BUFFER ALLOCATION STRATEGIES IN SHOP FLOOR USING SIMULATION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

in

Mechanical Engineering

By

SANJIT JESTHI

AND

ABHINAV CHANAKYA

Department of Mechanical Engineering
National Institute of Technology
Rourkela
2007

BUFFER ALLOCATION STRATEGIES IN SHOP FLOOR USING SIMULATION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

in

Mechanical Engineering

By

SANJIT JESTHI

AND

ABHINAV CHANAKYA

Under the guidance of

Dr. S.S.MAHAPATRA

Department of Mechanical Engineering
National Institute of Technology
Rourkela

2007

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "BUFFER ALLOCATION STRATEGIES IN SHOP FLOOR USING SIMULATION" submitted by Sri. SANJIT JESTHI and Sri. ABHINAV CHANAKYA in partial fulfillments for the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date: 1st –May-2007

Dr. S.S. Mahapatra
Prof., NIT Rourkela
Dept. of Mechanical Engineering
NIT, Rourkela.

ACKNOWLEDGEMENT

We wish to express our deep sense of gratitude and indebtedness to Dr. S. S. Mahapatra, Department of Mechanical Engineering, N.I.T Rourkela for introducing the present topic and for his inspiring guidance, constructive criticism and valuable suggestion throughout this project work.

We would like to express our gratitude to Dr. B.K. Nanda (Head of the Department) for his constant support and encouragement. We are also thankful to all staff members of Department of Mechanical Engineering, NIT Rourkela.

Date: 1ST-May-2007

Abhinav Chanakya
Roll: 10303062

Sanjit Jesthi
Roll: 10303066

CONTENTS

LIST OF FIGURES:

ABSTRACT

Buffer allocation is considered to be an important strategy in real life production system because 75% of working capital is tied up in-process inventory in any industry. Therefore an optimum buffer allocation strategy may help in better inventory management of the industry. Consideration of buffer strategy and work distribution play vital role in design of flow lines. However analysis of flow lines using queuing theory become intractable when number of machines increases.

Simulation models were made with discrete event simulation being adopted to gain better insight into the problem. To this end, a flow line model has been developed using EXTEND- v.4 to conduct experiments to meet the objective of designing flow lines for buffer allocation and work allocation. The effect of varying number of inter-stage buffers, varying time of each machine, using different process input to study the corresponding outcome is to be experimented ahead.

On the basis of analysis of all three models we came to know about some basic patterns like

1) Maximum queue length increase with buffer capacity.
2) Average queue length increases with buffer capacity.
3) Average wait increases with buffer capacity.
4) Throughput increases with buffer capacity.
5) Machine utilization increases with buffer capacity to some extend
6) Maximum wait increases with buffer capacity.

Now coming to the most important part of the project that is analysis of practical model from toy car industry. This industry has a small floor space between the assembling line which can accommodate a maximum of ten buffers. So they wanted us to analyze their flow process and tell them what would be the best strategy for smooth flow of assembling process. Then we made the simulation model of there process and analyzed for three most important inter-stage buffers.

By increasing the middle buffer than side buffer gave higher output than by increasing the side buffers. This trend was prominent, but only upto the strategy 4-6-4 then the increase in throughput was very marginal and will not be economical considering increase in required floor area, reprocessing investment(in some cases due to long wait).

On the basis of all this study we concluded and suggested them that 4 – 6 – 4 buffer allocation strategies will be the best one for their toy car assembling process.

Chapter 1

INTRODUCTION

1. INTRODUCTION:

This study investigates the buffer allocation strategy of a flow-shop-type production system that possesses a given total amount of buffers and finite buffer capacity for each workstation as well as general inter-arrival and service times in order to optimize such system performances as minimizing work-tin-process, cycle time and blocking probability, maximizing throughput, or their combinations. In theory, the buffer allocation problem is in itself a difficult NP-hard combinatorial optimization problem; it is made even more difficult by the fact that the objective function is not obtainable in closed form for inter-relating the integer decision variables (i.e., buffer sizes) and the performance measures of the system. Therefore, the purpose of this paper is to present an effective design methodology for buffer allocation in the production system. Our design methodology uses a dynamic programming process along with the embedded approximate analytic procedure for computing system performance measures under a certain allocation strategy. Numerical experiments show that our design methodology can quickly and quite precisely seek out the optimal or sub-optimal allocation strategy for most production system patterns. Buffer allocation is an important, yet intriguingly difficult issue in physical layout and location planning for production systems with finite floor space. Adequate allocation and placement of available buffers among workstations could help to reduce work-in-process, alleviate production system's congestion and even blocking, and smooth products manufacturing flow. In view of the problem complexity, we focus on flow-shop-type production systems with general arrival and service patterns as well as finite buffer capacity. The flow-shop-type lines, which usually involve with product-based layout, play an important role in mass production type of manufacturing process organization such as transfer line, batch flow line, etc. The purpose of this paper is to present a design methodology with heuristic search and imbedded analytic algorithm of system performances for obtaining the optimal or sub-optimal buffer allocation strategy. Successful use of this design methodology would improve the production efficiency and effectiveness of flow-shop-type production systems.

Chapter 2

SIMULATION

2.1 SIMULATION – A MODELLING TOOL:

The operation of various kinds of real-world facilities or processes can be achieved through simulation. The facility or process of interest is usually called a system, and in order to study it significantly we often have to make a number of assumptions about hoe to works. These assumptions, which usually take the form of mathematical or logical assumptions, constitute a model that is used to try to gain some understanding of how that corresponding system behaves. If the relationship that compose the model are simple enough, it may be possible to use mathematical model and methods (such as algebra, calculus or probability theory) to obtain exact information on questions of interest; this is called an analytical solution. However, most real world problems are too complex to allow these models to be evaluated analytically and these models must be studied by means of simulation. In a simulation we use a computer to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristic of the model. As an example of the use of simulation, consider a manufacturing company that is contemplating building a large extension onto one of its plants but is not sure if the potential gain in productivity would justify the construction cost. If certainly wouldn't b e cost efficient to build the extension and then re move it later if it doesn't work-out. However a careful simulation study could throw some light on the question by simulating the operation of the plant as it certainly exists and as it would be if the operation of the plant were expanded.

Application areas of simulation are numerous and diverse. Below is the list of particular kind of problems for which simulation has been found to be useful and powerful tool:

1. Designing and analyzing manufacturing systems.
2. Evaluating military weapon systems or their logistic requirements.
3. Determining hardware and software requirements of computer systems.
4. Determining hardware requirements or protocols for communication networks.
5. Designing and operating transportation system such as airports, freeways, ports and subways.

6. Evaluating design for service organizations such as call-centers, restaurants, banks, hospitals and offices.
7. Re-engineering of business processes.
8. Determining ordering policies of an investor system.
9. Analyzing financial or economic system.

Simulation is one of the most widely use operations-research and management science techniques, if not the most widely used. One indication of this is the winter

Simulation Conference which attracts 600 to 700 people every year. In addition there are several conferences with over 100 participants per year. There have been, however, several impediments to even wider acceptance of simulation. First, models used to study large scale systems tend to be very complex, and writing computer programs to execute them can a tedious task indeed. This task has been made much easier by the years by developing excellent softwares products that automatically provide many of the features needed to program a simulation model. A second problem with simulation is complex system is that a large amount of computer time is sometimes required. However, this difficulty is becoming much less severe as computer become faster and cheaper. Finally there appears to be an unfortunate impression that simulation is just an exercise in computer programming, albeit a complicated one. Consequently, many simulation studies have composed of heuristics model building, coding and a single run of the program to obtain the answer. We fear that this attitude , which neglects the important issue of how a properly coded model should be used to make interferences about the system of interest, has doubtlessly led to erroneous conclusions being drawn from many simulation studies.

2.1.1 Advantages of simulation:

1. Most complex, real world system with stochastic elements can not be accurately described by a mathematical model that can be evaluated analytically. Thus a simulation is the only type of investigation possible.
2. Simulation allows one to estimate the performance of an existing system under some projected set of operating conditions.

3. Alternative proposed system design or alternative operating policies for a single system can be compared via simulation to see which best meets specified requirements.
4. In a simulation we can maintain much better control over experimental conditions that would not be generally possible while operating on system itself.
5. Simulation allows us to study a system with a long time frame.

2.1.2 Disadvantages of Simulation:

1. Each run of stostic simulation model produces only estimate of a models true characteristics for a particular set of input parameters. Thus several independent runs of the model will be probably required for each set of input parameters to be studied.
2. Simulation models are generally time consuming and expensive to develop.
3. Larger volume of number produced by a simulation study or a persuasive impact of a realistic animation often creates a tendency to place greater confidence in a study's result than is justified.
4. If a model is not a valid representation of a system under study the simulation result, no matter how impressive it maybe, would provide little information about the system.

2.1.3 Pit-fall of Simulation:

- Failure to have a well defined set of objects at the beginning of simulation.
- Inappropriate level of model details.
- Failure to communicate with management throughout the course of simulation study.
- Misunderstanding of simulation by management.
- Treating a simulation study as if it were primarily an exercise in computer programming. Failure to have people to have knowledge of simulation methodology and statistic on the modeling team.

2.2 SOFTWARE USED FOR SIMULATION:

Extend from Imagine That Inc. is simulation software which the company advertises as software for the next millennium. I had not seen this software before, and therefore, was not sure of what to expect from it. But I was pleasantly surprised with its abilities after working with it for a few days. *Extend* is supplied on a CD, accompanied by a Users Manual which covers various topics such as building a model, enhancing the model and running the model with the blocks provided with the model. It also has extensive discussion on the programming language ModL with which new blocks can be created. Software can run on both Windows as well as Macintosh platforms. The requirements for Windows version are: 486, Pentium or Pentium Pro computer, 8 MB RAM (16 MB recommended), 20 MB hard disk space and Windows 3.1, Windows 95 or above, or Windows NT 3.5+. The requirements for Macintosh are 68020+ or Power Macintosh, 8 MB RAM, 25 MB hard disk space. The installation itself is extremely simple, straightforward and fast. I tried it out on a Pentium MMX 200 MHz/32 Mb with Windows 95, and it took less than 5 minutes. One of the best features of the design of *Extend* is the ease of building the model and running them. With *Extend* you can create a block diagram of a process where each block describes one part of the process. *Extend* comes with a wide variety of blocks (in excess of 400) which are stored in different libraries. The libraries provided with *Extend* are Generic, Discrete Event and Plotter. Other libraries include animation, electronic engineering, utility and sample libraries. Apart from these libraries that come with basic package, the blocks available in these libraries are sufficient to meet the requirements of most of the simulations in a variety of fields such as business, science and engineering. Some of the examples provided along with the software, such as car wash line, lake pollution, drug absorption in blood, predator–prey model, PID control of the process convinced me about the wide range of the applicability of the software. These blocks come with different types of connectors with which blocks can be assembled in the desired manner for building the model. The connections can be made by using the graphical interface (GUI) with the click of the mouse. For more complex models, a concept of hierarchy blocks can be used. A hierarchy blocks concept represents the subsystems of the model and these can be easily interfaced. It is possible to extend the applicability by creating the custom-made blocks as per your requirement. This can be done in ModL language which is similar to C language. The package also includes extensive plotting software to view the results of the simulation. Some of the other features of the software are: sensitivity analysis to investigate how a parameter change impacts the pattern of behavior for the entire model, cross platform compatibility between Windows & Macintosh, interfacing with C and Fortran language, I/O links with other software, etc. I tried several demonstration programs supplied with the package and found running them very easy. What interested me most was the ease with which one could understand the process by looking at the model on the screen. This, I believe, is the result of block representation and connections, what you see on the screen are the translation of your conceptual idea of the model (flow diagram) into a computer model. The large numbers of equations which are characteristic of the typical model written in any programming language are invisible. This makes understanding of the model much easier not only for the developer of the model but also for the subsequent users. This, I found, is one of the appealing features of this software. I have not seen such a type of software before. I feel that the software can form an excellent tool as a teaching aid to demonstrate various ideas. I also tried developing a model for chemical reactor using the blocks provided with the package and I found it relatively easy. I did not try building my own blocks using ModL language but I suspect it will require considerable familiarity with the language and efforts will be similar to writing any C language program. I did not find some of the functions such as solving nonlinear algebraic equations (which I use very often) as a part of this package. Perhaps one will have to develop custom blocks to do so. I also found options in some of the blocks limited. For example, integrate block has the option of only using Euler's forward or backward method or trapezoidal rule. These may be enough for most applications but some stiff differential equations may require different methods. The manual which accompanies the software gives extensive guidelines for simulations and on-line help is also available. However, the help is given according to block name and function which presumes you know these names. I missed the standard Contents/Index/Find format of Windows applications. *Extend* has a presence on the World Wide Web (http://www.imaginethatinc.com). The company's homepage contains a lot of useful information and also lists several companies who are offering model development support, training and consultancy based on this software. With site licenses and volume discounts, it is likely that they would be less expensive. Apart from basic package, the company offers two add-ons, business processes reengineering (BPR) and Manufacturing Engineering packages, of course at extra cost. The site also announces free demonstration copies. Once you see the facilities of *Extend*, there is a very good chance that you would be justifiably tempted to buy it. Not having seen the comparable versions of the other competing products, it is not possible for me to give any authoritative opinion on cost-effectiveness of the package. However, to have all these facilities in a single, powerful, easy-to-use, continuously improving, and internet-supported package is something which is strongly in favour of *Extend*. There is no doubt whosoever needs to carry out model building and simulation would find that use of *Extend* leads to a substantial enhancement in productivity in research, development and teaching. It may even motivate some to undertake innovative and ambitious modeling exercises.

