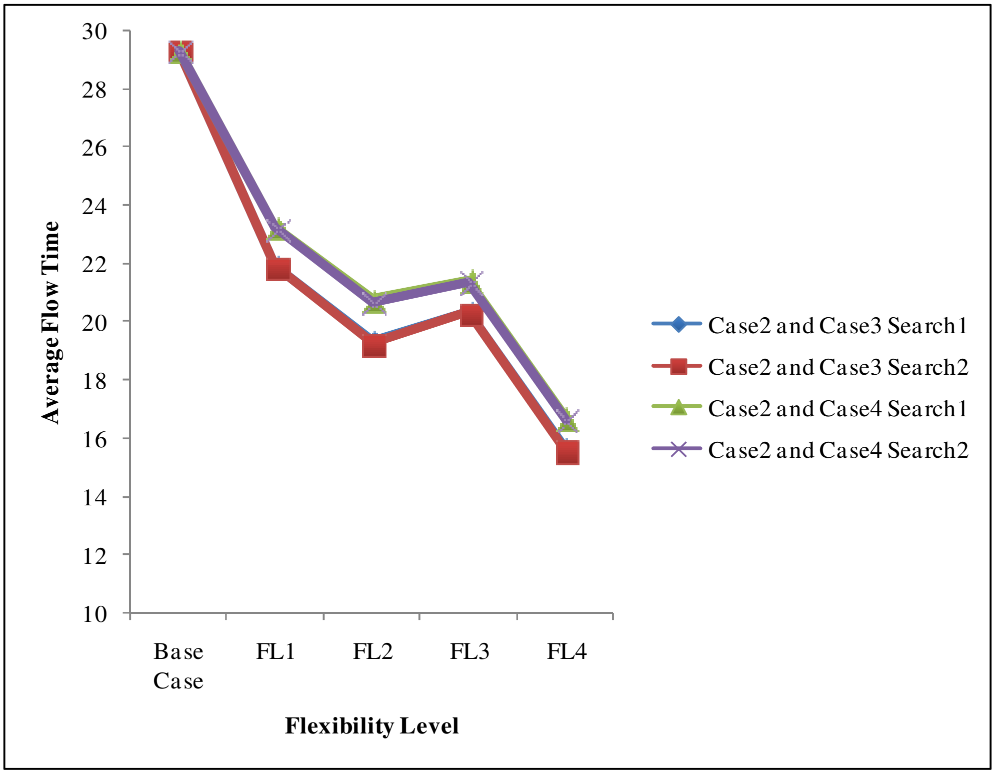

Figure 5.19 The average flow times for 70% shop utilization for scenario 10

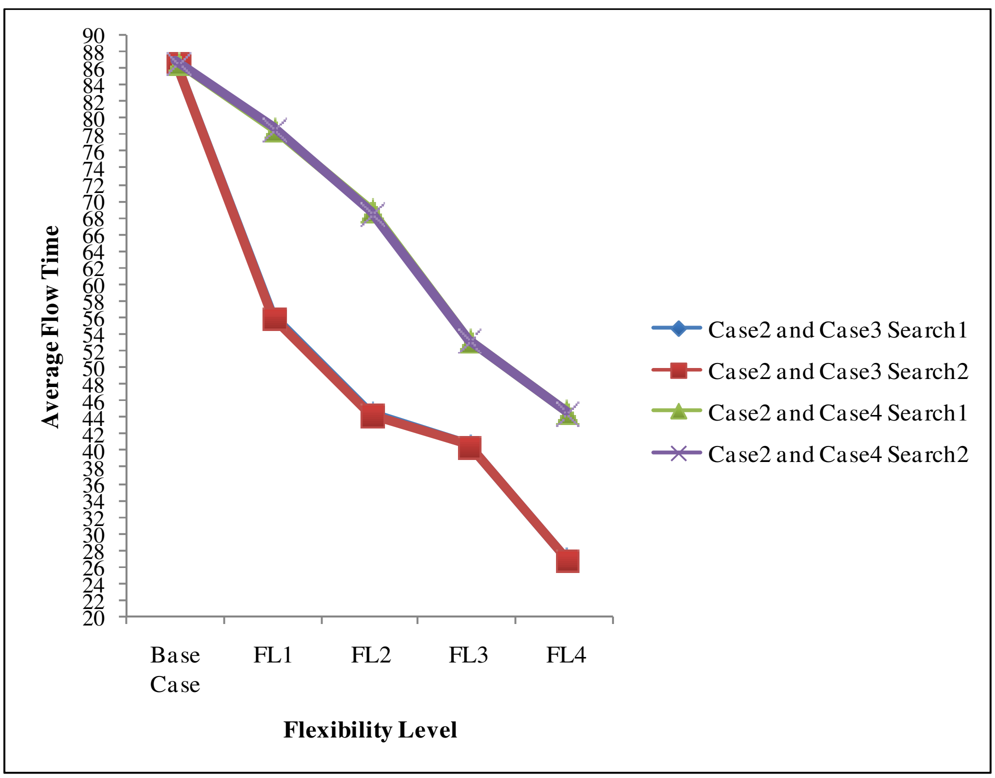

Figure 5.20 The average flow times for 90% shop utilization for scenario 10

Scenario 11

The details about scenario 11 can be found in Chapter 4. Scenario 11 is a different version of scenario 7 and thereby scenario 3. Scenario 11 also includes jockeying however, conditions required for jockeying is different as indicated in scenario 9, and scenario 10. As indicated in scenario 3 and scenario 7, this scenario includes instable system especially for 90% shop utilization and case 4. Therefore, results given in Table 5.11 shows that the AFT values increases in an insignificant amount.

Table 5.11 The average flow times for scenario 11

		Case2 and Case3		**Case2 and Case4**	
		Search1	**Search2**	**Search1**	**Search2**
70%	**Base Case**	28.593	28.593	28.593	28.593
	FL1	21.463	21.489	22.764	22.824
	FL2	19.277	19.268	20.663	20.835
	FL3	19.992	20.023	20.988	20.966
	FL4	16.158	16.591	17.526	17.407
90%	**Base Case**	81.607	81.607	81.607	81.607
	FL1	51.567	51.767	72.980	73.923
	FL2	43.965	44.514	69.214	70.013
	FL3	36.994	46.284	47.959	48.467
	FL4	37.310	40.615	73.984	79.127

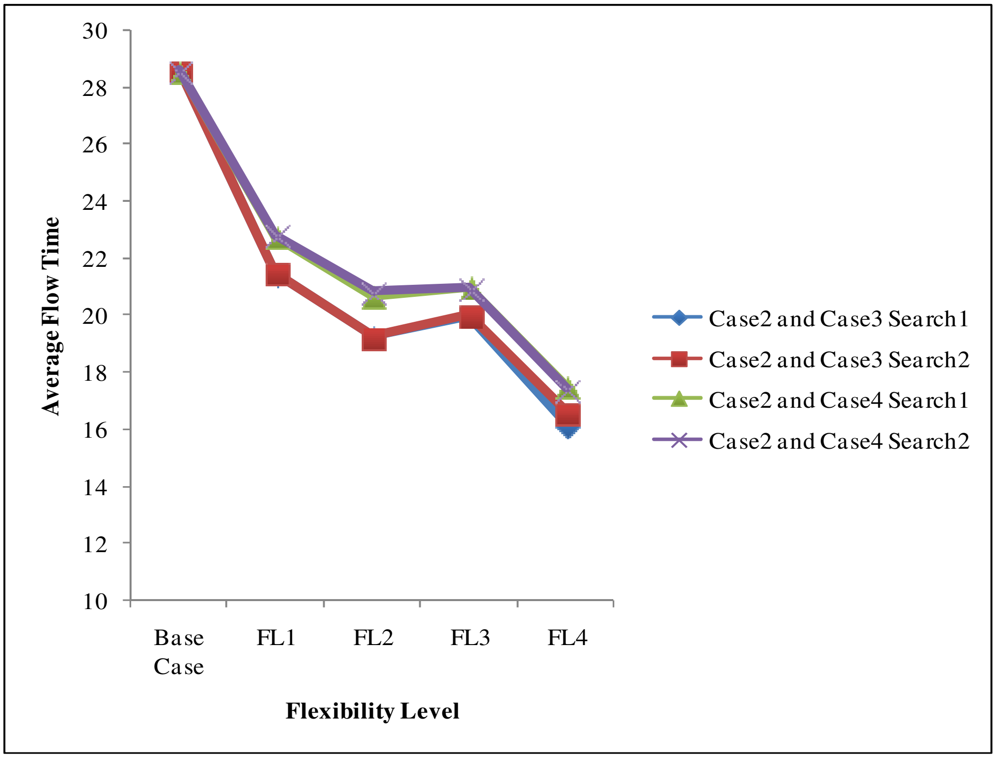

Figure 5.21 The average flow times for 70% shop utilization for scenario 11

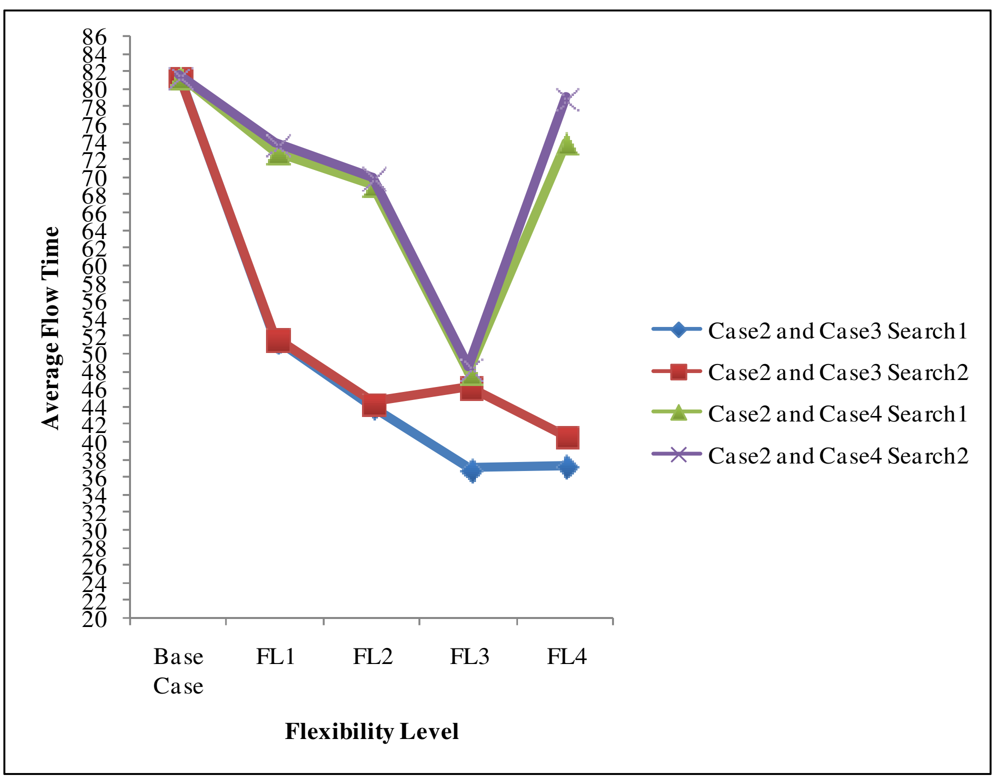

Figure 5.22 The average flow times for 90% shop utilization for scenario 11

Scenario 12

The details about scenario 12 can be found in Chapter 4. Scenario 12 is a different version of scenario 8 and thereby scenario 4. Scenario 12 also includes jockeying however, conditions required for jockeying is different as mentioned in scenario 11. In this scenario, AFT values are consistently better or equal to the results given in scenario 8. As it can be seen from Table 5.10, AFT values are better but they do not create significant improvements.