Chapter 3

MODEL -1

3.1 DESCRIPTION:

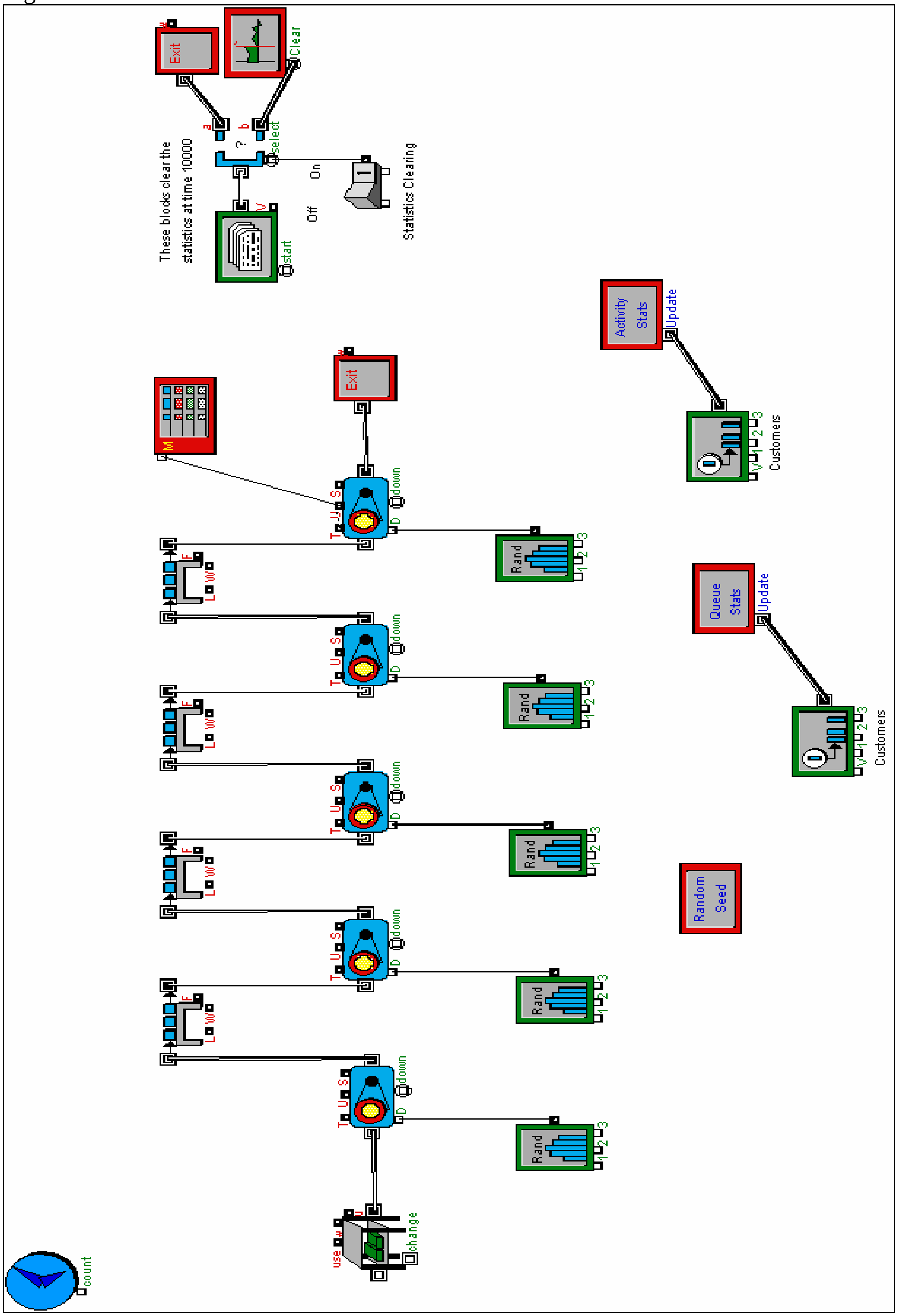
A flow line model was designed with the following vital parameters using *EXTEND* v-4.

- Number of machines = 5
- Number of inter-stage buffers = 4
- Buffer capacity = n
- Number of runs = 10
- Statistic clearance at = 10,000
- Data collected in each run = 10,000
- Processing time of each machine is exponentially distributed with mean 2

3.2 SIMULATION CONDUCTED:

1. Varying buffer capacity.
2. Varying inter-stage buffers.
3. Varying machine parameters

Fig: 3.1


These blocks clear the statistics at time 10000
Exit
Clear
select
start
On
Off
Statistics Clearing
Activity Stats
Update
Customers
Queue Stats
Update
Customers
Random Seed
Rand
down
change
use
count

3.3 DATA COLLECTED:

The result for various values of buffer capacity and different buffer allocation strategies were noted by simulating to model development.

The data collected for each simulation were:-

- For buffer:
    1. Average length of queue.
    2. Maximum length of queue.
    3. Average waiting time.
    4. Maximum waiting time.
- For machines:
    1. Number of arrivals.
    2. Number of departure.
    3. Machine utilization.

These data were obtained as per 95% confidence interval. The number of buffers was kept same but the buffer capacity was varied from 1 to 3.

Statistic clearance was done at 10,000 time units and the simulation reading taken for more 10,000 time units. The previous time was excluded so as to take reading after machines achieved steady state.

Buffer allocation Strategy - 1 , 1 , 1, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	0.708±0.00572	1.00±0.00	2.34±0.0236	17.9±1.24
6	Buffer	0.579±0.00693	1.00±0.00	1.92±0.0273	17.9±1.14
10	Buffer	0.466±0.00524	1.00±0.00	1.54±0.0193	16.4±0.936
17	Buffer	0.323±0.00442	1.00±0.00	1.07±0.0153	15.6±1.21

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3022±13.84	3021±13.87	0.6062±0.00416
3	Machine	3021±13.91	3020±13.94	0.7343±0.002845
4	Machine	3020±14.04	3019±14.12	0.701±0.005121
5	Machine	3020±14.17	3019±14.19	0.6675±0.004288
11	Machine	3019±14.32	3018±14.37	0.6051±0.004446

Buffer allocation Strategy - 1 , 1 , 2, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	0.677±0.0066	1.00±0.00	2.17±0.0282	17.4±1.25
6	Buffer	0.519±0.00963	1.00±0.00	1.66±0.0322	17.1±1.46
10	Buffer	0.89±0.0247	2.00±0.00	2.85±0.0821	20.8±1.95
17	Buffer	0.35±0.00773	1.00±0.00	1.12±0.0258	15.0±1.92

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3128±14.43	3127±14.42	0.6286±0.005611
3	Machine	3127±14.38	3127±14.40	0.7447±0.00436
4	Machine	3127±14.50	3126±14.53	0.6906±0.005076
5	Machine	3126±14.49	3125±14.47	0.6957±0.006641
11	Machine	3125±14.31	3124±14.23	0.6251±0.00579

Buffer allocation Strategy - 2 , 1 , 1, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	1.54±0.0128	2.00±0.00	4.98±0.053	23.9±1.10
6	Buffer	0.631±0.0074	1.00±0.00	2.04±0.03	18.0±1.10
10	Buffer	0.493±0.00569	1.00±0.00	1.60±0.0214	16.7±1.25
17	Buffer	0.338±0.00501	1.00±0.00	1.09±0.0175	15.6±1.32

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3090±13.72	3089±13.68	0.6197±0.005114
3	Machine	3089±13.60	3088±13.59	0.7712±0.003496
4	Machine	3088±13.54	3087±13.45	0.725±0.004544
5	Machine	3087±13.41	3087±13.43	0.6864±0.004013
11	Machine	3087±13.37	3086±13.34	0.6185±0.004936

Buffer allocation Strategy - 1 , 2 , 1, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	0.676±0.00567	1.00±0.00	2.16±0.0216	18.6±1.22
6	Buffer	1.21±0.018	2.00±0.00	3.85±0.0661	23.1±1.63
10	Buffer	0.514±0.00756	1.00±0.00	1.64±0.027	16.9±1.05
17	Buffer	0.347±0.00497	1.00±0.00	1.11±0.0171	15.5±1.18

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3131±14.03	3130±14.07	0.6282±0.00421
3	Machine	3130±14.07	3129±14.06	0.7355±0.004022
4	Machine	3129±14.01	3128±13.94	0.7388±0.004144
5	Machine	3128±13.98	3127±13.96	0.6996±0.003713
11	Machine	3127±13.98	3127±14.09	0.6258±0.004741

Buffer allocation Strategy - 1 , 1 , 1, 2

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	0.693±0.00635	1.00±0.00	2.25±0.0213	17.9±0.98
6	Buffer	0.549±0.00876	1.00±0.00	1.78±0.0313	17.1±0.956
10	Buffer	0.409±0.00624	1.00±0.00	1.33±0.0213	16.0±1.12
17	Buffer	0.525±0.0113	2.00±0.00	1.70±0.0365	19.2±1.29

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3083±12.01	3082±12.05	0.6182±0.004719
3	Machine	3083±12.05	3082±12.04	0.7394±0.003043
4	Machine	3082±12.01	3081±12.05	0.6985±0.005729
5	Machine	3081±12.01	3080±12.09	0.6501±0.004706
11	Machine	3080±12.11	3080±12.08	0.6173±0.005733

Buffer allocation Strategy - 1 , 2 , 2, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	0.629±0.00626	1.00±0.00	1.91±0.0232	17.6±1.25
6	Buffer	0.991±0.0216	2.00±0.00	3.01±0.0737	20.8±1.15
10	Buffer	0.844±0.0161	2.00±0.00	2.56±0.0485	20.6±1.34
17	Buffer	0.624±0.0148	2.00±0.00	1.89±0.0449	19.9±1.44

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3300±18.24	3299±18.19	0.6626±0.004599
3	Machine	3299±18.07	3299±18.17	0.7466±0.003389
4	Machine	3298±18.33	3298±18.38	0.7289±0.005409
5	Machine	3297±18.40	3296±18.36	0.7057±0.00451
11	Machine	3297±18.43	3296±18.46	0.6585±0.006214

Buffer allocation Strategy - 1 , 3 , 3 , 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
6	Buffer	1.37±0.0366	3.00±0.00	4.01±0.107	25.3±1.66
7	Buffer	0.592±0.00629	1.00±0.00	1.73±0.0217	17.6±1.08
10	Buffer	1.34±0.027	3.00±0.00	3.90±0.0789	24.6±1.07
17	Buffer	0.698±0.0165	2.00±0.00	2.04±0.0481	19.8±1.40

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3426±18.04	3425±18.05	0.688±0.005799
3	Machine	3425±18.01	3424±17.98	0.7494±0.002897
4	Machine	3424±18.13	3424±18.22	0.7464±0.006654
5	Machine	3424±18.13	3423±18.18	0.7415±0.003856
11	Machine	3423±18.39	3422±18.37	0.684±0.006024

Buffer allocation Strategy - 2 , 2 , 2, 2

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	1.37±0.0127	2.00±0.00	4.04±0.0512	22.6±0.991
6	Buffer	1.13±0.0174	2.00±0.00	3.34±0.0602	21.3±1.09
10	Buffer	0.927±0.0196	2.00±0.00	2.73±0.0576	20.7±1.25
17	Buffer	0.669±0.0167	2.00±0.00	1.97±0.0492	19.3±1.24

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3392±20.44	3391±20.42	0.681±0.005525
3	Machine	3391±20.39	3390±20.47	0.7918±0.00279
4	Machine	3390±20.52	3390±20.45	0.7601±0.005106
5	Machine	3389±20.49	3389±20.53	0.7318±0.005166
11	Machine	3389±20.48	3388±20.45	0.6776±0.006074

Buffer allocation Strategy - 2 , 3 , 2 , 2

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	1.33±0.0153	2.00±0.00	3.84±0.0511	22.8±1.22
6	Buffer	1.76±0.0284	3.00±0.00	5.09±0.087	25.9±1.47
10	Buffer	1.01±0.0168	2.00±0.00	2.91±0.0486	21.1±1.18
17	Buffer	0.704±0.0131	2.00±0.00	2.04±0.0376	20.1±1.48

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3463±16.33	3462±16.37	0.6953±0.006085
3	Machine	3461±16.33	3460±16.37	0.7931±0.002665
4	Machine	3460±16.59	3459±16.62	0.7871±0.00473
5	Machine	3459±16.66	3459±16.64	0.7517±0.004562
11	Machine	3459±16.50	3458±16.48	0.6916±0.00523

Buffer allocation Strategy - 2 , 3 , 3 , 2

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	1.29±0.0112	2.00±0.00	3.66±0.0399	22.7±1.34
6	Buffer	1.62±0.0354	3.00±0.00	4.59±0.107	25.7±1.78
10	Buffer	1.46±0.0345	3.00±0.00	4.15±0.0962	24.5±1.13
17	Buffer	0.742±0.0161	2.00±0.00	2.10±0.0441	19.8±1.19

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3528±20.54	3527±20.54	0.7085±0.004659
3	Machine	3527±20.37	3526±20.35	0.796±0.003746
4	Machine	3526±20.36	3525±20.38	0.7798±0.005935
5	Machine	3524±20.12	3523±20.12	0.7685±0.005379
11	Machine	3523±19.68	3523±19.58	0.7047±0.006471

Buffer allocation Strategy - 3 , 3 , 3 , 3

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	2.01±0.0249	3.00±0.00	5.53±0.0839	27.1±1.26
6	Buffer	1.68±0.0364	3.00±0.00	4.62±0.107	26.1±1.49
10	Buffer	1.39±0.0277	3.00±0.00	3.83±0.0732	24.7±0.99
17	Buffer	1.03±0.0329	3.00±0.00	2.83±0.0851	23.3±1.26

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3642±21.83	3641±21.87	0.7308±0.006073
3	Machine	3641±21.42	3640±21.44	0.828±0.003784
4	Machine	3639±21.31	3638±21.26	0.7991±0.006074
5	Machine	3638±20.81	3637±20.79	0.7729±0.004615
11	Machine	3637±20.67	3636±20.63	0.7277±0.008329

Buffer allocation Strategy - 3 , 2 , 2 , 3

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	2.15±0.0228	3.00±0.00	6.18±0.0812	27.8±1.21
6	Buffer	1.17±0.0204	2.00±0.00	3.36±0.0639	21.9±0.97
10	Buffer	0.884±0.0146	2.00±0.00	2.54±0.0411	20.0±1.04
17	Buffer	0.904±0.0221	3.00±0.00	2.59±0.0616	22.8±1.22

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3489±18.18	3488±18.18	0.7004±0.005534
3	Machine	3487±18.39	3487±18.43	0.821±0.002673
4	Machine	3486±18.71	3486±18.67	0.7777±0.005401
11	Machine	3485±18.69	3484±18.64	0.6968±0.005807

Buffer allocation Strategy - 3 , 2 , 3, 2

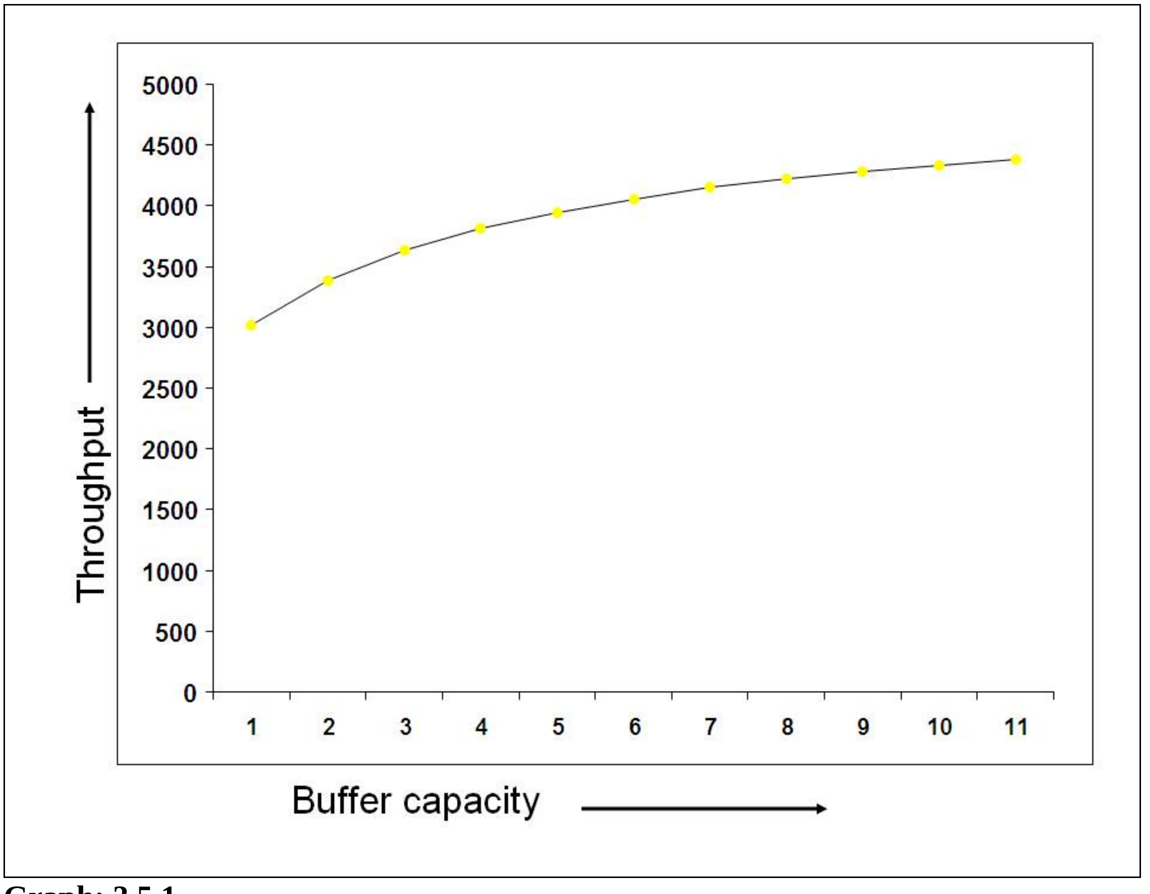
Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
7	Buffer	2.13±0.0194	3.00±0.00	6.05±0.0732	27.0±1.08
6	Buffer	1.14±0.0204	2.00±0.00	3.24±0.0668	21.1±1.10
10	Buffer	1.43±0.0315	3.00±0.00	4.07±0.0892	25.1±1.21
17	Buffer	0.734±0.0148	2.00±0.00	2.09±0.0414	20.5±1.32

Block	Block Name	Arrival	Departure	Utilization
2	Machine	3515±19.65	3514±19.63	0.706±0.005199
3	Machine	3514±19.23	3513±19.20	0.8222±0.003722
4	Machine	3513±19.23	3512±19.27	0.773±0.00588
11	Machine	3511±18.94	3510±18.93	0.7021±0.005928

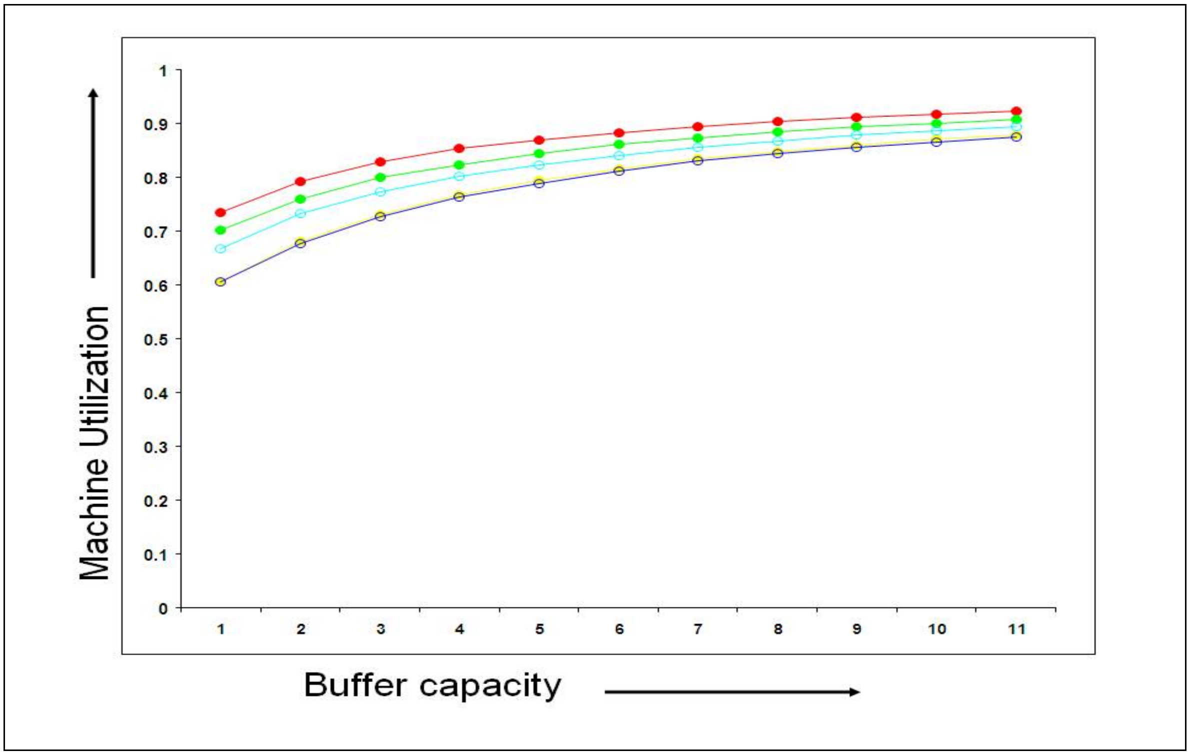
3.4 CONCLUSION DRAWN SO FAR:

1. Increase in buffer capacity increased machine utilization.
2. Increase in buffe5r capacity increased number of departures.
3. Strategy of buffer allocation with 1-2-2-1 gave better utilization and greater number of departure than 2-1-1-2. Similarly 2-3-3-2 gave better results than 3-2-2-3. These data conclude that if buffer allocation is increased in idle stages then the machine utilization is more and number of departures is also higher then when buffer allocation is increased at end stages.
4. Waiting time was also found to increase with increase of buffer capacity.
5. Increasing buffer capacity increased productivity. But the rise in productivity per rise in buffer capacity was marked to reduce as buffer capacity was increased.