Table 5.12 The average flow times for scenario 12

		Case2 and Case3		Case2 and Case4	
		Search1	**Search2**	**Search1**	**Search2**
70%	**Base Case**	28.593	28.593	28.593	28.593
	FL1	21.678	21.664	22.999	23.012
	FL2	19.149	19.158	20.562	20.641
	FL3	20.088	20.033	21.115	21.061
	FL4	15.614	15.578	16.695	16.651
90%	**Base Case**	81.607	81.607	81.607	81.607
	FL1	53.446	53.493	75.684	75.622
	FL2	43.068	43.646	67.793	69.153
	FL3	37.332	37.229	48.965	48.938
	FL4	27.079	27.041	44.928	44.929

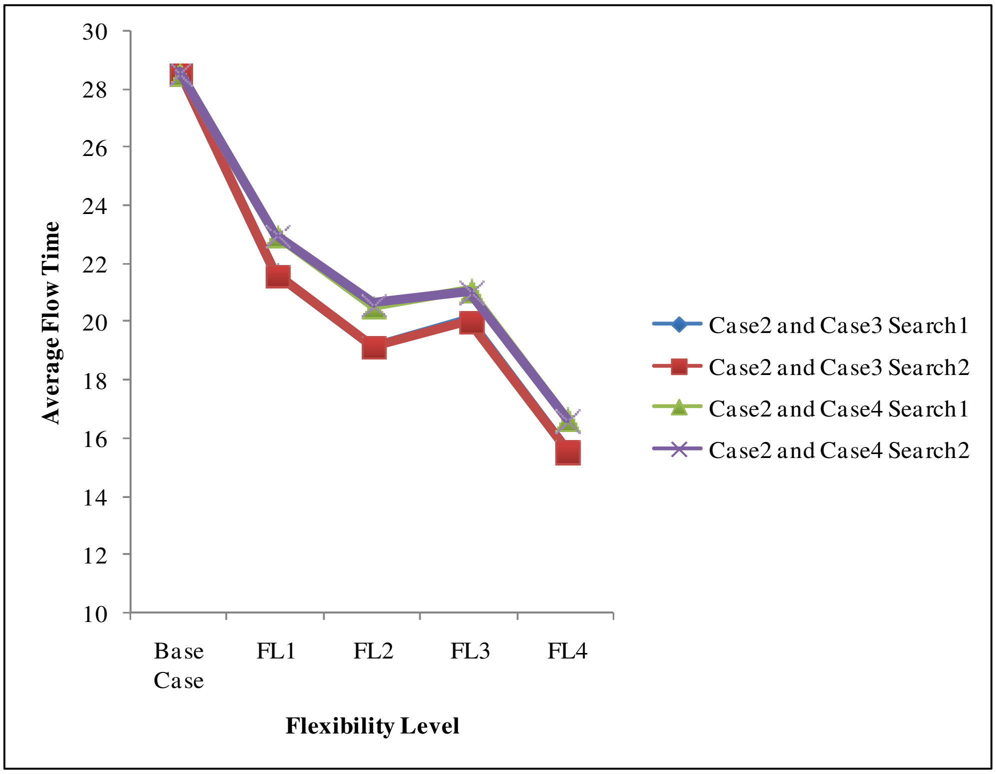

Figure 5.23 The average flow times for 70% shop utilization for scenario 12

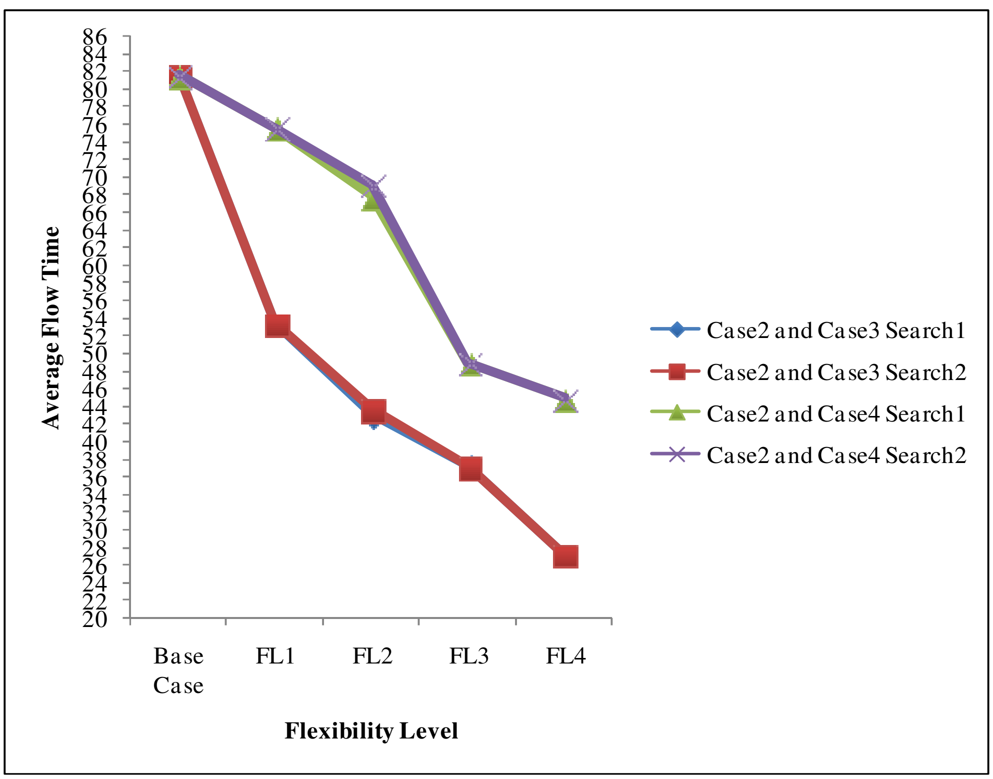

Figure 5.24 The average flow times for 70% shop utilization for scenario 12

Table 5.13 presents the minimum and maximum values of AFT for all combinations of cases. Results presented in Table 5.13 indicates that minimum values are obtained for scenario 5, scenario 9 where jockeying is employed along with FSFS dispatching rule. However, the minimum values for FL4 is same for more than one scenario. The benefits obtained with jockeying can obviously seen from these results.

Table 5.13Min-max of AFT values obtained for combination of cases

Cases	Shop Load		AFT for FL1	Scenarios (Search Rule)	AFT for FL2	Scenarios (Search Rule)	AFT for FL3	Scenarios (Search Rule)	AFT for FL4	Scenarios (Search Rule)
Case 1 & Case 3	70	Min	20.314	5(1)	18.131	5(1)	18.989	5(2)	15.400	6-8(1)
		Max	21.195	2(1)	19.090	2(1)	19.872	2(1)	16.530	3(1)
	90	Min	48.490	5(1)	38.816	5(1)	34.576	5(2)	26.754	5(1)
		Max	55.339	2(1)	44.801	2(1)	40.589	2(1)	38.602	3(1)
Case 1 & Case4	70	Min	21.479	5(1)	19.432	5(1)	19.972	5(1)	16.470	5-6(2)8-(1)
		Max	22.517	2(1)	20.589	2(1)	20.970	2(1)	17.959	3(1)
	90	Min	67.227	5(1)	59.169	5(1)	43.780	5(1)	44.448	5(1)
		Max	78.190	2(1)	70.812	2(1)	53.234	2(1)	79.021	7(1)
Case 2 & Case 3	70	Min	21.246	9(1)	18.861	9(1)	19.924	9(1)	15.573	5-6-9-10(2)
		Max	23.402	2(1)	20.067	2(1)	20.981	2(1)	16.759	3(1)
	90	Min	49.398	9(1)	39.659	9(2)	35.650	9(2)	26.928	5-6(2)
		Max	56.679	2(1)	46.038	2(1)	46.284	11(2)	40.744	3(2)
Case 2 & Case4	70	Min	22.425	9(1)	20.165	9(1)	20.883	9(1)	16.642	5-6-9(2)
		Max	23.664	2(1)	21.582	2(1)	22.086	2(1)	18.210	3(1)
	90	Min	68.321	9(1)	59.350	5(1)	44.983	9(1)	44.632	10(2)
		Max	79.380	2(1)	71.955	2(1)	54.443	2(1)	79.127	11(2)

5.3 Results via rank of Flexibility Levels

The ranks of the flexibility levels are analyzed in this part of the chapter. Flexibility levels are ranked in an ascending order of flow times since it is desired to have smaller flow times. Table 5.13 represents the ranks of flexibility levels for 70% shop utilization. Similarly, Table 5.14 represents the ranks of flexibility levels for 90% shop utilization.

Table 5.14 Ranks of flexibility levels for 70% shop utilization

	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case1 & Case3	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	-	-	-	-
Search1	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	-	-	-	-
	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	-	-	-	-
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	-	-	-	-
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	-	-	-	-
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case1 & Case3	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	-	-	-	-
Search2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	-	-	-	-
	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	-	-	-	-
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	-	-	-	-
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	-	-	-	-
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case1 & Case4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	-	-	-	-
Search1	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	-	-	-	-
	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	-	-	-	-
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	-	-	-	-
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	-	-	-	-
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case1 & Case4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	-	-	-	-
Search2	FL2	FL2	FL3	FL2	FL2	FL2	FL3	FL2	-	-	-	-
	FL3	FL3	FL2	FL3	FL3	FL3	FL2	FL3	-	-	-	-
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	-	-	-	-
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	-	-	-	-
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case2 & Case3	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4
Search1	FL2	FL2	FL2	FL2	FL3	FL2	FL2	FL2	FL2	FL2	FL2	FL2
	FL3	FL3	FL3	FL3	FL2	FL3	FL3	FL3	FL3	FL3	FL3	FL3
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case2 & Case3	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4
Search2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2
	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case2 & Case4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4
Search1	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2
	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case2 & Case4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4
Search2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2
	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C

There are 80 ranking for the %70 utilization as stated in Table 5.13. Two of these rankings are ordered as: FL4-FL3-FL2-FL1-Base Case. The remaining 78 of rankings are ordered as: FL4-FL2-FL3-FL1- Base Case. The percentage graph of these rankings is presented in Figure 5.25.

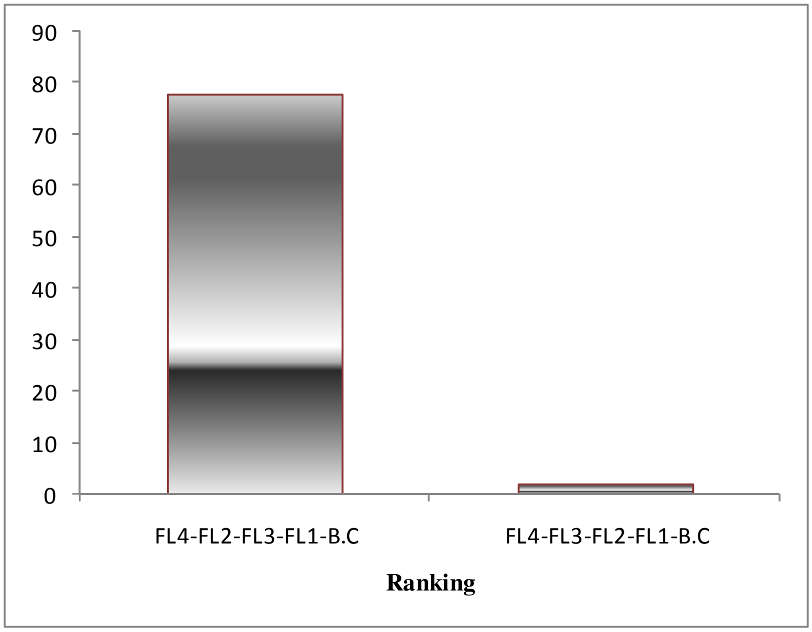

Figure 5.25 The percentage graph of flexibility rankings for 70% utilization.

Table 5.15 Ranks of flexibility levels for 90% shop utilization

	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case1 & Case3	FL4	FL4	FL3	FL4	FL4	FL4	FL3	FL4	-	-	-	-
Search1	FL3	FL3	FL4	FL3	FL3	FL3	FL4	FL3	-	-	-	-
	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	-	-	-	-
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	-	-	-	-
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	-	-	-	-
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case1 & Case3	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL4	-	-	-	-
Search2	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL3	-	-	-	-
	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	-	-	-	-
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	-	-	-	-
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	-	-	-	-
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case1 & Case4	FL3	FL4	FL3	FL4	FL3	FL4	FL3	FL4	-	-	-	-
Search1	FL4	FL3	FL2	FL3	FL4	FL3	FL2	FL3	-	-	-	-
	FL2	FL2	FL1	FL2	FL2	FL2	FL1	FL2	-	-	-	-
	FL1	FL1	FL4	FL1	FL1	FL1	FL4	FL1	-	-	-	-
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	-	-	-	-
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case1 & Case4	FL4	FL4	FL3	FL4	FL3	FL4	FL3	FL4	-	-	-	-
Search2	FL3	FL3	FL4	FL3	FL4	FL3	FL2	FL3	-	-	-	-
	FL2	FL2	FL2	FL2	FL2	FL2	FL1	FL2	-	-	-	-
	FL1	FL1	FL1	FL1	FL1	FL1	FL4	FL1	-	-	-	-
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	-	-	-	-
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case2 & Case3	FL4	FL4	FL3	FL4	FL4	FL4	FL4	FL4	FL4	FL4	FL3	FL4
Search1	FL3	FL3	FL4	FL3	FL3	FL3	FL3	FL3	FL3	FL3	FL4	FL3
	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C
Case2 & Case3	**SC1**	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Search2	FL4	FL4	FL3	FL4	FL4	FL4	FL3	FL4	FL4	FL4	FL4	FL4
	FL3	FL3	FL4	FL3	FL3	FL3	FL4	FL3	FL3	FL3	FL2	FL3
	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL2	FL3	FL2
	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1	FL1
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case2 & Case4	FL4	FL3	FL3	FL4	FL4	FL4	FL3	FL4	FL4	FL4	FL3	FL4
Search1	FL3	FL4	FL2	FL3	FL3	FL3	FL2	FL3	FL3	FL3	FL2	FL3
	FL2	FL2	FL1	FL2	FL2	FL2	FL1	FL2	FL2	FL2	FL1	FL2
	FL1	FL1	FL4	FL1	FL1	FL1	FL4	FL1	FL1	FL1	FL4	FL1
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**
Case2 & Case4	FL4	FL4	FL3	FL4	FL4	FL4	FL3	FL4	FL4	FL4	FL3	FL4
Search2	FL3	FL3	FL4	FL3	FL3	FL3	FL2	FL3	FL3	FL3	FL2	FL3
	FL2	FL2	FL2	FL2	FL2	FL2	FL1	FL2	FL2	FL2	FL1	FL2
	FL1	FL1	FL1	FL1	FL1	FL1	FL4	FL1	FL1	FL1	FL4	FL1
	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C	B.C

There are 80 ranking for the %90 utilization as stated in Table 5.14. 59 of these rankings are ordered as: FL4-FL3-FL2-FL1-Base Case. 12 of rankings are ordered as: FL3-FL4-FL2-FL1-Base Case. 8 of rankings are ordered as: FL3- FL2-FL1- FL4-Base Case. The remaining 1 is as: FL4-FL2-FL3-FL1-Base Case. The percentage graph of these rankings is presented in Figure 5.26. Most of the rankings are as expected: FL4-FL3-FL2-FL1. As the flexibility level increases, average flow time decreases. Dissimilar to 70% utilization level, chain configuration have great effect on the average flow time. Effect of chain configuration sometimes (for 8 cases) is more than the fully flexibility. There are a few cases (for 1 case) where chain configuration loses its expected benefit. As indicated in the previous parts, full flexibility in some cases lead (8 cases) the worst results.