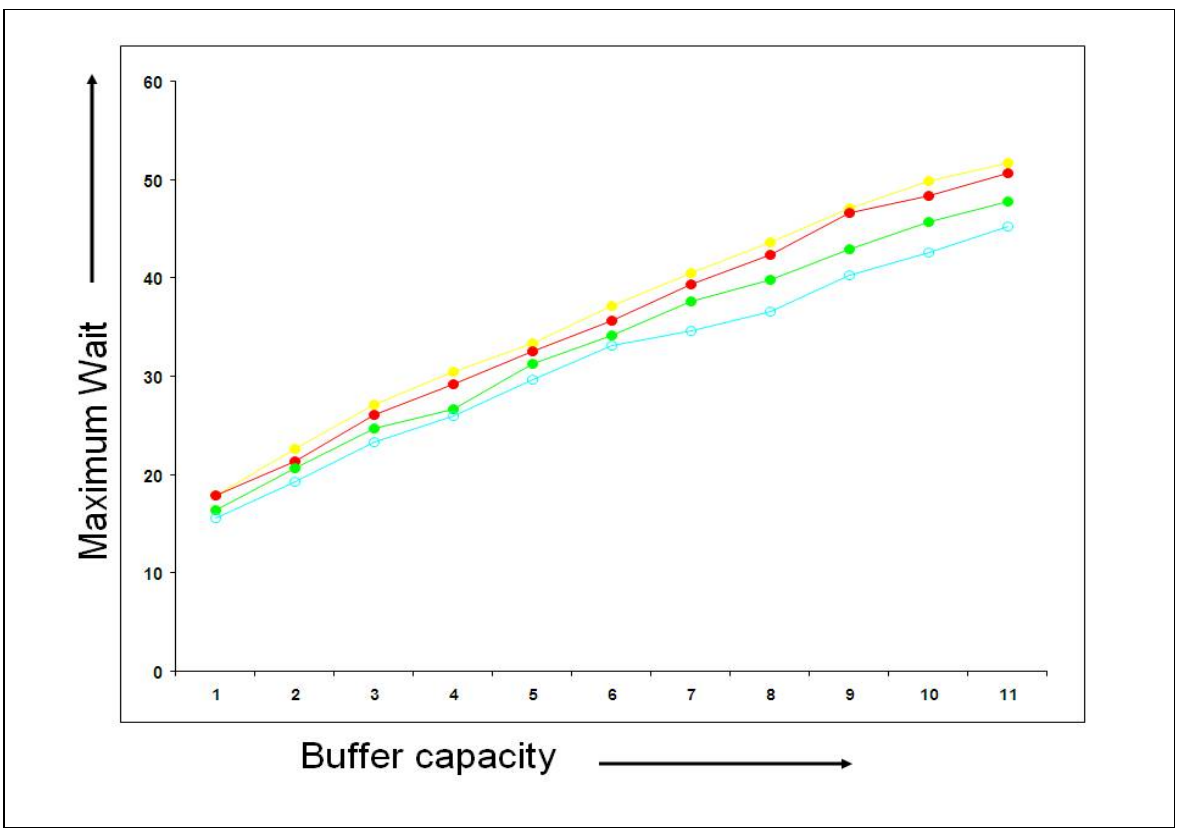
3.5 GRAPHS:



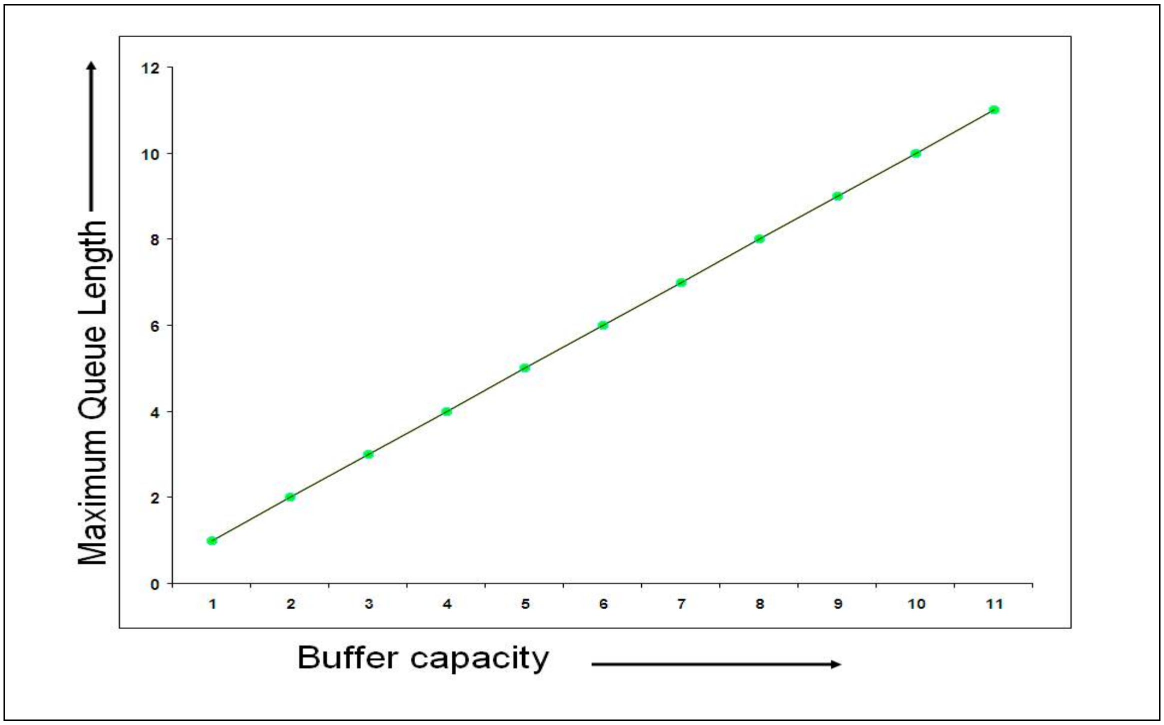
Graph: 3.5.1



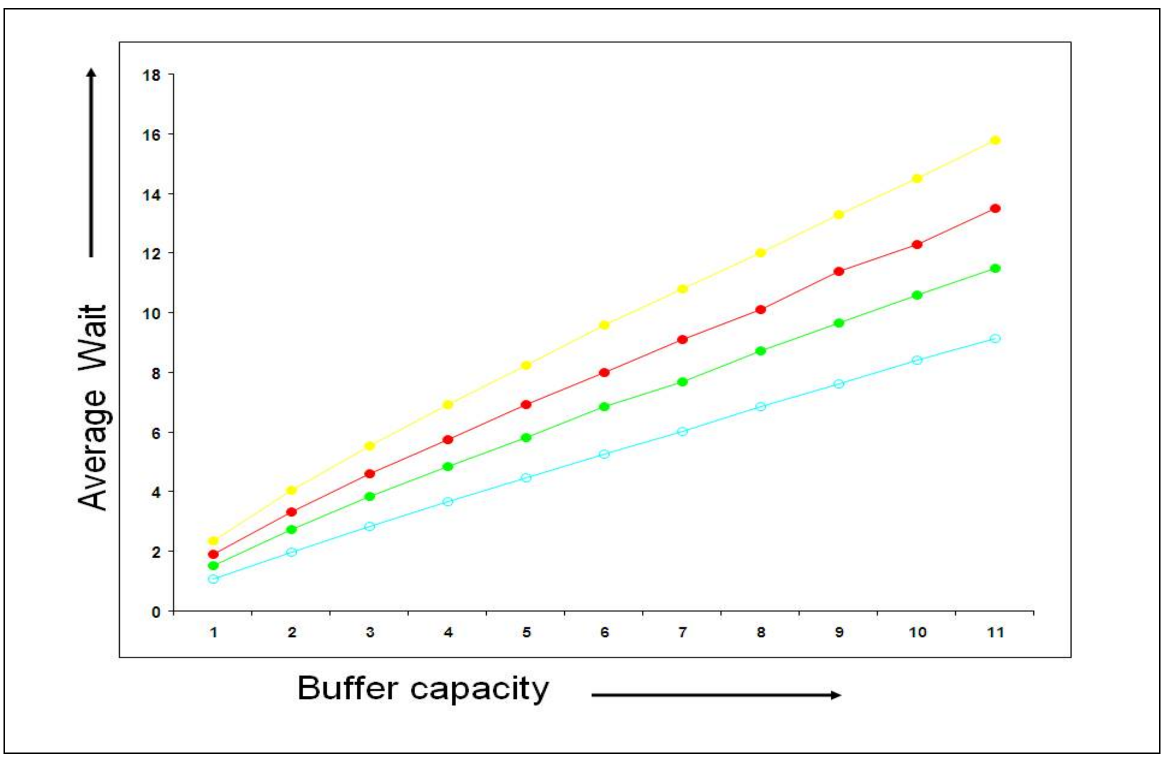
Graph: 3.5.2



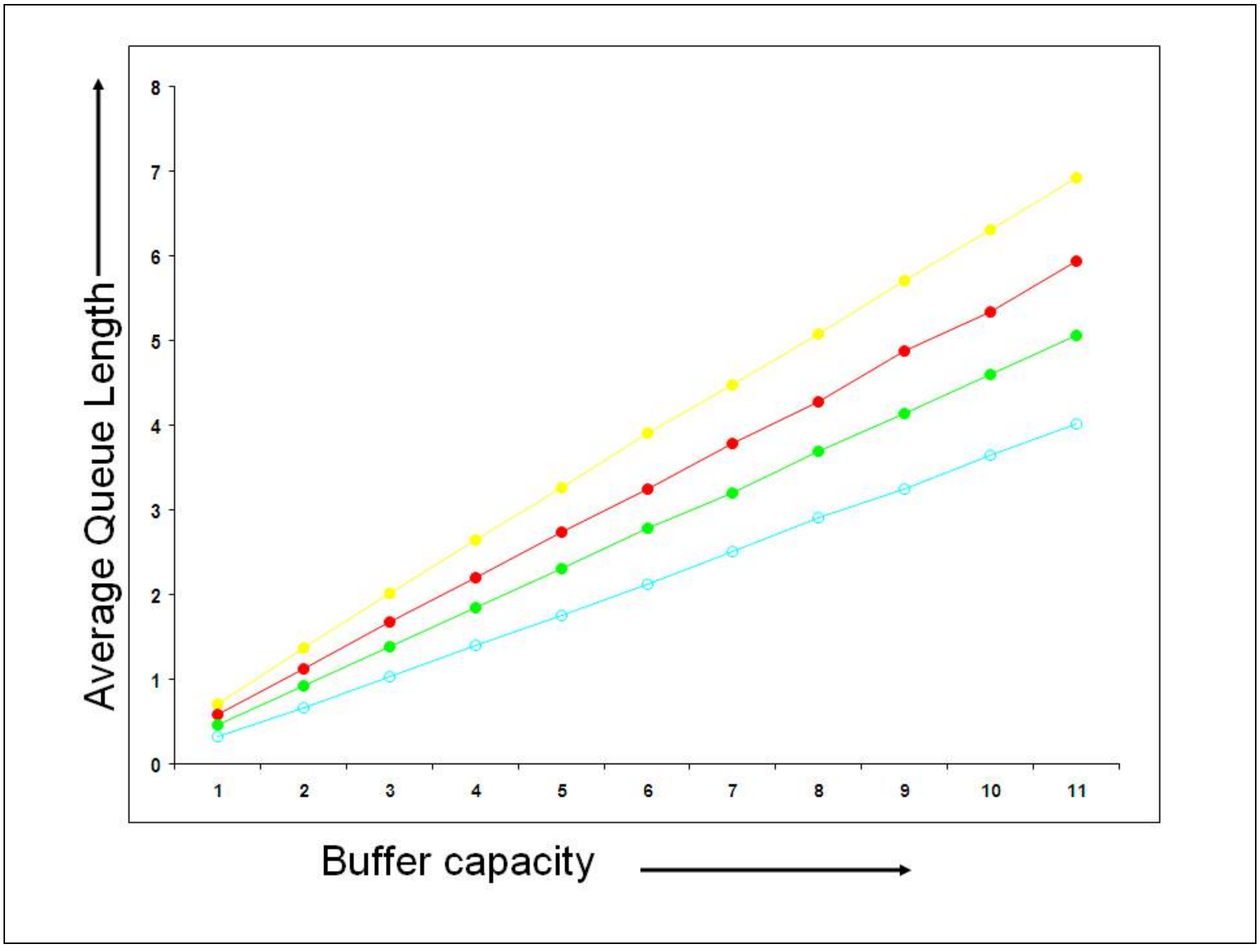
Graph: 3.5.3



Graph: 3.5.4



Graph: 3.5.4



Graph: 3.5.5

3.6 CONCLUSIONS FROM GRAPHS:

1. **Maximum queue length Vs Buffer Capacity:**

   Graph shows a constantly increasing trend. Here buffer capacity was varied from 1 to 11 we observed constant increase in Maximum queue length.

2. **Average queue length Vs Buffer Capacity:**

   Graph shows a constantly increasing trend for all the four machines. While varying the buffer from 1 to 11 we observed constant increase in average queue length with maximum of 7.1 in machine 4.

3. **Average wait Vs Buffer Capacity:**

This graph also shows a constantly increasing trend for all the four machines. While varying the buffer from 1 to 11 we observed constant increase in average wait with maximum 15.8 time units in machine 4.

4. **Throughput Vs Buffer Capacity:**

Graph shows a constantly increasing trend with saturation while varying the buffer from 1 to 11. We observed constant increase in throughput but the rate of increase in throughput decreases that is it shows saturation.

5. **Machine utilization Vs Buffer Capacity:**

Graph shows a saturation type of increasing trend for all four machines while varying the buffer from 1 to 11.

6. **Maximum wait Vs Buffer Capacity:**

Graph shows a constantly increasing trend while varying the buffer from 1 to 11 for all four machines.

Chapter 4

ASSEMBLY LINE MODEL

4.1 INTRODUCTION:

Productivity improvement in assembly lines is very important because it increases capacity and reduces cost. If the capacity of the line is insufficient, one possible way to increase the capacity is to construct parallel lines. In this study, new procedures and a mathematical model on the single model assembly line balancing problem with parallel lines are proposed. The procedures are illustrated with numerical examples. Lastly, active case procedure and the mathematical **model** are tested on well-known problems in the line balancing literature.

4.2 DESCRIPTION:

The assembly line model was designed with following vital parameters using *EXTEND-v4.*

- Number of machines = 3
- Number of inter-stage buffers = 3
- Buffer capacity = n
- Number of runs = 10
- Statistic clearance at = 10,000
- Data collected in each run = 10,000
- Processing time of each machine is exponentially distributed.
    - Mean of machine 1 = 1
    - Mean of machine 2 = 10
    - Mean of machine 3 = 3

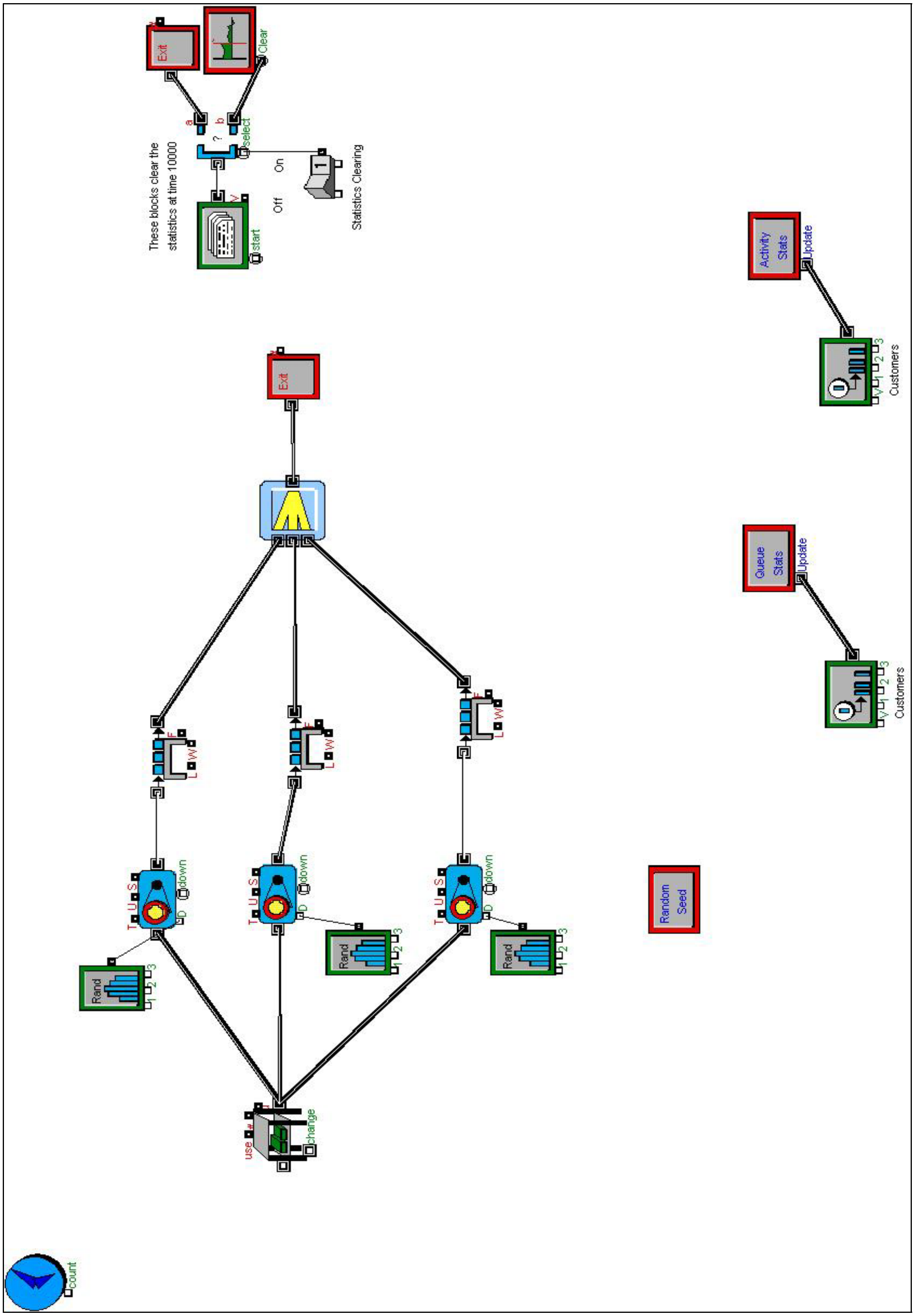

These blocks clear the
statistics at time 10000
Exit
Clear
start
select
On
Off
Statistics Clearing
Exit
Activity
Stats
Update
Customers
Queue
Stats
Update
Customers
down
down
down
Rand
Rand
Rand
Random
Seed
change
use
count

Fig: 4.1

4.2 DATA COLLECTED:

Buffer allocation Strategy - 1 , 1 , 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.128±0.00576	1.00±0.00	0.284±0.0129	28.4±2.00
33	Buffer	1.00±0.000107	1.00±0.00	22.1±0.124	45.5±2.24
34	Buffer	0.128±0.0058	1.00±0.00	0.284±0.0133	28.6±2.66

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4511±24.45	4510±24.45	0.9024±0.004964
4	Machine	452.2±2.606	451.6±2.547	0.0894±0.001877
5	Machine	4511±24.73	4510±24.75	0.9027±0.004422

Buffer allocation Strategy - 1 , 2, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.128±0.00576	1.00±0.00	0.284±0.0129	28.4±2.00
33	Buffer	2.00±0.000219	2.00±0.00	44.3±0.252	74.7±2.83
34	Buffer	0.128±0.0058	1.00±0.00	0.284±0.0133	28.6±2.66

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4511±24.45	4510±24.45	0.9024±0.004964
4	Machine	452.7±2.734	452.1±2.644	0.08944±0.00199
5	Machine	4511±24.73	4510±24.75	0.9027±0.004422

Buffer allocation Strategy - 2 , 1 , 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.271±0.0134	2.00±0.00	0.595±0.0302	28.9±2.26
33	Buffer	1.00±0.00012	1.00±0.00	22.0±0.129	44.8±1.39
34	Buffer	0.117±0.00595	1.00±0.00	0.258±0.0137	27.9±1.87

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4551±25.84	4550±25.79	0.9106±0.005704
4	Machine	456.3±2.729	455.8±2.625	0.09008±0.00195
5	Machine	4551±25.44	4550±25.42	0.9106±0.004798

Buffer allocation Strategy - 2, 1, 2

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.25±0.0121	2.00±0.00	0.546±0.027	29.8±1.92
33	Buffer	1.00±6.44e-005	1.00±0.00	21.8±0.134	46.3±2.51
34	Buffer	0.247±0.0117	2.00±0.00	0.538±0.027	30.1±2.06

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4585±27.71	4585±27.67	0.9178±0.004933
4	Machine	459.8±2.935	459.1±2.858	0.09059±0.00193
5	Machine	4586±27.51	4585±27.54	0.918±0.004583

Buffer allocation Strategy - 1 , 3 , 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.128±0.00576	1.00±0.00	0.284±0.0129	28.4±2.00
33	Buffer	3.00±0.000446	3.00±0.00	66.4±0.385	100±3.41
34	Buffer	0.128±0.0058	1.00±0.00	0.284±0.0133	28.6±2.66

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4511±24.45	4510±24.45	0.9024±0.004964
4	Machine	453.2±2.890	452.6±2.760	0.08963±0.00200
5	Machine	4511±24.73	4510±24.75	0.9027±0.004422

Buffer allocation Strategy - 3 , 1 , 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.428±0.0197	3.00±0.00	0.934±0.0432	31.4±1.99
33	Buffer	1.00±6.88e-005	1.00±0.00	21.8±0.128	45.9±2.37
34	Buffer	0.107±0.00507	1.00±0.00	0.235±0.0116	28.9±2.54

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4585±26.23	4584±26.16	0.918±0.004735
4	Machine	459.6±2.809	459.1±2.717	0.09095±0.00214
5	Machine	4585±26.16	4584±26.16	0.9179±0.004262

Buffer allocation Strategy - 3 , 1 , 3

17	Buffer	0.358±0.021	3.00±0.00	0.771±0.0459	31.8±2.74
33	Buffer	1.00±0.000163	1.00±0.00	21.5±0.136	45.3±2.72
34	Buffer	0.363±0.0193	3.00±0.00	0.781±0.0432	29.4±2.08