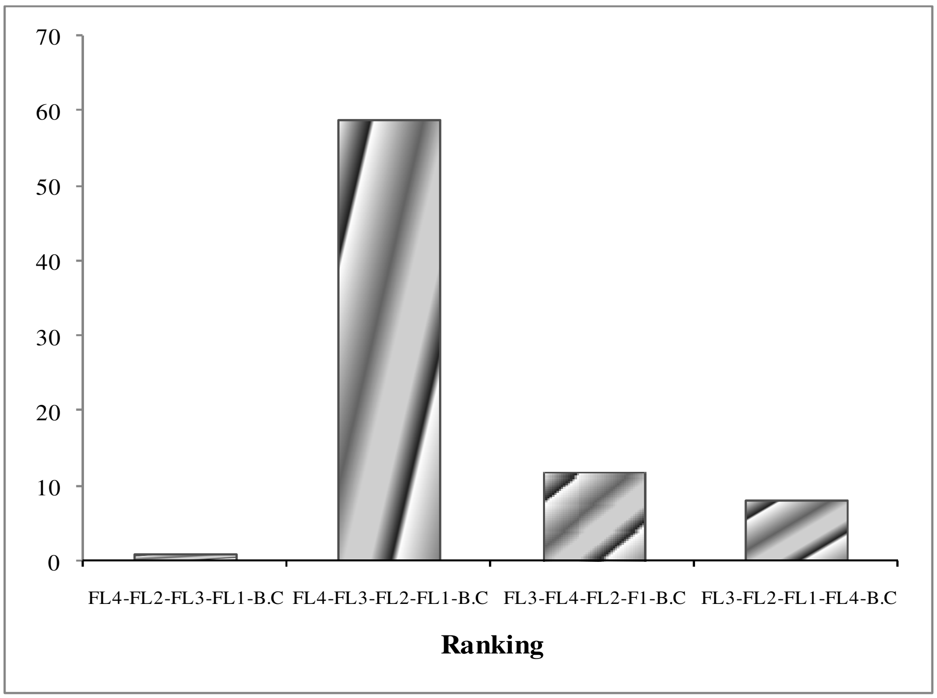

Figure 5.26 The percentage graph of flexibility rankings for 90% utilization.

5.4 Findings and Discussion

Scenarios and the ranks are all discussed at the previous sections, there are many observations obtained from the results of the experiments. These observations and the corresponding statements can be listed as follows:

OBSERVATION 1: In 70% shop utilization level system is not as crowded as 90% shop utilization level and therefore system is relatively more relaxed and queue lengths are naturally small. As a consequence, effects of improvements obtained with flexibility are relatively small when compared with 90% shop utilization.

STATEMENT 1: Effect of flexibility increases as the shop utilization level increases.

OBSERVATION 2: It should be noticed that, in both FL1 and FL3 levels, each machine is capable of performing two different operations however FL3 is capable of doing much more then FL1 does for 70% shop utilization level. Moreover, FL3 sometimes (in 2 of the rankings over 80 rankings) performed as well as FL2 performs (three machine flexibility). In 90% shop utilization level, it performs much better and it sometimes even competes with full flexibility. In 12 of the cases over 80, FL3 are ranked as the first and FL4 has been the second. The potential of FL3 (chain flexibility) is much more than expected since it can shift the access workload to idle machines.

STATEMENT 2: Effect of chain configuration is much more than any other two machine flexibility.

OBSERVATION 3: Experimentations indicate that, in full flexibility (without jockeying conditions), AFT value does not change for FL4 for FCFS and FSFS for both of the shop utilization levels. As mentioned before, this case is the result of the equivalence of arrival time and machine arrival times. However, in the other levels of flexibility FSFS performs better than FCFS.

STATEMENT 3: FSFS have the highest positive effect for both shop utilization levels.

OBSERVATION 4: Experimentations indicate that, AFT values for base case of FSFS and MAPT does not change since each machine is allowed to perform only one type of operation with the same expected (average) duration of processing time. As indicated in the system description chapter, if conditions are equal, FSFS is employed as the tie break. Therefore, results do not change.

STATEMENT 4: If the system is not flexible, it does not matter whether MAPT or FSFS is employed as a dispatching rule.

OBSERVATION 5: Control mechanisms are very crucial and it is very important how they are employed. In the scenarios where MAPT is used as the dispatching rule, two different types of control are employed. As details given before, in one of these controls, a job is not allowed to leave the machine unless it has an operation that cannot be performed at the current machine. In the second type of control, job releases the machine and the novel job having the operation with the smallest average processing time is seized. Results indicate that the first control rule resulted in better AFT values and the second resulted in undesired AFT values (especially for Case4- FL4).

STATEMENT 5: Control mechanisms implemented with a certain dispatching rule may change the results marginally.

OBSERVATION 6: Experimentations showed that the scenarios where jockeying is allowed, have better or at worst the same AFT values. In these scenarios, jockeying reduced differences of AFT values among the search1 and search2 rules.

STATEMENT 6: A queue control mechanism like jockeying may improve the performance of a system.

OBSERVATION 7: Observation 4, Observation 5 and Observation 6 all presented that the "true" use of a control mechanism may convert potential of flexibility into very brilliant opportunities. However, there is more to imply. Improvements obtained with the indicated control mechanisms are more significant for 90% shop utilization level. This means that a crowded system has much opportunity to convert potential of flexibility into very brilliant state.

STATEMENT 7: As the shop utilization level increases, importance (the benefits obtained) of control mechanisms (such as: dispatching rules, queue management policies) increase.

CHAPTER 6- CONCLUSION

6.1 Introduction

This thesis is divided into six chapters. In Chapter 1, an overview of the problem studied, research objectives and approaches, and performance measures of interests were presented. In Chapter 2, the background knowledge about simulation and the manufacturing were given. Chapter 3 reviewed and summarized the relevant literature in the area of flexibility. Chapter 4 described the proposed models and the 12 scenarios for the experimentation. In Chapter 5, results of the simulation models and effects of flexibility are discussed.

In this final chapter, an overview of the key discussion issues associated with factors affecting the "Average Flow Time" (AFT) is presented. It is built on the discussions of the analysis and the findings. Conclusions, contributions and implications that emerge from this research are also presented. This chapter individually addresses the research objectives and outcomes of simulation experimentations.

6.2 An Overview of the Results

A manufacturing system *is* a complex arrangement of physical elements, (such as machines, equipment, and workers) and policies (such as order acceptance policy, due date assignment policy and dispatching policy…etc). It is slight important how well these policies are implemented. Several tools and performance indicators are operational for the performance analysis of manufacturing systems. As stated several times, average flow time (AFT) has been considered as the performance indicator of the system given in this thesis.

It is known that several attempts have been performed to understand on AFT. Numerous reasons can be listed for these efforts on gaining insight about AFT. As Baker stated in 1984, AFT is a basic measure of a shop's performance at turning around orders, and it is therefore often used as an indicator of success in responding quickly to customers.

Authors frequently mentioned and experimented on minimization of the AFT by making proper adjustments on the components of flow time. As well known, flow time is formulized as the sum of setup times, transportation time, waiting times in the machine queues and the processing times (Baykasoğlu et al, 2007). Therefore; efforts presented in the literature, are mostly based on these components. If any improvement can be obtained on one of these components, AFT values is expected to be positively affected from these changes. Waiting times in the machine queues, is one of the most important component building up AFT. As Orlicky (1975) stated, a job's flow time is composed of 10% processing time and 90% waiting. Therefore efforts mostly focused on decreasing the waiting times. Certainly, there has been a significant body of knowledge that has produced guidelines on how to decrease queue lengths such as alternate routings for jobs and shifts of operations between the machines. Flexibility, thereby resource/machine sharing, has been key elements to decrease queue lengths and waiting times at queues. As discussed in back ground chapter, in related literature, previous studies focused on two scenarios which are pooling and specialization. In pooling, machines are set into functional pools, where each pool is associated with a set of operations, whereas in specialization each machine is dedicated to a single operation type. Pooling is frequently employed in flexible manufacturing systems (FMS), cellular manufacturing systems (CMS), job shops. Specialization is more common in dedicated flow lines where a sufficiently high volume of a single part type is being manufactured (Jordan and Graves, 1995).

In this thesis more than 640 models are run. Up to our knowledge, it has been first that jockeying is used as a control mechanism. Existing studies mostly restricted their systems with several assumptions, however in this thesis, amount of variability is increased and a multi-dimensional analysis is performed. Findings of this thesis can be listed as follows, corresponding explanations can be found in the previous chapter.

- Effect of flexibility increases as the shop utilization level increases.
- Effect of chain configuration is much more than any other two machine flexibility.
- FSFS have the highest positive effect within the compared rules for both shop utilization levels.

- Control mechanisms created for a certain dispatching rule may change the results marginally.
- A queue control mechanism like jockeying may create different and very useful results for the systems.
- As the shop utilization level increases, importance (the benefits obtained) of control mechanisms (such as: dispatching rules, queue management policies) increase.
- If well configured, flexibility can achieve more than expected. Configuration of flexibility requires a detailfull analysis of the manufacturing systems. One flexibility type defined for a system may not be good for another.
- Transportation time, machine dependent machine times may decrease the effects of flexibility on AFT.
- Full flexibility can be preferable state since decreases the AFT. However, obtaining full benefits of full flexibility requires much better control.

In the literature, some authors considered that pooling may not be the best. For example, Buzacott (1996) studied a variety of pooling scenarios and reveled that when different customer classes have different service times, pooling increases the queue waiting times. Smith and Whitt (1981) also claimed when rare customers have long service times, pooling can be worse than dedicated one. Gurumurthi and Benjaar (2004) claimed that higher flexibility does not always improve throughput. Most of these studies have been performed in service systems and under the assumption that there is only one queue for each group of machine. However dissimilar to their findings this thesis shows that full flexibility is preferable state for improving system performance. On the other hand, control of the system gets harder. Scenario 3, scenario 7 and scenario 11 are typical examples of this case.

6.3 Statistical Significance of Findings

In the previous parts and the chapters, results are presented and discussed by scenarios and the rankings that they make up. In the scenarios analyzed several factors and the levels were used and it is still questionable which builds the AFT value and in what amount? It should be noticed that the question mentioned was also one of the research questions of this thesis. MINITAB 13, statistical software package, has been used to evaluate the experimental results in order to answer this question. A great strength of correlation analysis is its ability to handle interaction of effects among the variables. Once a variable has been selected as a predictor, it has been factored out of the analysis, and the further splits are all conditioned on the prior ones. In this thesis predictors of AFT are considered as the "Shop Utilization Levels", "Search Rules" "Transportation", "Machine Dependent Processing Times" and "Flexibility Levels". Table 6.1 shows these correlation values and their corresponding significance by providing "p values". P values which are approximate to zero show that the results are very significant. Higher "p values" indicate the lower level of significance.

Table 6.1 Factors and their effects on AFT

Factors / Levels	**AFT**	**Significance (p-value)**
Shop Utilization Levels	0.803	0.000
Search Rules	0.001	0.974
Transportation	0.020	0.577
Machine Dependent Processing Times	0.186	0.000
Flexibility	0.411	0.000

As it can be seen from Table 6.1; shop utilization levels highly affects (80%) the AFT values. However, search rules do not have the similar consistent effect. The effect of transportation is 2% and this value is not statistically significant. This case occurs due to the small values of transportation times relative to processing times. Machine dependent processing times also affect the AFT significantly. The effect of flexibility levels are 41% and this finding is highly significant.

The main effect of an independent variable is the effect of the variable averaging over all levels of other variables in the experiment. Analysis of variance (ANOVA) provides a significance test for the main effect of each variable in the design. Main effect analysis shows the general tendency of variables to change at interested dependent variable. For this purpose "main effect plot" has been drawn using Minitab and presented in Figure 6.1.

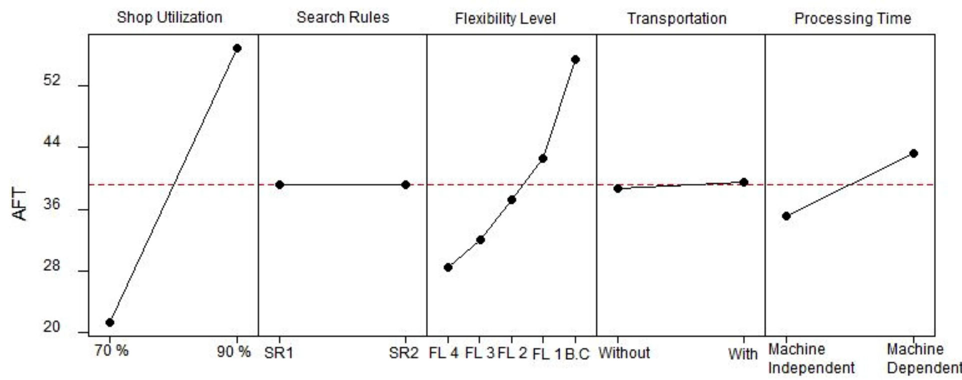

Figure 6.1 Main effects plot for AFT

Figure 6.1 can be used to make the following comments:

- As the shop utilization increases, AFT value increase
- Search mechanisms used in this thesis do not significantly affect the AFT
- Cases with transportation have tendency to increase AFT
- Machine dependent processing times increases the value of AFT
- As the flexibility increases, AFT values tend to decrease.

6.4 Future Work

In this thesis, several scenarios have been considered. However, these scenarios can be extended with the addition of new control mechanisms. These control mechanisms may include different dispatching rules, conditional search mechanisms, and different versions of queue jockeying (such as controlling queue in predetermined intervals and jockeying according to work load balances). In addition, different chaining configurations can be tried and compared with full flexibility especially for the high shop utilization levels.

In this thesis, transportation times have assumed relatively short, new trials can be performed with longer transportation times. Indicated trials with transportation may lead full flexibility to perform better relative to chain configuration.

The performance criteria used in this thesis (AFT) can be changed or multi-objectives including more than unique criteria can be defined and employed.

Another future work can be investigation of the effects of flexibility levels on "due date assignment."

Moreover, cost/benefit analysis can be performed to compare benefits obtained with the implementation of full flexibility and the costs occurred due to building novel control mechanisms.

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APPENDICES

APPENDIX A

!Model File of Scenario 9/Case 2 and 4/Search 1/FL2/90% shop utilization

```
BEGIN;
CREATE,,: EXPO(2.5,1):MARK(Enterance);

ASSIGN:cESIT=DISC(0.1,1,0.2,2,0.3,3,0.4,4,0.5,5,0.6,6,0.7,7,0.8,8,0.
9,9,1,10,1);


BRANCH,     1:
                        IF, cESIT==1,1:
                        IF, cESIT==2,ORDER2:
                        IF, cESIT==3,ORDER3:
                        IF, cESIT==4,ORDER4:
                        IF, cESIT==5,ORDER5:
                        IF, cESIT==6,ORDER6:
                        IF, cESIT==7,ORDER7:
                        IF, cESIT==8,ORDER8:
                        IF, cESIT==9,ORDER9:
                        IF, cESIT==10,ORDER10;
ORDER1 COUNT:Jtype1;
ASSIGN:Optype(1)=1: Optype(2)=2: Optype(3)=1: Optype(4)=5:
TotalOp=4:OpControl=4:Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER2 COUNT:     Jtype2;
ASSIGN: Optype(1)=2: Optype(2)=3: Optype(3)=6: Optype(4)=2:
TotalOp=4:OpControl=4:Opsira=1: Mach(TotalOp+1)=7:
Next(SIRALA);


ORDER3 COUNT:     Jtype3;
ASSIGN: Optype(1)=3: Optype(2)=5: Optype(3)=4: Optype(4)=6:
TotalOp=4:OpControl=4:Opsira=1: Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER4 COUNT:     Jtype4;
ASSIGN: Optype(1)=4: Optype(2)=2: Optype(3)=3: Optype(4)=2:
Optype(5)=6:
TotalOp=5:OpControl=5:Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER5 COUNT:     Jtype5;
ASSIGN: Optype(1)=5: Optype(2)=1: Optype(3)=4: Optype(4)=5:
Optype(5)=6:
TotalOp=5:OpControl=5: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER6 COUNT:     Jtype6;
ASSIGN: Optype(1)=6: Optype(2)=4: Optype(3)=2: Optype(4)=5:
Optype(5)=3:
TotalOp=5:OpControl=5: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);
```

```
ORDER7 COUNT:     Jtype7;
ASSIGN: Optype(1)=1: Optype(2)=3: Optype(3)=1: Optype(4)=5:
Optype(5)=4: Optype(6)=1:
TotalOp=6:OpControl=6: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER8 COUNT:     Jtype8;
ASSIGN: Optype(1)=2: Optype(2)=4: Optype(3)=3: Optype(4)=1:
Optype(5)=5: Optype(6)=1:
TotalOp=6:OpControl=6: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER9 COUNT:     Jtype9;
ASSIGN: Optype(1)=1: Optype(2)=2: Optype(3)=4: Optype(4)=2:
Optype(5)=5: Optype(6)=3: Optype(7)=6: TotalOp=7:OpControl=7:
Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER10 COUNT:    Jtype10;
ASSIGN: Optype(1)=3: Optype(2)=1: Optype(3)=5: Optype(4)=4:
Optype(5)=6: Optype(6)=1: Optype(7)=3: Optype(8)=4:
TotalOp=8:OpControl=8: Opsira=1 :Mach(TotalOp+1)=7:
Next(SIRALA);


SIRALA BRANCH,    1:
                  IF, opsira <=totalop,SIRALA2:
                  ELSE,SIFIRLA;

SIRALA2           FINDJ, 1,
NumMem(Optype(Opsira)):MIN((NQ(Member(Optype(Opsira),J))*
machoptimes(Member(Optype(Opsira),J),11))
+trans(ilkmak,Member(Optype(Opsira),J))+
(Nr(Member(Optype(Opsira),J)) *
(MX((TotDur(member(optype(opsira),j),1) - TNOW),0))));
ASSIGN: Mach(OpSira)=P(OpType(OpSira), J);

ASSIGN: OpSira= Opsira +1 :ilkmak=Mach(opsira-1): Next(SIRALA);

SIFIRLA ASSIGN:opsira=1:NEXT(SHOP);


SHOP  ASSIGN:NS=1 : IS=Mach(OpSira)-1 ;
SHOP1       ROUTE:      yol,        SEQ;
            STATION,    StationSet;
            ASSIGN:     SetIndex=MemIdx(StationSet,M):
yold(opsira)=yold(opsira)+yol;

HAZIR  ASSIGN:mecbur=optype(opsira);
IF:   (NQ(Mach(opsira))+NR(Mach(opsira)))==0;
      ASSIGN: siradan=siradan +1:NEXT(GEL);
ENDIF;

IF: arastir==1;
      ASSIGN: siradan=siradan +1:NEXT(GEL);
ENDIF;

QUEUE,      QUEUESET(SetIndex):MARK(QentT):detach;
GEL         SEIZE:      MACHINESET(SetIndex);
            ASSIGN:     entsay(mach(opsira))=entsay(mach(opsira))+1;
TALLY:      AvgMachQWT, MachQWT(SETINDEX);
```

```
            ASSIGN: proces(opsira)=
Opt(optype(opsira),mach(opsira)):
                  proce(opsira)=proces(opsira):
                  TotDur(mach(opsira),1)=TNOW + proces(opsira);

DELAY:      Proces(opsira);
ASSIGN:     MachOpTimes(Mach(Opsira),1)= Proces(Opsira):Ndxe=10;
CALC2       ASSIGN:     MachOpTimes(Mach(Opsira),Ndxe)=
                        MachOpTimes(Mach(Opsira),Ndxe-1): Ndxe=Ndxe-
1;
BRANCH, 1:
            IF, Ndxe==1, FREE:
            ELSE, CALC2;
FREE  IF: entsay(mach(opsira))<9;
            ASSIGN:MachOptimes(Mach(opsira),11)= (MachOpTimes(Mach
                  (Opsira),2) + MachOpTimes(Mach(Opsira),3)+
                  MachOpTimes(Mach(Opsira),4)+MachOpTimes(Mach
                  (Opsira),5)+ MachOpTimes(Mach(Opsira),6)+
MachOpTimes             (Mach(Opsira),7)+
MachOpTimes(Mach(Opsira),8)
      +MachOpTimes(Mach(Opsira),9)+ MachOpTimes(Mach
      (Opsira),10))/ (entsay(mach(opsira))) :NEXT(OLDU) ;
      ENDIF;

ASSIGN: MachOpTimes(Mach(Opsira),11)=
       (MachOpTimes(Mach(Opsira),2)+ MachOpTimes(Mach(Opsira),3)+
       MachOpTimes(Mach(Opsira),4)+MachOpTimes(Mach(Opsira),5)+
       MachOpTimes(Mach(Opsira),6)+ MachOpTimes(Mach(Opsira),7)+
       MachOpTimes(Mach(Opsira),8)+MachOpTimes(Mach(Opsira),9)+
       MachOpTimes(Mach(Opsira),10))/9;

OLDU RELEASE:     MACHINESET(SetIndex);
ASSIGN:arastir=0:bulma=0;

BRANCH,1:
                  IF,opsira>=totalOp,SONOP:
                  ELSE,DOWN;
SONOP  ASSIGN :   NS=1 : IS=6 : yol=Trans(MACH(OPsira),MACH(OPsira+
                  1)):lazim=8;
BRANCH, 2:
                  ALWAYS, SHOP1:
                  ALWAYS, KONTEK;burda

DOWN        ASSIGN:     Opsira=Opsira + 1 : kontsayac=1:NEXT(DONGU)
;

DONGU       IF: kontsayac <limit;
            IF:P(optype(opsira),kontsayac)==mach(opsira-1);
                  ASSIGN:bittimi=1;
BITMEDI           IF:bittimi<=NQ(mach(opsira-1));
                        ASSIGN:www=AQUE ( (mach(opsira-1)),
                        bittimi,NSYM(enterance)) ;
                              IF: www<enterance;
                                    ASSIGN:gecici=www:NEXT(OLMADI);
                              ELSE;
                                    ASSIGN:bittimi=bittimi +1:NEXT
                                    (BITMEDI);
                              ENDIF;
                  ELSE;
                        ASSIGN:siradan=siradan+1:NEXT(ATAMA);
                  ENDIF;
```

```
            ELSE;
                  ASSIGN: kontsayac=kontsayac + 1:NEXT(DONGU);

            ENDIF;

ELSE;
ASSIGN:siradan=siradan+1:NEXT(OLMADI);
ENDIF;
OLMADI FINDJ, 1,
NumMem(Optype(Opsira)):MIN((NQ(Member(Optype(Opsira),J))*
machoptimes(Member(Optype(Opsira),J),11))
+trans(mach(opsira-1),Member(Optype(Opsira),J))+
(Nr(Member(Optype(Opsira),J)) *
(MX((TotDur(member(optype(opsira),j),1) - TNOW),0))) );

ASSIGN: mach(opsira)=P(OpType(OpSira), J):yol=Trans(MACH(Opsira-
1),MACH(opsira)):bulma=1:lazim=8;

OHBE  BRANCH, 2:
                  ALWAYS, SHOP:
                  ALWAYS, KONTEK;
            STATION,    ExitSystem;
            COUNT:      TotalCompJobs;
            ASSIGN:     TFT=TNOW-ENTERANCE;
            TALLY:      AvgFT,INT(Enterance);
            BRANCH, 1 :
                        IF, NC(TotalCompJobs)==CompJobs, YAZ:
                        ELSE, DLT;
YAZ   WRITE, Statis :TNOW,tavg(AvgFT), nrep;
WRITE, UTIL: davg(Machine1 Utilization Rate), davg(Machine2
Utilization Rate), davg(Machine3 Utilization Rate), davg(Machine4
Utilization Rate), davg(Machine5 Utilization Rate), davg(Machine6
Utilization Rate)
,NC(Jtype1),NC(Jtype2),NC(Jtype3),NC(Jtype4),NC(Jtype5),NC(Jtype6),N
C(Jtype7),NC(Jtype8),NC(Jtype9),NC(Jtype10),;
WRITE, QLGTH: davg(Machine1 Queue Length), davg(Machine2 Queue
Length), davg(Machine3 Queue Length), davg(Machine4 Queue Length),
davg(Machine5 Queue Length), davg(Machine6 Queue Length): NEXT(DLT);

KONTEK      ASSIGN: arac=1:arastir=0;

BAKIYOR IF: arac<7;

            IF:  arac<>lazim.And.NR(arac)==0.And.NQ(arac)>0;
                  ASSIGN:siradan=siradan-1:kac=kac+1:NExt(Durum1);

            ELSEIF:  arac<>lazim.And.NR(arac)==0.And.NQ(arac)==
                      0.And.NE(Arac)==0;
                     ASSIGN:siradan=siradan-1:NExt(DURUM2);

            ELSE;
                     ASSIGN: arac=arac + 1 : NExt(BAKIYOR);
            ENDIF;
ELSE;
            ASSIGN: siradan=siradan +1:NEXT(DLT);

ENDIF;

DURUM1 SEARCH, arac, 1, nq :MIN(Enterance);
CEK3   REMOVE:  J, arac, ATAMCEK;
ASSIGN:arac=arac+1:NEXT(BAKIYOR);
```

```
DURUM2  ASSIGN:yokmu=0:bosmak=arac:kontrol=1:minent
=100000000: Mindis=100:knt=0;
TARA IF:kontrol<limit;
ASSIGN:yol=Trans(bosmak,P(bosmak,kontrol));
      IF:bosmak==P(bosmak,kontrol);
            ASSIGN:kontrol=kontrol+1:NEXT(TARA);
      ENDIF;
  IF:yol<Mindis;
      ASSIGN:siradan=siradan +1:NEXT(KUCUK);
  ELSEIF:yol==Mindis;
      ASSIGN:siradan=siradan +1:NEXT(ESIT);
   ELSEIF:yol>Mindis;
      ASSIGN:kontrol=kontrol+1:Next(TARA);
   ENDIF;
ELSE;
      ASSIGN:siradan=siradan+1:NExt(SONKONT);
ENDIF;

KUCUK SEARCH, P(bosmak,kontrol),1,NQ:MIN(enterance);
      IF:J==0;
            ASSIGN:kontrol=kontrol+1:NEXT(TARA);
      ELSE;
            ASSIGN:Mindis=yol:
                  Gecicimak=P(bosmak,kontrol):
                  Knt=kontrol:Minent= AQUE(Gecicimak,J,NSYM
                  (enterance)):sayacak=J:
                  kontrol=kontrol+1:NExt(TARA);
            ENDIF;

ESIT Search,P(bosmak,kontrol),1,NQ :(enterance<Minent);
            IF:J==0;
            ASSIGN: kontrol=kontrol+1:NEXT(TARA);
            ELSE;
                  ASSIGN: Gecicimak=P(bosmak,kontrol):
                   Minent=AQUE(Gecicimak,J,NSYM(enterance)):
                  Knt=kontrol:bsm=bosmak:sayacak=J:
                  Kontrol=kontrol+1:NEXT(TARA);
            ENDIF;
SONKONT     IF:Mindis==100.or.knt==0;
                  ASSIGN:arac=arac+1:NEXT(BAKIYOR);
            ELSE;
                       ASSIGN:kontrol=knt: NEXT(CEK4);

            ENDIF;
CEK4 REMOVE:  sayacak, gecicimak, ATAMAJOK;
 ASSIGN:arac=arac+1:NEXT(DLT);
ATAMA       ASSIGN: mach(opsira)=mach(opsira-1):
                  yol=Trans(MACH(Opsira-1),MACH(opsira)):arastir=1 :
                  lazim = Mach(opsira-1):NEXT(OHBE);
ATAMAJOK
ASSIGN:yol=Trans(mach(opsira),bosmak):GELmak(opsira)=mach(opsira):ma
ch(opsira)=bosmak;
BRANCH,2:
ALWAYS,SHOP:
ALWAYS,BAKIYOR;
ATAMCEK ASSIGN:arastir=1:NEXT(HAZIR);
DLT DISPOSE;
END;
```