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4649±28.64	4648±28.64	0.9307±0.005125
4	Machine	466.0±3.127	465.5±3.008	0.09172±0.00224
5	Machine	4649±28.92	4648±28.92	0.9307±0.004596

Buffer allocation Strategy – 1, 4, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.128±0.00576	1.00±0.00	0.284±0.0129	28.4±2.00
33	Buffer	4.00±0.000813	4.00±0.00	88.4±0.523	125±3.32
34	Buffer	0.128±0.0058	1.00±0.00	0.284±0.0133	28.6±2.66

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4511±24.45	4510±24.45	0.9024±0.004964
4	Machine	453.7±2.995	453.2±2.890	0.08968±0.00198
5	Machine	4511±24.73	4510±24.75	0.9027±0.004422

Buffer allocation Strategy – 4, 1, 4

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.485±0.0403	4.00±0.00	1.04±0.0879	30.4±2.17
33	Buffer	1.00±0.000157	1.00±0.00	21.3±0.125	45.6±2.65
34	Buffer	0.484±0.0255	4.00±0.00	1.03±0.0548	30.8±1.80

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4693±26.77	4692±26.77	0.9398±0.005785
4	Machine	470.5±2.855	469.9±2.789	0.09261±0.00225
5	Machine	4693±27.05	4692±27.05	0.9395±0.003899

Buffer allocation Strategy – 4, 1, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.60±0.0274	4.00±0.00	1.30±0.0593	32.2±2.38
33	Buffer	1.00±0.000131	1.00±0.00	21.6±0.128	45.5±2.13
34	Buffer	0.0989±0.00454	1.00±0.00	0.214±0.0105	26.8±1.73

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4618±27.29	4617±27.29	0.9244±0.004599
4	Machine	463.0±2.915	462.5±2.814	0.09134±0.00228
5	Machine	4618±26.57	4617±26.55	0.9243±0.003836

Buffer allocation Strategy – 5, 1, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.795±0.0456	5.00±0.00	1.71±0.0996	32.8±2.15
33	Buffer	1.00±0.000171	1.00±0.00	21.5±0.144	44.0±2.23
34	Buffer	0.0925±0.00584	1.00±0.00	0.199±0.0134	26.9±2.14

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4648±29.42	4647±29.41	0.9307±0.005018
4	Machine	465.9±3.161	465.3±3.067	0.09213±0.00278
5	Machine	4646±29.84	4645±29.82	0.9303±0.004739

Buffer allocation Strategy – 5, 1, 5

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.622±0.0444	5.00±0.00	1.32±0.0952	32.4±2.33
33	Buffer	1.00±0.000175	1.00±0.00	21.2±0.0953	47.4±2.75
34	Buffer	0.618±0.0354	5.00±0.00	1.31±0.0763	34.8±2.65

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4722±21.42	4721±21.42	0.9454±0.004967
4	Machine	473.2±2.352	472.7±2.258	0.0936±0.002125
5	Machine	4722±20.88	4721±20.86	0.9452±0.004005

Buffer allocation Strategy – 1, 5, 1

Block	Block Name	Avg. Length	Max. Length	Avg. Wait	Max. Wait
17	Buffer	0.128±0.00576	1.00±0.00	0.284±0.0129	28.4±2.00
33	Buffer	5.00±0.00108	5.00±0.00	110±0.671	151±4.05
34	Buffer	0.128±0.0058	1.00±0.00	0.284±0.0133	28.6±2.66

Block	Block Name	Arrival	Departure	Utilization
3	Machine	4511±24.45	4510±24.45	0.9024±0.004964
4	Machine	454.3±3.115	453.7±3.034	0.08979±0.00195
5	Machine	4511±24.73	4510±24.75	0.9027±0.004422

Chapter 5

INDUSTRY MODEL

5.1 PRACTICAL MODEL:

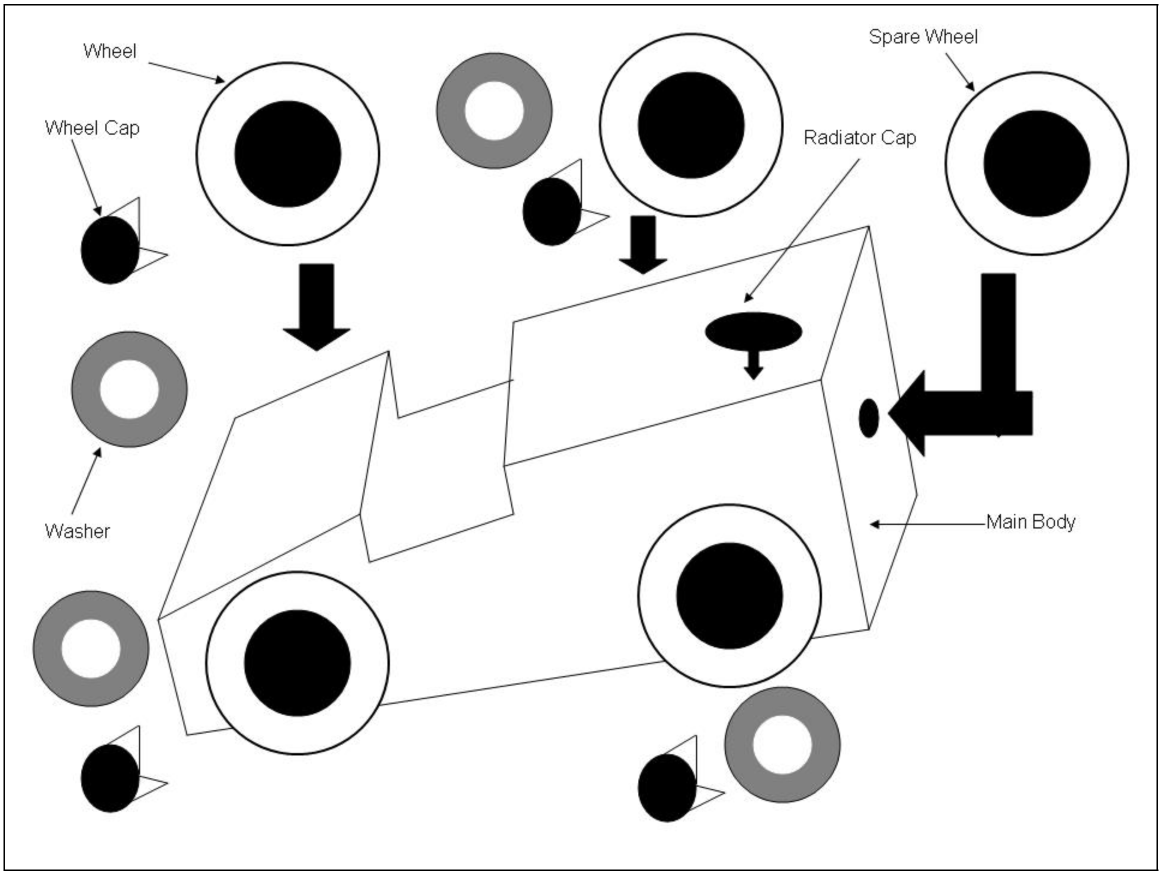


Fig: 5.1

(Model from a toy car industry named BLOWPLAST ltd, Mumbai)

5.2 DESCRIPTION:

This is a toy car manufactured by BLOWPLAST ltd. Mumbai. It has the following main parts:

- Main body
- Four wheels
- One spare wheel
- Washer
- Wheel hub
- Radiator Cap
- Head lights
- Axle

These parts are individually made and assembled in three stages

- First stage : Washer and axle are put.
- Second stage : Wheel and wheel hub is put.
- Third stage : Headlight and radiator cap is put

All these processes have their own processing time and hence the process can not be continuous hence buffers are put in between to have a continuous output of the system. We have to optimize this buffer allocation.

5.3 PRECEDENCE REQUIREMENTS:

By examining the toy car, we can see the sequence restrictions that must be observed in its assembly. For example, the hub caps must be installed on the wheels prior to subsequent assembly steps to ensure that the axle is not broken as a result of impact. Finally the wheels can not be assembled until the axle has been inserted in the car body.

These sequences must be observed because the toy car cannot be assembled correctly in any other way. On the other hand, it makes no difference whether the headlights are assembled before or after the wheels are assembled. Similarly, whether the front or rear wheels are assembled first is irrelevant.

The task sequence restrictions for the toy car can be seen. In general, the assembly tasks are broken down into the smallest whole activity. For each task, there is a task which immediately precedes it.

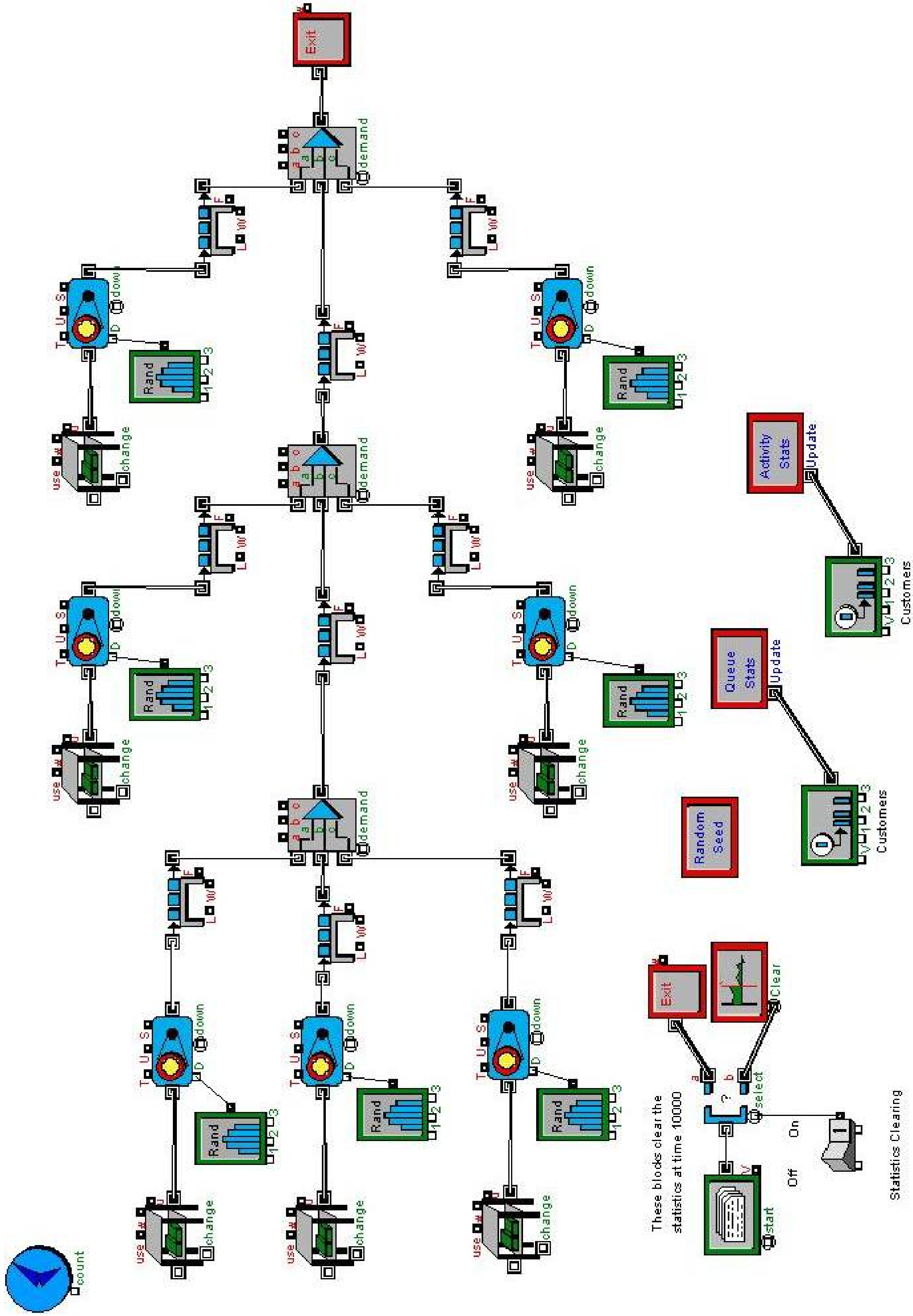
5.4 CYCLE TIME AND CAPACITY:

Now we can proceed with the grouping of tasks to obtain balance. But balance at what rate of output? What is to be capacity of the line? This is an important point and one that makes the line balancing problem difficult. If there were no capacity restrictions, the problem would be simple, one could take the lowest common multiple approach. For example, if we had three operations that required 3.2, 2.0, 4.0 minutes respectively, we could provide eight work places for the first, five for second and ten for third. The capacity of the line is 150 units per hour at each of the operation and cycle time would be 0.4 minutes. But capacity would be specified by balance rather than by market considerations. For this illustration we assume market studies justify a capacity of about 2600 toy cars per day or an average cycle time of 11 seconds.

5.5 OPTIMUM SOLUTION:

To meet this capacity requirement, no station could be assigned more than 11 second of works on the tasks. The total of all tasks time is 53 seconds. Therefore with an 11-second cycle,(53/11=4.8) five stations are the minimum possible. This all we saw keeping the time constant for a process. But practically time taken for a process everytime is not same. So here we will be taking Normal Distribution of the processing time.

Fig: 5.1



Exit
demand
down
change
use
Rand
Activity Stats
Update
Customers
Queue Stats
Update
Customers
Random Seed
Exit
Clear
select
These blocks clear the statistics at time 10000
On
Off
Statistics Clearing
start
count

It is a complete assembling process where assembling is done in three stages. Here we have as many as 8 inter-stage buffers. But we will be considering the main flow 3 inter stage buffers. The capacity of these buffers can be varied from 1 to 10. “Ten” requires a lot of surface area and also makes the object wait for much longer. Similarly “one” may make the process idle more often than not.

5.6 SPECIFICATIONS:

Machine No.		Processing time (units)
2	:	4
27	:	1
28	:	3
3	:	1
4	:	1
40	:	1
41	:	5

Here we have taken exponential distribution.

1 unit time = 10 seconds.

5.7 INTERSTAGE BUFFER STRATEGIES CONSIDERED:

1) 1-2-1
2) 2-2-1
3) 2-2-2
4) 2-3-2
5) 2-3-3
6) 3-3-3
7) 4-3-3
8) 4-3-4
9) 4-4-4
10) 4-5-4
11) 4-6-4
12) 4-7-4
13) 4-8-4
14) 4-9-4
15) 4-10-4
16) 5-4-5
17) 6-4-6
18) 7-4-7
19) 10-4-10

5.8 OBJECTIVE OF ABOVE CONSIDERATIONS:

1) We had to see the change in output when middle had more buffer compared to when middle had less buffer.
2) We have also increased the buffer from level 1 to 10 to find an optimized value such that, above it increasing the buffer space does not give us an economical percentage increase in output.
3) Changes in number of departures were also required with increase in buffer allocation.
4) To check for the waiting time.
5) Machine utilization study.

5.9 DATA COLLECTED

Inter-stage Buffer Allocation 1-2-1

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	0.431±0.325	0.50±0.377	1.94±1.46	9.98±7.55
36	Buffer	0.576±0.436	1.00±0.754	2.60±1.97	12.9±9.76
47	Buffer	0.168±0.127	0.50±0.377	0.758±0.575	8.97±6.86

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2218±1672	2216±1672	0.4449±0.3355
27	Machine	2216±1671	2216±1671	0.4387±0.3308
28	Machine	2216±1671	2215±1671	0.4488±0.3385
3	Machine	1108±835.6	1108±835.6	0.226±0.1705
4	Machine	2218±1672	2216±1672	0.444±0.3349
40	Machine	2215±1670	2214±1670	0.441±0.3325
41	Machine	2216±1671	2215±1671	0.4405±0.3322

Inter-stage Buffer Allocation 2-2-1

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	0.924±0.697	1.00±0.754	4.19±3.16	14.4±10.9
36	Buffer	0.593±0.449	1.00±0.754	2.69±2.03	13.8±10.5
47	Buffer	0.182±0.139	0.50±0.377	0.826±0.63	9.70±7.35

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2209±1665	2208±1665	0.4403±0.332
27	Machine	2210±1666	2209±1666	0.4393±0.3313
28	Machine	2210±1665	2209±1665	0.4384±0.3306
3	Machine	1105±832.4	1104±832.4	0.2197±0.1657
4	Machine	2209±1665	2208±1665	0.4421±0.3334
40	Machine	2209±1665	2208±1665	0.4415±0.333
41	Machine	2208±1664	2207±1664	0.4419±0.3333

Inter-stage Buffer Allocation 2-2-2

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	0.921±0.694	1.00±0.754	4.14±3.12	13.8±10.4
36	Buffer	0.568±0.432	1.00±0.754	2.56±1.94	13.8±10.4
47	Buffer	0.345±0.263	1.00±0.754	1.55±1.18	12.5±9.53

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2223±1676	2222±1676	0.4459±0.3363
27	Machine	2224±1676	2223±1676	0.4429±0.334
28	Machine	2225±1677	2224±1677	0.4479±0.3378
3	Machine	1111±838.0	1111±838.0	0.2226±0.1679
4	Machine	2224±1676	2223±1676	0.4441±0.335
40	Machine	2226±1678	2226±1678	0.450±0.3393
41	Machine	2227±1679	2226±1679	0.442±0.3333

Inter-stage Buffer Allocation 2-3-2

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	0.919±0.693	1.00±0.754	4.15±3.13	14.5±11.0
36	Buffer	0.987±0.754	1.50±1.13	4.46±3.41	17.4±13.2
47	Buffer	0.343±0.262	1.00±0.754	1.55±1.18	12.3±9.42

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2214±1669	2213±1669	0.4395±0.3315
27	Machine	2212±1667	2211±1667	0.4494±0.339
28	Machine	2213±1668	2212±1668	0.4467±0.3369
3	Machine	1107±834.2	1106±834.2	0.2225±0.1679
4	Machine	2212±1668	2211±1668	0.4418±0.3333
40	Machine	2213±1668	2212±1668	0.4427±0.3339
41	Machine	2213±1668	2212±1668	0.442±0.3333

Inter-stage Buffer Allocation 2-3-3

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	0.913±0.688	1.00±0.754	4.07±3.07	14.9±11.3
36	Buffer	0.76±0.586	1.50±1.13	3.39±2.61	16.3±12.3
47	Buffer	0.416±0.315	1.50±1.13	1.85±1.40	15.2±11.5

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2246±1693	2245±1693	0.4453±0.3359
27	Machine	2245±1692	2244±1692	0.4451±0.3357
28	Machine	2242±1690	2241±1690	0.4516±0.3406
3	Machine	1122±845.6	1121±845.6	0.224±0.169
4	Machine	2244±1691	2243±1691	0.4471±0.3372
40	Machine	2242±1690	2241±1690	0.4423±0.3336
41	Machine	2244±1692	2243±1692	0.4462±0.3365

Inter-stage Buffer Allocation 3-3-3

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	1.41±1.07	1.50±1.13	6.29±4.75	18.7±14.3
36	Buffer	0.897±0.679	1.50±1.13	4.00±3.02	16.5±12.5
47	Buffer	0.466±0.353	1.50±1.13	2.08±1.57	15.3±11.6

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2245±1692	2244±1692	0.443±0.3342
27	Machine	2243±1691	2242±1691	0.4451±0.3356
28	Machine	2244±1691	2243±1691	0.4538±0.3422
3	Machine	1123±846.2	1122±846.2	0.2244±0.1692
4	Machine	2245±1692	2244±1692	0.4455±0.336
40	Machine	2241±1690	2241±1690	0.4452±0.3358
41	Machine	2241±1689	2240±1689	0.4437±0.3347

Inter-stage Buffer Allocation 4-3-3

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	1.91±1.44	2.00±1.51	8.59±6.48	20.9±15.8
36	Buffer	0.761±0.579	1.50±1.13	3.43±2.61	17.5±13.3
47	Buffer	0.468±0.355	1.50±1.13	2.10±1.60	14.9±11.3

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2222±1675	2221±1675	0.4422±0.3335
27	Machine	2224±1676	2223±1676	0.4389±0.3311
28	Machine	2223±1676	2222±1676	0.451±0.3401
3	Machine	1112±837.7	1111±837.7	0.2231±0.1683
4	Machine	2224±1676	2223±1676	0.4513±0.3404
40	Machine	2227±1678	2226±1678	0.4427±0.3339
41	Machine	2226±1678	2225±1678	0.4423±0.3335

Inter-stage Buffer Allocation 4-3-4

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	1.92±1.45	2.00±1.51	8.57±6.46	21.0±15.9
36	Buffer	0.761±0.578	1.50±1.13	3.39±2.58	17.3±13.2
47	Buffer	0.654±0.51	2.00±1.51	2.91±2.27	18.3±13.9

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2241±1689	2240±1689	0.4522±0.3412
27	Machine	2246±1693	2245±1693	0.4485±0.3382
28	Machine	2247±1694	2246±1694	0.4428±0.334
3	Machine	1121±845.3	1121±845.3	0.2207±0.1665
4	Machine	2243±1690	2242±1690	0.4449±0.3355
40	Machine	2245±1692	2244±1692	0.4476±0.3377
41	Machine	2246±1693	2245±1693	0.4476±0.3376

Inter-stage Buffer Allocation 4-4-4

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	1.91±1.44	2.00±1.51	8.48±6.40	21.5±16.3
36	Buffer	1.06±0.809	2.00±1.51	4.73±3.60	20.2±15.4
47	Buffer	0.701±0.553	2.00±1.51	3.12±2.46	18.7±14.4

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2252±1697	2251±1697	0.4516±0.3406
27	Machine	2247±1694	2246±1694	0.4497±0.3391
28	Machine	2250±1696	2249±1696	0.4425±0.3337
3	Machine	1126±848.5	1125±848.5	0.2263±0.1707
4	Machine	2251±1696	2250±1696	0.4478±0.3377
40	Machine	2248±1695	2248±1695	0.4468±0.3369
41	Machine	2249±1695	2248±1695	0.4464±0.3367

Inter-stage Buffer Allocation 4-5-4

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	1.91±1.44	2.00±1.51	8.48±6.40	21.7±16.6
36	Buffer	1.51±1.14	2.50±1.89	6.69±5.09	26.1±20.3
47	Buffer	0.781±0.595	2.00±1.51	3.47±2.64	20.6±15.9

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2254±1699	2253±1699	0.4475±0.3374
27	Machine	2251±1697	2250±1697	0.4509±0.340
28	Machine	2251±1697	2250±1697	0.4465±0.3367
3	Machine	1127±849.0	1126±849.0	0.225±0.1697
4	Machine	2253±1698	2252±1698	0.4509±0.340
40	Machine	2251±1697	2251±1697	0.4462±0.3365
41	Machine	2251±1697	2250±1697	0.4513±0.3404

Inter-stage Buffer Allocation 4-6-4

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	1.91±1.44	2.00±1.51	8.46±6.38	20.6±15.7
36	Buffer	1.70±1.29	3.00±2.26	7.53±5.70	25.0±18.9
47	Buffer	0.639±0.512	2.00±1.51	2.82±2.26	18.9±14.3

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2264±1706	2263±1706	0.4536±0.342
27	Machine	2263±1706	2262±1706	0.4502±0.3395
28	Machine	2264±1706	2263±1706	0.4543±0.3426
3	Machine	1131±852.8	1131±852.8	0.2231±0.1683
4	Machine	2263±1706	2262±1706	0.4525±0.3413
40	Machine	2261±1704	2260±1704	0.4457±0.3361
41	Machine	2262±1705	2261±1705	0.4497±0.3392