!Experiment File of Scenario 9/Case 2 and 4/Search 1/FL2/90% shop utilization

```
BEGIN;
ATTRIBUTES : Enterance: Opsira: OpControl : TotalOp :Mach(1..10):
TFT : QEntT : MachQWT (1..6): OpTimes : SetIndex: mecbur: proce(8):
proces(8)
:yol:yold(9):optype(10):cesit:arastir,0:ilkmak,8:gelmak(10);

VARIABLES:bsm: Ndxe: Wrm:MachOpTimes(6,11): TotDur(6,1):
CompJobs,18000: siradan:bulma:
entsay(6):lazim:arac:limit,4:kontsayac:www:bittimi:gecici:
Mindis:kontrol:gecicimak:bosmak:Minent:sayacak:yokmu:knt:
Trans(1..8,1..8),
0,0.133333,0.266667,0.133333,0.188562,0.298142,0.274874,0,
0.13333,0,0.133333,0.188562,0.133333,0.188562,0.149071,0,
0.266667,0.133333,0,0.298142,0.188562,0.133333,0.066667,0,
0.133333,0.188562,0.298142,0,0.133333,0.266667,0.274874,0,
0.188562,0.133333,0.188562,0.133333,0,0.133333,0.149071,0,
0.298142,0.188562,0.133333,0.266667,0.133333,0,0.066667,0,
0.274874,0.149071,0.066667,0.274874,0.149071,0.066667,0,0,
0,0,0,0,0,0,0,0;

QUEUES : Mach1Q,LVF(enterance):Mach2Q,LVF(enterance):
Mach3Q,LVF(enterance: Mach4Q,LVF(enterance): Mach5Q,LVF(enterance):
Mach6Q,LVF(enterance);

STATIONS :  Mach1 : Mach2 : Mach3 : Mach4 : Mach5 : Mach6 :
ExitSystem;

RESOURCES : Mach1R : Mach2R : Mach3R : Mach4R : Mach5R : Mach6R;

SETS :1,QS1, Mach1Q,Mach2Q,Mach3Q:
      2,QS2, Mach1Q,Mach2Q,Mach3Q:
      3,QS3, Mach1Q,Mach2Q,Mach3Q:
      4,QS4, Mach4Q,Mach5Q,Mach6Q:
      5,QS5, Mach4Q,Mach5Q,Mach6Q:
      6,QS6,Mach4Q,Mach5Q,Mach6Q:
      QUEUESET, Mach1Q , Mach2Q , Mach3Q , Mach4Q , Mach5Q , Mach6Q
:

      MACHINESET, Mach1R , Mach2R , Mach3R , Mach4R , Mach5R ,
Mach6R :

      STATIONSET, Mach1 , Mach2 , Mach3 , Mach4 , Mach5 , Mach6;

      SEQUENCES :1,Types,Mach1&Mach2&Mach3&Mach4&Mach5&Mach6&
                  ExitSystem;
      EXPRESSIONS:
      Opt(1..6,1..6),

Unif(1.8,2.25),Unif((2.35*1.05),(2.85*1.05)),Unif((2.35*1.05),(2.85*
1.05)),0,0,0,

Unif((1.8*1.05),(2.25*1.05)),Unif(2.35,2.85),Unif((2.35*1.05),(2.85*
1.05)),0,0,0,

Unif((1.8*1.05),(2.25*1.05)),Unif((2.35*1.05),(2.85*1.05)),Unif(2.35
,2.85), 0,0,0,
       0,0,0, Unif(2.35,2.85),
Unif((2.35*1.05),(2.85*1.05)),Unif((3.15*1.05),(3.25*1.05)),
```

```
       0,0,0,Unif((2.35*1.05),(2.85*1.05)), Unif(2.35,2.85),
Unif((3.15*1.05),(3.25*1.05)),
       0,0,0,Unif((2.35*1.05),(2.85*1.05)),
Unif((2.35*1.05),(2.85*1.05)), Unif(3.15,3.25);
PARAMETERS:       1, 1,2,3:
                  2, 1,2,3:
                  3, 1,2,3:
                  4, 4,5,6:
                  5, 4,5,6:
                  6, 4,5,6;

DSTATS:          NQ(Mach1Q), Machine1 Queue Length :
                  NR(Mach1R)*100, Machine1 Utilization Rate :
                  NQ(Mach2Q), Machine2 Queue Length :
                  NR(Mach2R)*100,Machine2 Utilization Rate :
                  NQ(Mach3Q), Machine3 Queue Length :
                  NR(Mach3R)*100,Machine3 Utilization Rate :
                  NQ(Mach4Q), Machine4 Queue Length :
                  NR(Mach4R)*100,Machine4 Utilization Rate :
                  NQ(Mach5Q), Machine5 Queue Length :
                  NR(Mach5R)*100,Machine5 Utilization Rate :
                  NQ(Mach6Q), Machine6 Queue Length :
                  NR(Mach6R)*100,Machine6 Utilization Rate ;

COUNTERS:   TotalCompJobs,18001:
            Jtype1:
            Jtype2:
            Jtype3:
            Jtype4:
            Jtype5:
            Jtype6:
            Jtype7:
            Jtype8:
            Jtype9:
            Jtype10;
TALLIES:    AvgFT:
            AvgMachQWT;

FILES:     1,Statis,"Statis_25_12_FL3.xls", seq, wks, dis:
            2,Util,"Util_25_12_FL3.xls", seq, wks, dis:
            3,QLgth, "QLgthUn7f25_12_FL3.xls", seq, wks, dis;

REPLICATE,25, 0, ,yes, yes, Wrm;
END;
```

APPENDIX B

!Model File of scenario 10/Case 2 and 4/Search 1/FL2/90% Shoputilization

```
BEGIN;
            CREATE,,: EXPO(2.5,1):MARK(Enterance);
ASSIGN:cesit=DISC(0.1,1,0.2,2,0.3,3,0.4,4,0.5,5,0.6,6,0.7,7,0.8,8,0.
9,9,1,10,1);
BRANCH,     1:
                        IF, cesit==1,ORDER1:
                        IF, cesit==2,ORDER2:
                        IF, cesit==3,ORDER3:
                        IF, cesit==4,ORDER4:
                        IF, cesit==5,ORDER5:
                        IF, cesit==6,ORDER6:
                        IF, cesit==7,ORDER7:
                        IF, cesit==8,ORDER8:
                        IF, cesit==9,ORDER9:
                        IF, cesit==10,ORDER10;
ORDER1 COUNT:Jtype1;
ASSIGN:Optype(1)=1: Optype(2)=2: Optype(3)=1: Optype(4)=5:
TotalOp=4:OpControl=4:Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER2 COUNT:     Jtype2;
ASSIGN: Optype(1)=2: Optype(2)=3: Optype(3)=6: Optype(4)=2:
TotalOp=4:OpControl=4:Opsira=1: Mach(TotalOp+1)=7:
Next(SIRALA);


ORDER3 COUNT:     Jtype3;
ASSIGN: Optype(1)=3: Optype(2)=5: Optype(3)=4: Optype(4)=6:
TotalOp=4:OpControl=4:Opsira=1: Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER4 COUNT:     Jtype4;
ASSIGN: Optype(1)=4: Optype(2)=2: Optype(3)=3: Optype(4)=2:
Optype(5)=6:
TotalOp=5:OpControl=5:Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER5 COUNT:     Jtype5;
ASSIGN: Optype(1)=5: Optype(2)=1: Optype(3)=4: Optype(4)=5:
Optype(5)=6:
TotalOp=5:OpControl=5: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER6 COUNT:     Jtype6;
ASSIGN: Optype(1)=6: Optype(2)=4: Optype(3)=2: Optype(4)=5:
Optype(5)=3:
TotalOp=5:OpControl=5: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER7 COUNT:     Jtype7;
ASSIGN: Optype(1)=1: Optype(2)=3: Optype(3)=1: Optype(4)=5:
Optype(5)=4: Optype(6)=1:
TotalOp=6:OpControl=6: Opsira=1:Mach(TotalOp+1)=7:
```

```
Next(SIRALA);

ORDER8 COUNT:     Jtype8;
ASSIGN: Optype(1)=2: Optype(2)=4: Optype(3)=3: Optype(4)=1:
Optype(5)=5: Optype(6)=1:
TotalOp=6:OpControl=6: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER9 COUNT:     Jtype9;
ASSIGN: Optype(1)=1: Optype(2)=2: Optype(3)=4: Optype(4)=2:
Optype(5)=5: Optype(6)=3: Optype(7)=6: TotalOp=7:OpControl=7:
Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER10 COUNT:    Jtype10;
ASSIGN: Optype(1)=3: Optype(2)=1: Optype(3)=5: Optype(4)=4:
Optype(5)=6: Optype(6)=1: Optype(7)=3: Optype(8)=4:
TotalOp=8:OpControl=8: Opsira=1 :Mach(TotalOp+1)=7:
Next(SIRALA);

SIRALA BRANCH,    1:
                        IF, opsira <=totalop,SIRALA2:
                        ELSE,SIFIRLA;

SIRALA2           FINDJ, 1,
NumMem(Optype(Opsira)):MIN((NQ(Member(Optype(Opsira),J))*
machoptimes(Member(Optype(Opsira),J),11))
+trans(ilkmak,Member(Optype(Opsira),J))+
(Nr(Member(Optype(Opsira),J)) *
(MX((TotDur(member(optype(opsira),j),1) - TNOW),0))));
            ASSIGN: Mach(OpSira)=P(OpType(OpSira), J);
            ASSIGN: OpSira= Opsira +1 :ilkmak=Mach(opsira-1): Next
                  (SIRALA);

SIFIRLA ASSIGN:opsira=1:NEXT(SHOP);

SHOP  ASSIGN:NS=1 : IS=Mach(OpSira)-1 ;
SHOP1       ROUTE:      yol,        SEQ;
            STATION,    StationSet;
            ASSIGN:     SetIndex=MemIdx(StationSet,M): yold(opsira)
                        =yol;




HAZIR ASSIGN:mecbur=optype(opsira);
IF: (NQ(Mach(opsira))+NR(Mach(opsira)))==0;
      ASSIGN: siradan=siradan +1:NEXT(GEL);
ENDIF;

IF: arastir==1;
      ASSIGN: siradan=siradan +1:NEXT(GEL);
ENDIF;

ASSIGN:           entsay(mach(opsira))=entsay(mach(opsira))+1;
TALLY:            AvgMachQWT, MachQWT(SETINDEX);
ASSIGN:            proces(opsira)= Opt(optype(opsira),mach(opsira)):
                  proce(opsira)=proces(opsira):
                  TotDur(mach(opsira),1)=TNOW + proces(opsira);

DELAY:      Proces(opsira);
```

```
ASSIGN:     MachOpTimes(Mach(Opsira),1)= Proces(Opsira):Ndxe=10;
Calc2       ASSIGN:     MachOpTimes(Mach(Opsira),Ndxe)=
                        MachOpTimes(Mach(Opsira),Ndxe-1): Ndxe=Ndxe-
1;
BRANCH, 1:
                        IF, Ndxe==1, FREE:
                        ELSE, Calc2;
FREE        IF: entsay(mach(opsira))<9;
                  ASSIGN:MachOptimes(Mach(opsira),11)= (MachOpTimes
                        (Mach(Opsira),2)+
MachOpTimes(Mach(Opsira),3)+
                        MachOpTimes(Mach(Opsira),4)+MachOpTimes(Mach
                        (Opsira),5)+ MachOpTimes(Mach(Opsira),6)+
                        MachOpTimes(Mach(Opsira),7)+
MachOpTimes(Mach
      (Opsira),8)+MachOpTimes(Mach(Opsira),9)+
                        MachOpTimes(Mach(Opsira),10))/ (entsay(mach
                        (opsira))) : NEXT(OLDU) ;
ENDIF;

ASSIGN: MachOpTimes(Mach(Opsira),11)=
       (MachOpTimes(Mach(Opsira),2)+ MachOpTimes(Mach(Opsira),3)+
       MachOpTimes(Mach(Opsira),4)+MachOpTimes(Mach(Opsira),5)+
       MachOpTimes(Mach(Opsira),6)+ MachOpTimes(Mach(Opsira),7)+
       MachOpTimes(Mach(Opsira),8)+MachOpTimes(Mach(Opsira),9)+
       MachOpTimes(Mach(Opsira),10))/9;

OLDU RELEASE:     MACHINESET(SetIndex);
ASSIGN:arastir=0:bulma=0;
BRANCH,1:
                  If,opsira>=totalOp,SONOP:
                  else,DOWN;
SONOP  ASSIGN :   NS=1 : IS=6 :
yol=Trans(MACH(OPsira),MACH(OPsira+1)):lazim=8;
BRANCH, 2:
                  ALWAYS, SHOP1:
                  ALWAYS, KONTEK;

DOWN        ASSIGN:     Opsira=Opsira + 1 : kontsayac=1:NEXT(DONGU)
;

DONGU IF: kontsayac <limit;
            IF:P(optype(opsira),kontsayac)==mach(opsira-1);
                  ASSIGN:bittimi=1;

BITMEDI           IF:bittimi<=NQ(mach(opsira-1));
                        ASSIGN:www=AQUE ( (mach(opsira-1)),
                        bittimi,NSYM(QentT)) ;

                              IF: www<QentT;
                                    ASSIGN:gecici=www:NEXT(OLMADI);
ELSEIF: www==qENTt;
                                    ASSIGN:giris= AQUE (
(mach(opsira-1)),
      bittimi,NSYM(enterance)) ;
                                    IF:giris<enterance;
                              ASSIGN:siradan=siradan+1:NEXT(OLMADI);
                                    ELSE;

      ASSIGN:bittimi=bittimi+1:NEXT(BITMEDI);
                                    ENDIF;
```

```
                              ELSE;
                                    ASSIGN:bittimi=bittimi +1:NEXT
                                    (BITMEDI);
                              ENDIF;
                  ELSE;
                        ASSIGN:siradan=siradan+1:NEXT(atama);
                  ENDIF;
            ELSE;
                  ASSIGN: kontsayac=kontsayac + 1:NEXT(DONGU);

            ENDIF;

ELSE;
ASSIGN:siradan=siradan+1:NEXT(OLMADI);
ENDIF;
OLMADI FINDJ, 1,
NumMem(Optype(Opsira)):MIN((NQ(Member(Optype(Opsira),J))*
machoptimes(Member(Optype(Opsira),J),11))
+trans(mach(opsira-1),Member(Optype(Opsira),J))+
(Nr(Member(Optype(Opsira),J)) *
(MX((TotDur(member(optype(opsira),j),1) - TNOW),0))) );

ASSIGN: bakalim(opsira)=mach(opsira):
      mach(opsira)=P(OpType(OpSira), J):yol=Trans(MACH(Opsira-
1),MACH(opsira)):bulma=1:lazim=8;

Ohbe  BRANCH, 2:
                  ALWAYS, SHOP:
                  ALWAYS, KONTEK;
            STATION,    ExitSystem;
            COUNT:      TotalCompJobs;
            ASSIGN:     TFT=TNOW-ENTERANCE;
            TALLY:      AvgFT,INT(Enterance);
            BRANCH, 1 :
                        IF, NC(TotalCompJobs)==CompJobs, YAZ:
                        ELSE, DLT;
YAZ   ASSIGN: PofTarJ=tnum(avgtarADRES)/tnum(avgLtADRES):
                    PofEarJ=tnum(AvgEarADRES)/tnum(avgLtADRES);
WRITE, Statis :TNOW,tavg(AvgFT),nrep;
WRITE, Util: davg(Machine1 Utilization Rate), davg(Machine2
Utilization Rate), davg(Machine3 Utilization Rate), davg(Machine4
Utilization Rate), davg(Machine5 Utilization Rate), davg(Machine6
Utilization Rate)
,NC(Jtype1),NC(Jtype2),NC(Jtype3),NC(Jtype4),NC(Jtype5),NC(Jtype6),N
C(Jtype7),NC(Jtype8),NC(Jtype9),NC(Jtype10),;
WRITE, QLgth: davg(Machine1 Queue Length), davg(Machine2 Queue
Length), davg(Machine3 Queue Length), davg(Machine4 Queue Length),
davg(Machine5 Queue Length), davg(Machine6 Queue Length): NEXT(DLT);

KONTEK      ASSIGN: arac=1:arastir=0;
BAKIYOR IF: arac<7;

      IF:  arac<>lazim.And.NR(arac)==0.And.NQ(arac)>0;
            ASSIGN:siradan=siradan-1:kac=kac+1:NExt(DURUM1);
      ELSEIF:
arac<>lazim.And.NR(arac)==0.And.NQ(arac)==0.and.NE(arac)==0;
            ASSIGN:siradan=siradan-1:NExt(DURUM2);
ELSE;
      ASSIGN: arac=arac + 1 : NExt(BAKIYOR);
      ENDIF;
```

```
ELSE;
ASSIGN: siradan=siradan +1:NEXT(DLT);

ENDIF;

DURUM1 ASSIGN:qENTt2=10000000000:girisbak=100000000000:siradan=1;
CABUK IF:siradan<=NQ(arac);
ASSIGN:GqENTt= AQUE(arac,siradan,NSYM(qENTt));
      IF: GqENTt == qENTt2;
            ASSIGN:giris= AQUE(arac,siradan,NSYM(enterance));
            IF:giris<girisbak;
                        ASSIGN:girisbak=giris:CEKil=siradan;
            ENDIF;
                        ASSIGN:siradan=siradan+1:NEXT(CABUK);
      ELSEIF:GqENTt<qENTt2;
            ASSIGN:qENTt2= AQUE(arac,siradan,NSYM(qENTt)):girisbak=
            AQUE(arac,siradan,NSYM(enterance)):CEKil=siradan:NEXT
            (CABUK);
      ELSE;
                  ASSIGN:siradan=siradan+1:NEXT(CABUK);
            ENDIF;

ELSE;
      ASSIGN:j=CEKil:NEXT(CEK3);
ENDIF;

CEK3   REMOVE:  J, arac, atamaCEK;
ASSIGN:arac=arac+1:NEXT(BAKIYOR);
DURUM2  ASSIGN:yokmu=0:bosmak=arac:kontrol=1:Minent
            =100000000: Mindis=100:knt=0;
TARA  IF:kontrol<limit;
            ASSIGN:yol=Trans(bosmak,P(bosmak,kontrol));
            IF:bosmak==P(bosmak,kontrol);
                  ASSIGN:kontrol=kontrol+1:NEXT(tara);
            ENDIF;
  IF:yol<Mindis;
      ASSIGN:siradan=siradan +1:NEXT(kucuk);
  ELSEIF:yol==Mindis;
      ASSIGN:siradan=siradan +1:NEXT(esit);
   ELSEIF:yol>Mindis;
      ASSIGN:kontrol=kontrol+1:Next(Tara);
   ENDIF;
ELSE;
      ASSIGN:siradan=siradan+1:NExt(SONKONT);
ENDIF;

KUCUK SEARCH, P(bosmak,kontrol),1,NQ:MIN(QentT);
IF:J==0;
      ASSIGN:kontrol=kontrol+1:NEXT(tara);
      ELSE;
ASSIGN:QentT2=100000000:girisbak=100000000000:siradan=1;
CABUK2      IF:siradan<=NQ(P(bosmak,kontrol));
ASSIGN:QentT= AQUE((P(bosmak,kontrol)),siradan,NSYM(QentT));
      IF:QentT==QentT2;
            ASSIGN:giris= AQUE((P(bosmak,kontrol)),siradan,NSYM
            (enterance));
            IF:giris<girisbak;
                        ASSIGN:girisbak=giris:CEKil=siradan;
            ENDIF;
                        ASSIGN:siradan=siradan+1:NEXT(CABUK2);
      ELSEIF:QentT<QentT2;
```

```
            ASSIGN:QentT2= AQUE((P(bosmak,kontrol)),siradan,NSYM(
            QentT)):girisbak= AQUE((P(bosmak,kontrol)),siradan,NSYM
            (enterance)):CEKil=siradan:NEXT(CABUK2);
      ELSE;
                  ASSIGN:siradan=siradan+1:NEXT(CABUK2);
            ENDIF;
      ELSE;
            ASSIGN:Mindis=yol:
                         Gecicimak=P(bosmak,kontrol):
      Knt=kontrol:QentT2=
AQUE(Gecicimak,CEKil,NSYM(QentT)):sayacak=CEKil:
 kontrol=kontrol+1:girisbak=
AQUE(Gecicimak,CEKil,NSYM(enterance)):NExt(tara);
      ENDIF;
   ENDIF;
ESIT Search,P(bosmak,kontrol),1,NQ :(QentT<=QentT2);
      IF:J==0;
       ASSIGN: kontrol=kontrol+1:NEXT(Tara);
      ELSE;
      ASSIGN:giris=AQUE ( gecicimak,J,NSYM(enterance)) ;
                  IF:QentT==QentT2;
                        IF:giris<girisbak;

                        ASSIGN: Gecicimak=P(bosmak,kontrol):
              QentT2=AQUE(Gecicimak,J,NSYM(QentT)):
            Knt=kontrol:bsm=bosmak:sayacak=J:
   Kontrol=kontrol+1:NEXT(Tara);
                        ELSE;
      ASSIGN:kontrol=kontrol+1:NEXT(tara);
                        ENDIF;
                  ENDIF;
      ENDIF;
SONKONT     IF:Mindis==100.or.knt==0;
                  ASSIGN:arac=arac+1:NEXT(BAKIYOR);
            ELSE;
                                    ASSIGN:kontrol=knt:
                  NEXT(CEK4);

      ENDIF;
CEK4 REMOVE:  sayacak, gecicimak, atamajok;
 ASSIGN:arac=arac+1:NEXT(DLT);

Atama       ASSIGN: bakalim(opsira)=mach              (opsira-
1):mach(opsira)=mach(opsira-1):
                  yol=Trans(MACH(Opsira-1),MACH(opsira)):arastir=1 :
                  lazim = Mach(opsira-1):NEXT(ohbe);
ATAMAJok
ASSIGN:yol=Trans(mach(opsira),bosmak):GELmak(opsira)=mach(opsira):ma
ch(opsira)=bosmak:arada=yol+arada:jok(opsira)=1:jokbek(opsira)=
(TNOW-Qentt):QentT=0;

Branch,2:
Always,SHOP:
Always,BAKIYOR;

atamaCEK ASSIGN:arastir=1:NEXT(HAZIR);
DLT DISPOSE;
END;
```

!Experiment File of scenario 10/Case 2 and 4/Search 1/FL2/90% shop utilization

```
BEGIN;
ATTRIBUTES :Enterance: Opsira: OpControl : TotalOp : Operasyon(10) :
Mach(1..10) :TFT : QEntT : MachQWT (1..6): OpTimes :SetIndex
mecbur:proce(8):proces(8):yol:yold(9): degisken(10):
optype(10):cesit: bakalim(10): arastir,0: ilkmak,8:
arada:jokbek(10):jok(10):gelmak(10): gQentt;

VARIABLES:bsm:bulacak: Wrm:MachOpTimes(6,11):OpTime(6,11):
TotDur(6,1): kac:CompJobs,18000: sayac(6),1,1,1,1,1,1:siradan:
bulma: entsay(6):
lazim:cekil:qentt2:giris:girisbak:ort(6,11):degiskn:arac:kontsayac:l
imit,4:www:bittimi:gecici:Mindis:kontrol:gecicimak:bosmak:Minent:say
acak:mutlak:acaba:yokmu:knt:
Trans(1..8,1..8),
0,0.133333,0.266667,0.133333,0.188562,0.298142,0.274874,0,
0.13333,0,0.133333,0.188562,0.133333,0.188562,0.149071,0,
0.266667,0.133333,0,0.298142,0.188562,0.133333,0.066667,0,
0.133333,0.188562,0.298142,0,0.133333,0.266667,0.274874,0,
0.188562,0.133333,0.188562,0.133333,0,0.133333,0.149071,0,
0.298142,0.188562,0.133333,0.266667,0.133333,0,0.066667,0,
0.274874,0.149071,0.066667,0.274874,0.149071,0.066667,0,0,
0,0,0,0,0,0,0,0;

QUEUES : Mach1Q,lvf(QentT) : Mach2Q,LVF(QentT): Mach3Q,lvf(QentT):
Mach4Q,lvf(QentT): Mach5Q,lvf(QentT): Mach6Q,lvf(QentT);


STATIONS :  Mach1 : Mach2 : Mach3 : Mach4 : Mach5 : Mach6 :
ExitSystem;

RESOURCES : Mach1R : Mach2R : Mach3R : Mach4R : Mach5R : Mach6R;

SETS : 1,QS1, Mach1Q,Mach2Q,Mach3Q:
      2,QS2, Mach1Q,Mach2Q,Mach3Q:
      3,QS3, Mach1Q,Mach2Q,Mach3Q:
      4,QS4, Mach4Q,Mach5Q,Mach6Q:
      5,QS5, Mach4Q,Mach5Q,Mach6Q:
      6,QS6,Mach4Q,Mach5Q,Mach6Q:
      QUEUESET, Mach1Q , Mach2Q , Mach3Q , Mach4Q , Mach5Q , Mach6Q
:

      MACHINESET, Mach1R , Mach2R , Mach3R , Mach4R , Mach5R ,
Mach6R :

      STATIONSET, Mach1 , Mach2 , Mach3 , Mach4 , Mach5 , Mach6;

      SEQUENCES :1,Types,Mach1&Mach2&Mach3&Mach4&Mach5&Mach6&
                  ExitSystem;
EXPRESSIONS:
Opt(1..6,1..6),

Unif(1.8,2.25),Unif((2.35*1.05),(2.85*1.05)),Unif((2.35*1.05),(2.85*
1.05)),0,0,0,

Unif((1.8*1.05),(2.25*1.05)),Unif(2.35,2.85),Unif((2.35*1.05),(2.85*
1.05)),0,0,0,
```

```
Unif((1.8*1.05),(2.25*1.05)),Unif((2.35*1.05),(2.85*1.05)),Unif(2.35
,2.85), 0,0,0,
       0,0,0, Unif(2.35,2.85),
Unif((2.35*1.05),(2.85*1.05)),Unif((3.15*1.05),(3.25*1.05)),

       0,0,0,Unif((2.35*1.05),(2.85*1.05)), Unif(2.35,2.85),
Unif((3.15*1.05),(3.25*1.05)),
       0,0,0,Unif((2.35*1.05),(2.85*1.05)),
Unif((2.35*1.05),(2.85*1.05)), Unif(3.15,3.25);

PARAMETERS:       1, 1,2,3:
                  2, 1,2,3:
                  3, 1,2,3:
                  4, 4,5,6:
                  5, 4,5,6:
                  6, 4,5,6;
DSTATS:          NQ(Mach1Q), Machine1 Queue Length :
                  NR(Mach1R)*100, Machine1 Utilization Rate :
                  NQ(Mach2Q), Machine2 Queue Length :
                  NR(Mach2R)*100,Machine2 Utilization Rate :
                  NQ(Mach3Q), Machine3 Queue Length :
                  NR(Mach3R)*100,Machine3 Utilization Rate :
                  NQ(Mach4Q), Machine4 Queue Length :
                  NR(Mach4R)*100,Machine4 Utilization Rate :
                  NQ(Mach5Q), Machine5 Queue Length :
                  NR(Mach5R)*100,Machine5 Utilization Rate :
                  NQ(Mach6Q), Machine6 Queue Length :
                  NR(Mach6R)*100,Machine6 Utilization Rate ;

COUNTERS:   TotalCompJobs,18001:
            Jtype1:
            Jtype2:
            Jtype3:
Jtype4:
Jtype5:
Jtype6:
Jtype7:
Jtype8:
Jtype9:
Jtype10;

TALLIES:    AvgMachQWT:
            AvgFT;

FILES:     1,Statis," Statis_25_12_FL3MF.xls", seq, wks, dis:
            2,Util,"Util_25_12_FL3MF.xls", seq, wks, dis:
            3,QLgth, "QLgthUn7f25_12_FL3MF.xls", seq, wks, dis;

REPLICATE, 25, 0, ,yes, yes, Wrm;

END;
```

APPENDIX C

!Model File of scenario 12/Case 2 and 4/Search 1/FL2/90% Shop utilization

```
BEGIN;
            CREATE,,: EXPO(2.5,1):MARK(Enterance);
ASSIGN:cesit=DISC(0.1,1,0.2,2,0.3,3,0.4,4,0.5,5,0.6,6,0.7,7,0.8,8,0.
9,9,1,10,1);
BRANCH,     1:
                        IF, cesit==1,ORDER1:
                        IF, cesit==2,ORDER2:
                        IF, cesit==3,ORDER3:
                        IF, cesit==4,ORDER4:
                        IF, cesit==5,ORDER5:
                        IF, cesit==6,ORDER6:
                        IF, cesit==7,ORDER7:
                        IF, cesit==8,ORDER8:
                        IF, cesit==9,ORDER9:
                        IF, cesit==10,ORDER10;
ORDER1 COUNT:Jtype1;
ASSIGN:Optype(1)=1: Optype(2)=2: Optype(3)=1: Optype(4)=5:
TotalOp=4:OpControl=4:Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER2 COUNT:     Jtype2;
ASSIGN: Optype(1)=2: Optype(2)=3: Optype(3)=6: Optype(4)=2:
TotalOp=4:OpControl=4:Opsira=1: Mach(TotalOp+1)=7:
Next(SIRALA);


ORDER3 COUNT:     Jtype3;
ASSIGN: Optype(1)=3: Optype(2)=5: Optype(3)=4: Optype(4)=6:
TotalOp=4:OpControl=4:Opsira=1: Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER4 COUNT:     Jtype4;
ASSIGN: Optype(1)=4: Optype(2)=2: Optype(3)=3: Optype(4)=2:
Optype(5)=6:
TotalOp=5:OpControl=5:Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER5 COUNT:     Jtype5;
ASSIGN: Optype(1)=5: Optype(2)=1: Optype(3)=4: Optype(4)=5:
Optype(5)=6:
TotalOp=5:OpControl=5: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER6 COUNT:     Jtype6;
ASSIGN: Optype(1)=6: Optype(2)=4: Optype(3)=2: Optype(4)=5:
Optype(5)=3:
TotalOp=5:OpControl=5: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER7 COUNT:     Jtype7;
ASSIGN: Optype(1)=1: Optype(2)=3: Optype(3)=1: Optype(4)=5:
Optype(5)=4: Optype(6)=1:
TotalOp=6:OpControl=6: Opsira=1:Mach(TotalOp+1)=7:
```

```
Next(SIRALA);

ORDER8 COUNT:     Jtype8;
ASSIGN: Optype(1)=2: Optype(2)=4: Optype(3)=3: Optype(4)=1:
Optype(5)=5: Optype(6)=1:
TotalOp=6:OpControl=6: Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER9 COUNT:     Jtype9;
ASSIGN: Optype(1)=1: Optype(2)=2: Optype(3)=4: Optype(4)=2:
Optype(5)=5: Optype(6)=3: Optype(7)=6: TotalOp=7:OpControl=7:
Opsira=1:Mach(TotalOp+1)=7:
Next(SIRALA);

ORDER10 COUNT:    Jtype10;
ASSIGN: Optype(1)=3: Optype(2)=1: Optype(3)=5: Optype(4)=4:
Optype(5)=6: Optype(6)=1: Optype(7)=3: Optype(8)=4:
TotalOp=8:OpControl=8: Opsira=1 :Mach(TotalOp+1)=7:
Next(SIRALA);

SIRALA BRANCH,    1:
                        IF, opsira <=totalop,SIRALA2:

                        Else,sifirla;

SIRALA2           FINDJ, 1,
NumMem(Optype(Opsira)):MIN((NQ(Member(Optype(Opsira),J))*
machoptimes(Member(Optype(Opsira),J),11))
+trans(ilkmak,Member(Optype(Opsira),J))+
(Nr(Member(Optype(Opsira),J)) *
(MX((TotDur(member(optype(opsira),j),1) - TNOW),0))));
            ASSIGN: Mach(OpSira)=P(OpType(OpSira), J);

            ASSIGN: OpSira= Opsira +1 :ilkmak=Mach(opsira-1):
Next(SIRALA);

sifirla ASSIGN:opsira=1:NEXT(SHOP);

SHOP  ASSIGN:NS=1 : IS=Mach(OpSira)-1 ;
SHOP1       ROUTE:      yol,        SEQ;
            STATION,    StationSet;
            ASSIGN:     SetIndex=MemIdx(StationSet,M):
yold(opsira)=yol+yold(opsira);

HAZIR  ASSIGN:ortp=Ortpro(optype(opsira),mach(opsira));

ASSIGN:mecbur=optype(opsira);
IF: (NQ(Mach(opsira))+NR(Mach(opsira)))==0;
       ASSIGN: siradan=siradan +1:NEXT(GEL);
ENDIF;

IF: arastir==1;
ASSIGN: siradan=siradan +1:NEXT(GEL);
ENDIF;
 QUEUE,     QUEUESET(SetIndex):MARK(QentT):detach;
 GEL        SEIZE:      MACHINESET(SetIndex);
ASSIGN:     entsay(mach(opsira))=entsay(mach(opsira))+1;

TALLY:      AvgMachQWT, MachQWT(SETINDEX);
            ASSIGN: proces(opsira)=
Opt(optype(opsira),mach(opsira)):
```

```
                  proce(opsira)=proces(opsira):
      TotDur(mach(opsira),1)=TNOW + proces(opsira);
DELAY:      Proces(opsira);
ASSIGN:MachOpTimes(Mach(Opsira),1)= Proces(Opsira):Ndxe=10;
CALC2 ASSIGN:     MachOpTimes(Mach(Opsira),Ndxe)=
                              MachOpTimes(Mach(Opsira),Ndxe-1):
                        Ndxe=Ndxe-1;
BRANCH, 1:
                        IF, Ndxe==1, FREE:
                        ELSE, CALC2;
FREE  IF: entsay(mach(opsira))<9;
ASSIGN:MachOptimes(Mach(opsira),11)= (MachOpTimes(Mach
      (Opsira),2)+ MachOpTimes(Mach(Opsira),3)+
       MachOpTimes(Mach(Opsira),4)+MachOpTimes(Mach(Opsira),5)+
       MachOpTimes(Mach(Opsira),6)+ MachOpTimes(Mach(Opsira),7)+
       MachOpTimes(Mach(Opsira),8)+MachOpTimes(Mach(Opsira),9)+
       MachOpTimes(Mach(Opsira),10))/ (entsay(mach(opsira))) : NEXT
      (OLDU) ;

ENDIF;

ASSIGN:     MachOpTimes(Mach(Opsira),11)=
       (MachOpTimes(Mach(Opsira),2)+ MachOpTimes(Mach(Opsira),3)+
       MachOpTimes(Mach(Opsira),4)+MachOpTimes(Mach(Opsira),5)+
       MachOpTimes(Mach(Opsira),6)+ MachOpTimes(Mach(Opsira),7)+
       MachOpTimes(Mach(Opsira),8)+MachOpTimes(Mach(Opsira),9)+
       MachOpTimes(Mach(Opsira),10))/9;

OLDU RELEASE:     MACHINESET(SetIndex);
ASSIGN:arastir=0:bulma=0;

BRANCH,1:
                  IF,opsira>=totalOp,SONOP:
                  ELSE,DOWN;
SONOP  ASSIGN :   NS=1 : IS=6 :
yol=Trans(MACH(OPsira),MACH(OPsira+1)):lazim=8;
BRANCH, 2:
                  ALWAYS, SHOP1:
                  ALWAYS, KONTEk;

DOWN        ASSIGN:     Opsira=Opsira + 1 : kontsayac=1:NEXT(DONGU)
;

DONGU IF: kontsayac <limit;
            IF:P(optype(opsira),kontsayac)==mach(opsira-1);

ASSIGN:ortp=Ortpro(optype(opsira),mach(opsira-1)):NEXT(atama);

            ELSE;
                  ASSIGN: kontsayac=kontsayac + 1:NEXT(DONGU);

            ENDIF;

ELSE;
ASSIGN:siradan=siradan+1:NEXT(OLMADI);
ENDIF;
OLMADI FINDJ, 1,
NumMem(Optype(Opsira)):MIN((NQ(Member(Optype(Opsira),J))*
machoptimes(Member(Optype(Opsira),J),11))
+trans(mach(opsira-1),Member(Optype(Opsira),J))+
```

```
(Nr(Member(Optype(Opsira),J)) *
(MX((TotDur(member(optype(opsira),j),1) - TNOW),0))) );

ASSIGN: bakalim(opsira)=mach(opsira):
      mach(opsira)=P(OpType(OpSira), J):yol=Trans(MACH(Opsira-
1),MACH(opsira)):bulma=1:lazim=8;

Ohbe  BRANCH, 2:
                  ALWAYS, SHOP:
                  ALWAYS, KONTEk;
            STATION,    ExitSystem;
            COUNT:      TotalCompJobs;
            ASSIGN:     TFT=TNOW-ENTERANCE;
            TALLY:      AvgFT,INT(Enterance);
            BRANCH, 1 :
                        IF, NC(TotalCompJobs)==CompJobs, YAZ:
                        ELSE, dlt;
YAZ   ASSIGN: PofTarJ=tnum(avgtarADRES)/tnum(avgLtADRES):
                    PofEarJ=tnum(AvgEarADRES)/tnum(avgLtADRES);
WRITE, Statis :TNOW, tavg(AvgFT),nrep;
WRITE, Util: davg(Machine1 Utilization Rate), davg(Machine2
Utilization Rate), davg(Machine3 Utilization Rate), davg(Machine4
Utilization Rate), davg(Machine5 Utilization Rate), davg(Machine6
Utilization Rate)
,NC(Jtype1),NC(Jtype2),NC(Jtype3),NC(Jtype4),NC(Jtype5),NC(Jtype6),N
C(Jtype7),NC(Jtype8),NC(Jtype9),NC(Jtype10),;
WRITE, QLgth: davg(Machine1 Queue Length), davg(Machine2 Queue
Length), davg(Machine3 Queue Length), davg(Machine4 Queue Length),
davg(Machine5 Queue Length), davg(Machine6 Queue Length): NEXT(Dlt);

KONTEk      ASSIGN: arac=1:arastir=0;

BAKIYOR IF: arac<7;
      IF:  arac<>lazim.And.NR(arac)==0.And.NQ(arac)>0;
            ASSIGN:siradan=siradan-1:kac=kac+1:NExt(DURUM1);


      ELSEIF:  arac<>lazim.And.NR(arac)==0.And.NQ(arac)==0;
            ASSIGN:siradan=siradan-1:NExt(DURUM2);

ELSE;
      ASSIGN: arac=arac + 1 : NExt(BAKIYOR);
      ENDIF;
ELSE;
ASSIGN: siradan=siradan +1:NEXT(Dlt);

ENDIF;
 DURUM1 ASSIGN:ortp2=100:girisbak=100000000000:siradan=1;
cabuk IF:siradan<=NQ(arac);
ASSIGN:ortp= AQUE(arac,siradan,NSYM(Ortp));
      IF:ortp==ortp2;
            ASSIGN:giris= AQUE(arac,siradan,NSYM(enterance));
            IF:giris<girisbak;
                        ASSIGN:girisbak=giris:CEKil=siradan;
            ENDIF;
                        ASSIGN:siradan=siradan+1:NEXT(cabuk);
      ELSEIF:ortp<ortp2;
            ASSIGN:ortp2= AQUE(arac,siradan,NSYM(Ortp)):girisbak=
AQUE(arac,siradan,NSYM(enterance)):CEKil=siradan:NEXT(cabuk);
      ELSE;
                  ASSIGN:siradan=siradan+1:NEXT(cabuk);
```

```
            ENDIF;

ELSE;
      ASSIGN:j=CEKil:NEXT(CEK3);
ENDIF;

CEK3   REMOVE:  J, arac, atamaCEK;

ASSIGN:arac=arac+1:NEXT(BAKIYOR);

DURUM2  ASSIGN:yokmu=0:bosmak=arac:kontrol=1:Minort
=100000000: Mindis=100:knt=0;
TARA IF:kontrol<limit;
ASSIGN:yol=Trans(bosmak,P(bosmak,kontrol));
      IF:bosmak==P(bosmak,kontrol);
            ASSIGN:kontrol=kontrol+1:NEXT(tara);
ENDIF;
  IF:yol<Mindis;
      ASSIGN:siradan=siradan +1:NEXT(kucuk);
  ELSEIF:yol==Mindis;
      ASSIGN:siradan=siradan +1:NEXT(esit);
   ELSEIF:yol>Mindis;
      ASSIGN:kontrol=kontrol+1:Next(Tara);
   ENDIF;
ELSE;
      ASSIGN:siradan=siradan+1:NExt(Sonkont);
ENDIF;

KUCUK SEARCH, P(bosmak,kontrol),1,NQ:MIN(Ortp);
IF:J==0;
      ASSIGN:kontrol=kontrol+1:NEXT(tara);
      ELSE;
            ASSIGN:ortp2=100:girisbak=100000000000:siradan=1;
Cabuk2      IF:siradan<=NQ(P(bosmak,kontrol));
ASSIGN:ortp= AQUE((P(bosmak,kontrol)),siradan,NSYM(ortp));
      IF:ortp==ortp2;
            ASSIGN:giris=
AQUE((P(bosmak,kontrol)),siradan,NSYM(enterance));
            IF:giris<girisbak;
                        ASSIGN:girisbak=giris:CEKil=siradan;
            ENDIF;
                        ASSIGN:siradan=siradan+1:NEXT(cabuk2);
      ELSEIF:ortp<ortp2;
            ASSIGN:ortp2=
AQUE((P(bosmak,kontrol)),siradan,NSYM(ortp)):girisbak=
AQUE((P(bosmak,kontrol)),siradan,NSYM(enterance)):CEKil=siradan:NEXT
(cabuk2);
      ELSE;
                  ASSIGN:siradan=siradan+1:NEXT(cabuk2);
            ENDIF;
ELSE;
            ASSIGN:Mindis=yol:
                         Gecicimak=P(bosmak,kontrol):
      Knt=kontrol:ortp2=
AQUE(Gecicimak,CEKil,NSYM(ortp)):sayacak=CEKil:
 kontrol=kontrol+1:girisbak=
AQUE(Gecicimak,CEKil,NSYM(enterance)):NExt(tara);
      ENDIF;
   ENDIF;

ESIT Search,P(bosmak,kontrol),1,NQ :(ortp<=ortp2);
```

```
      IF:J==0;
       ASSIGN: kontrol=kontrol+1:NEXT(Tara);
      ELSE;
      ASSIGN:giris=AQUE ( gecicimak,J,NSYM(enterance)) ;
                IF:ortp==ortp2;
                      IF:giris<girisbak;

                      ASSIGN: Gecicimak=P(bosmak,kontrol):
             ortp2=AQUE(Gecicimak,J,NSYM(ortp)):
           Knt=kontrol:bsm=bosmak:sayacak=J:
   Kontrol=kontrol+1:NEXT(Tara);
                      ELSE;
      ASSIGN:kontrol=kontrol+1:NEXT(tara);
                      ENDIF;
                ENDIF;
      ENDIF;
      SONKONT     IF:Mindis==100.or.knt==0;
                ASSIGN:arac=arac+1:NEXT(BAKIYOR);
            ELSE;
                                  ASSIGN:kontrol=knt:
                NEXT(CEK4);

      ENDIF;
CEK4 REMOVE:  sayacak, gecicimak, atamajok;
 ASSIGN:arac=arac+1:NEXT(dlt);
Atama       ASSIGN: bakalim(opsira)=mach             (opsira-
1):mach(opsira)=mach(opsira-1):
                yol=Trans(MACH(Opsira-1),MACH(opsira)):arastir=1 :
                lazim = Mach(opsira-1):NEXT(ohbe);
ATAMAJok
ASSIGN:yol=Trans(mach(opsira),bosmak):GELmak(opsira)=mach(opsira):ma
ch(opsira)=bosmak:arada=yol+arada:jok(opsira)=1:jokbek(opsira)=
(TNOW-Qentt):QentT=0;

Branch,2:
Always,SHOP:
Always,BAKIYOR;

atamaCEK ASSIGN:arastir=1:NEXT(HAZIR);
Dlt DISPOSE;
END;
```

!Experiment File of scenario 12/Case 2 and 4/Search 1/FL2/90% SHOP utilization

```
BEGIN;
ATTRIBUTES : Enterance: Opsira: OpControl : TotalOp : Operasyon(10)
: Mach(1..10):TFT : QEntT: MachQWT (1..6): OpTimes : SetIndex:
mecbur:
proce(8):proces(8):yol:yold(9):optype(10):cesit:bakalim(10):geciciis
:gecicibas:makq(8):arastir,0:ilkmak,8:arada:jokbek(10):jok(10):gelma
k(10): gecQentt:ortp:giris:girisbak;

VARIABLES:bsm:Ndxe: Wrm:: MachOpTimes(6,11): OpTime(6,11): yEADRES :
deneme: TotDur(6,1): kac:
CompJobs,18000::sayac(6),1,1,1,1,1,1:siradan: bulma:
entsay(6):bir:lazim: ort(6,11):degiskn:arac:kontsayac:limit,4:www:
bittimi:gecici:Mindis:kontrol:gecicimak:bosmak:Minort:sayacak:mutlak
: yokmu:knt:ortp2:cekil:
Trans(1..8,1..8),
0,0.133333,0.266667,0.133333,0.188562,0.298142,0.274874,0,
0.13333,0,0.133333,0.188562,0.133333,0.188562,0.149071,0,
0.266667,0.133333,0,0.298142,0.188562,0.133333,0.066667,0,
0.133333,0.188562,0.298142,0,0.133333,0.266667,0.274874,0,
0.188562,0.133333,0.188562,0.133333,0,0.133333,0.149071,0,
0.298142,0.188562,0.133333,0.266667,0.133333,0,0.066667,0,
0.274874,0.149071,0.066667,0.274874,0.149071,0.066667,0,0,
0,0,0,0,0,0,0,0: Ortpro(1..6,1..6),2.025,2.73,2.73,0,0,0,
                  2.126,2.6,2.73,0,0,0,
                    2.126,2.73,2.6,0,0,0,
                    0,0,0,2.6,2.73,3.36,
                    0,0,0,2.73,2.6,3.36,
                  0,0,0,2.73,2.73,3.2;
QUEUES : Mach1Q,lvf(Ortp) : Mach2Q,LVF(Ortp): Mach3Q,lvf(Ortp):
Mach4Q,lvf(Ortp): Mach5Q,lvf(Ortp): Mach6Q,lvf(Ortp);

STATIONS :  Mach1 : Mach2 : Mach3 : Mach4 : Mach5 : Mach6 :
ExitSystem;
RESOURCES : Mach1R : Mach2R : Mach3R : Mach4R : Mach5R : Mach6R;

SETS : 1,QS1, Mach1Q,Mach2Q,Mach3Q:
      2,QS2, Mach1Q,Mach2Q,Mach3Q:
      3,QS3, Mach1Q,Mach2Q,Mach3Q:
      4,QS4, Mach4Q,Mach5Q,Mach6Q:
      5,QS5, Mach4Q,Mach5Q,Mach6Q:
      6,QS6,Mach4Q,Mach5Q,Mach6Q:
      QUEUESET, Mach1Q , Mach2Q , Mach3Q , Mach4Q , Mach5Q , Mach6Q
:

      MACHINESET, Mach1R , Mach2R , Mach3R , Mach4R , Mach5R ,
Mach6R :

      STATIONSET, Mach1 , Mach2 , Mach3 , Mach4 , Mach5 , Mach6;

      SEQUENCES :1,Types,Mach1&Mach2&Mach3&Mach4&Mach5&Mach6&
                  ExitSystem;
EXPRESSIONS:
Opt(1..6,1..6),

Unif(1.8,2.25),Unif((2.35*1.05),(2.85*1.05)),Unif((2.35*1.05),(2.85*
1.05)),0,0,0,
```

```
Unif((1.8*1.05),(2.25*1.05)),Unif(2.35,2.85),Unif((2.35*1.05),(2.85*
1.05)),0,0,0,

Unif((1.8*1.05),(2.25*1.05)),Unif((2.35*1.05),(2.85*1.05)),Unif(2.35
,2.85), 0,0,0,
       0,0,0, Unif(2.35,2.85),
Unif((2.35*1.05),(2.85*1.05)),Unif((3.15*1.05),(3.25*1.05)),

       0,0,0,Unif((2.35*1.05),(2.85*1.05)), Unif(2.35,2.85),
Unif((3.15*1.05),(3.25*1.05)),
       0,0,0,Unif((2.35*1.05),(2.85*1.05)),
Unif((2.35*1.05),(2.85*1.05)), Unif(3.15,3.25);


PARAMETERS:       1, 1,2,3:
                  2, 1,2,3:
                  3, 1,2,3:
                  4, 4,5,6:
                  5, 4,5,6:
                  6, 4,5,6;
DSTATS:          NQ(Mach1Q), Machine1 Queue Length :
                  NR(Mach1R)*100, Machine1 Utilization Rate :
                  NQ(Mach2Q), Machine2 Queue Length :
                  NR(Mach2R)*100,Machine2 Utilization Rate :
                  NQ(Mach3Q), Machine3 Queue Length :
                  NR(Mach3R)*100,Machine3 Utilization Rate :
                  NQ(Mach4Q), Machine4 Queue Length :
                  NR(Mach4R)*100,Machine4 Utilization Rate :
                  NQ(Mach5Q), Machine5 Queue Length :
                  NR(Mach5R)*100,Machine5 Utilization Rate :
                  NQ(Mach6Q), Machine6 Queue Length :
                  NR(Mach6R)*100,Machine6 Utilization Rate ;

COUNTERS:   TotalCompJobs,18001:
            Jtype1:
            Jtype2:
            Jtype3:
            Jtype4:
            Jtype5:
            Jtype6:
            Jtype7:
            Jtype8:
            Jtype9:
            Jtype10;
TALLIES:    AvgMachQWT:
            AvgFT;

FILES:     1,Statis," Statis _25_8_FL3msPT.xls", seq, wks, dis:
            2,Util,"Util_25_8_FL3msPT.xls", seq, wks, dis:
            3,QLgth, "QLgthUn7f25_8_FL3msPT.xls", seq, wks, dis:
            4,QWait, "QWait25_8_FL3msPT.xls", seq, wks, dis;



REPLICATE, 25, 0, ,yes, yes, Wrm;

END;
```