Inter-stage Buffer Allocation 4-7-4

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	1.91±1.44	2.00±1.51	8.40±6.34	20.9±15.9
36	Buffer	2.25±1.72	3.50±2.64	9.93±7.58	27.0±20.4
47	Buffer	0.883±0.68	2.00±1.51	3.89±3.00	19.1±14.4

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2270±1711	2268±1711	0.4472±0.3372
27	Machine	2270±1711	2269±1711	0.4538±0.3423
28	Machine	2269±1710	2268±1710	0.4498±0.3392
3	Machine	1134±855.0	1134±855.0	0.2283±0.1722
4	Machine	2267±1709	2267±1709	0.4555±0.3435
40	Machine	2270±1711	2269±1711	0.4559±0.3438
41	Machine	2270±1711	2269±1711	0.4535±0.342

Inter-stage Buffer Allocation 4-10-4

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	1.90±1.43	2.00±1.51	8.45±6.37	21.0±15.8
36	Buffer	3.17±2.43	5.00±3.77	14.0±10.8	37.9±28.6
47	Buffer	0.721±0.565	2.00±1.51	3.19±2.50	19.8±15.0

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2254±1699	2253±1699	0.4527±0.3414
27	Machine	2258±1702	2257±1702	0.4522±0.3411
28	Machine	2258±1702	2257±1702	0.4513±0.3404
3	Machine	1127±849.6	1127±849.6	0.2271±0.1713
4	Machine	2252±1698	2252±1698	0.4541±0.3425
40	Machine	2256±1701	2255±1701	0.4466±0.3369
41	Machine	2256±1701	2255±1701	0.4529±0.3415

Inter-stage Buffer Allocation 5-4-5

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	2.41±1.82	2.50±1.89	10.7±8.06	24.3±18.4
36	Buffer	1.11±0.845	2.00±1.51	4.94±3.75	19.1±14.5
47	Buffer	0.817±0.645	2.50±1.89	3.62±2.85	20.6±15.8

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2256±1701	2255±1701	0.449±0.3387
27	Machine	2258±1702	2257±1702	0.4508±0.340
28	Machine	2259±1703	2258±1703	0.4483±0.3381
3	Machine	1128±850.3	1128±850.3	0.2244±0.1693
4	Machine	2256±1700	2255±1700	0.4525±0.3413
40	Machine	2258±1702	2257±1702	0.449±0.3387
41	Machine	2258±1702	2257±1702	0.448±0.3379

Inter-stage Buffer Allocation 6-4-6

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	2.90±2.19	3.00±2.26	12.9±9.73	27.6±20.9
36	Buffer	1.02±0.78	2.00±1.51	4.51±3.47	20.6±15.6
47	Buffer	0.939±0.763	3.00±2.26	4.17±3.38	23.9±18.5

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2252±1697	2251±1697	0.4504±0.3396
27	Machine	2251±1697	2250±1697	0.4481±0.3379
28	Machine	2249±1696	2248±1696	0.4516±0.3406
3	Machine	1126±848.5	1125±848.5	0.2271±0.1713
4	Machine	2251±1697	2250±1697	0.4535±0.342
40	Machine	2250±1696	2250±1696	0.4494±0.3391
41	Machine	2252±1698	2251±1698	0.4514±0.3405

Inter-stage Buffer Allocation 7-4-7

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	3.40±2.56	3.50±2.64	15.2±11.4	30.6±23.1
36	Buffer	1.01±0.778	2.00±1.51	4.51±3.46	20.0±15.3
47	Buffer	1.04±0.847	3.50±2.64	4.64±3.74	26.2±20.2

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2240±1689	2239±1689	0.4502±0.3396
27	Machine	2242±1690	2241±1690	0.4472±0.3373
28	Machine	2244±1691	2243±1691	0.4495±0.339
3	Machine	1120±844.5	1120±844.5	0.2246±0.1694
4	Machine	2241±1689	2240±1689	0.4455±0.3359
40	Machine	2244±1692	2243±1692	0.4454±0.336
41	Machine	2245±1693	2244±1693	0.4471±0.3373

Inter-stage Buffer Allocation 10-4-10

Block	Block Name	Avg. Length	Max Length	Avg. Wait	Max. Wait
11	Buffer	4.91±3.70	5.00±3.77	21.9±16.5	38.2±28.9
36	Buffer	0.94±0.744	2.00±1.51	4.18±3.31	18.6±14.1
47	Buffer	1.22±1.07	5.00±3.77	5.45±4.74	30.0±22.9

Block	Block Name	Arrivals	Departures	Utilization
2	Machine	2247±1694	2246±1694	0.4533±0.3419
27	Machine	2246±1693	2246±1693	0.4562±0.344
28	Machine	2245±1693	2244±1693	0.4486±0.3384
3	Machine	1123±847.1	1123±847.1	0.2242±0.1691
4	Machine	2248±1694	2247±1694	0.4536±0.3422
40	Machine	2248±1695	2248±1695	0.4503±0.3397
41	Machine	2248±1695	2247±1695	0.4499±0.3393

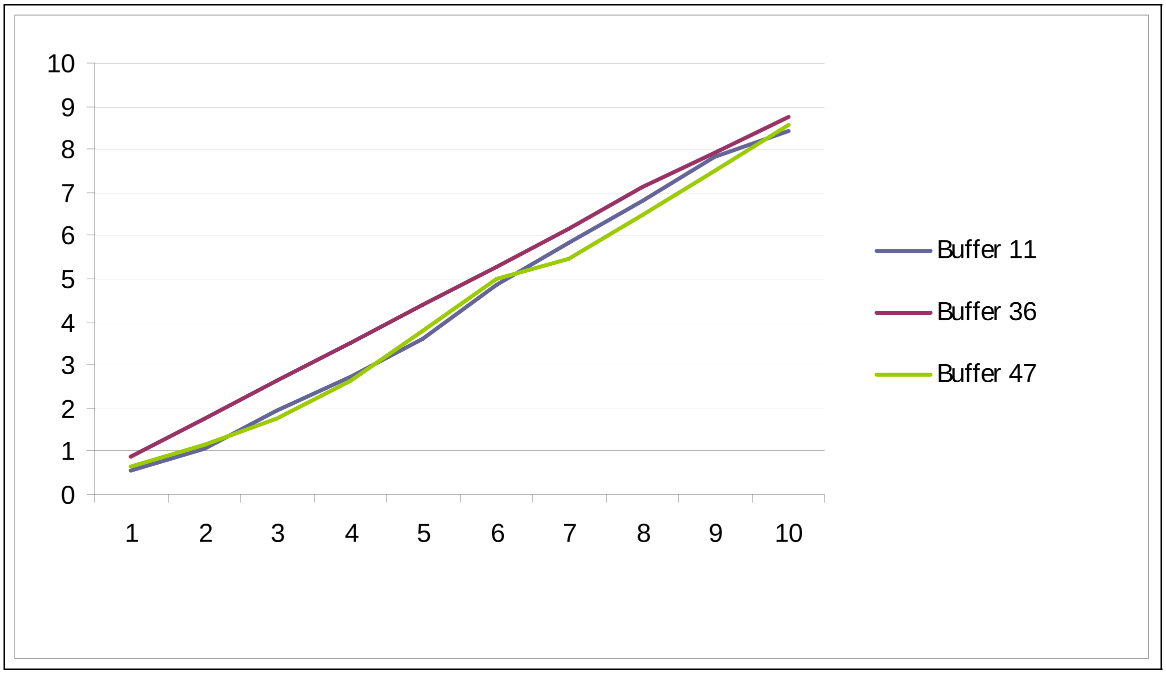
5.10 GRAPHS:

1) Maximum queue length Vs Buffer capacity:-

Data table for graph:

	Buffer 11	Buffer 36	Buffer 47
1	0.54	0.86	0.63
2	1.07	1.75	1.18
3	1.93	2.63	1.77
4	2.71	3.51	2.63
5	3.63	4.39	3.81
6	4.86	5.26	5.01
7	5.82	6.14	5.47
8	6.82	7.14	6.5
9	7.82	7.9	7.5
10	8.43	8.77	8.55

Graph :



Graph: 5.10.1

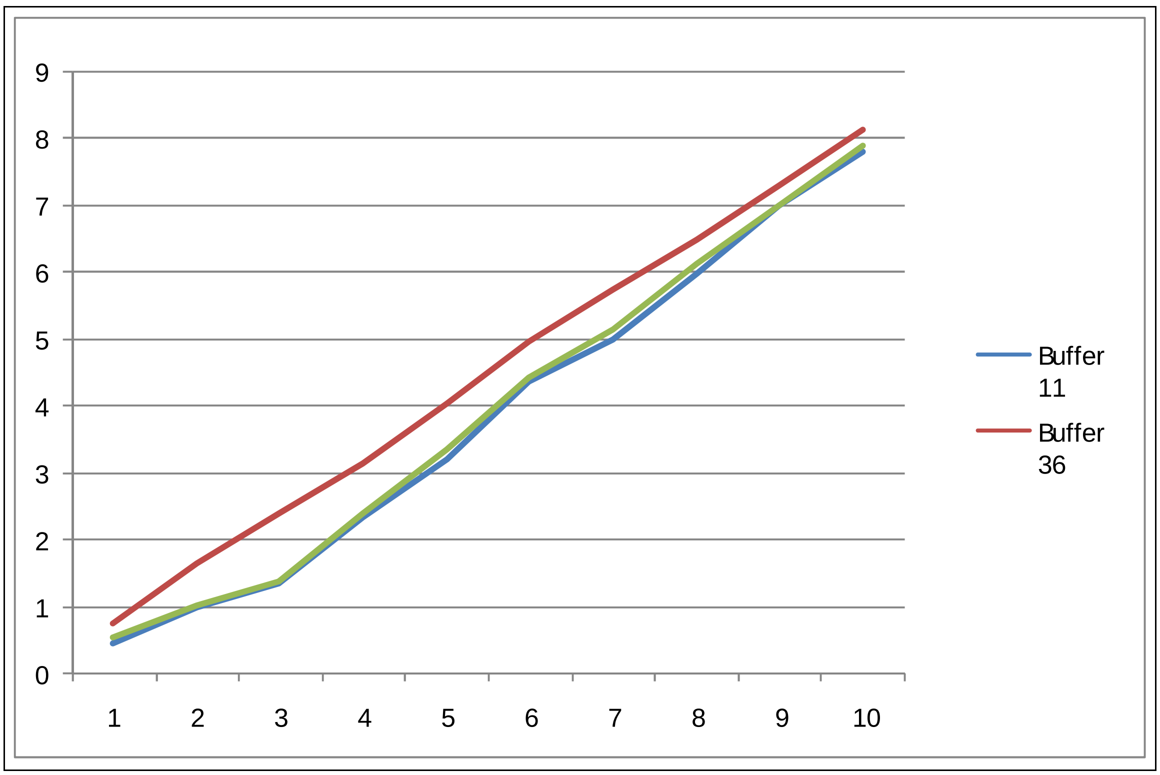
In this graph we see a constantly increasing trend. With increase in buffer allocation, Maximum wait also increased.

2) Average queue length Vs Buffer capacity:-

Data table for graph:

	Buffer 11	Buffer 36	Buffer 47
1	0.44	0.75	0.53
2	0.98	1.64	1.01
3	1.34	2.41	1.36
4	2.32	3.14	2.39
5	3.21	4.04	3.34
6	4.37	4.98	4.41
7	5.01	5.74	5.14
8	6	6.5	6.14
9	7	7.3	7
10	7.82	8.14	7.9

Graph:



Graph: 5.10.2

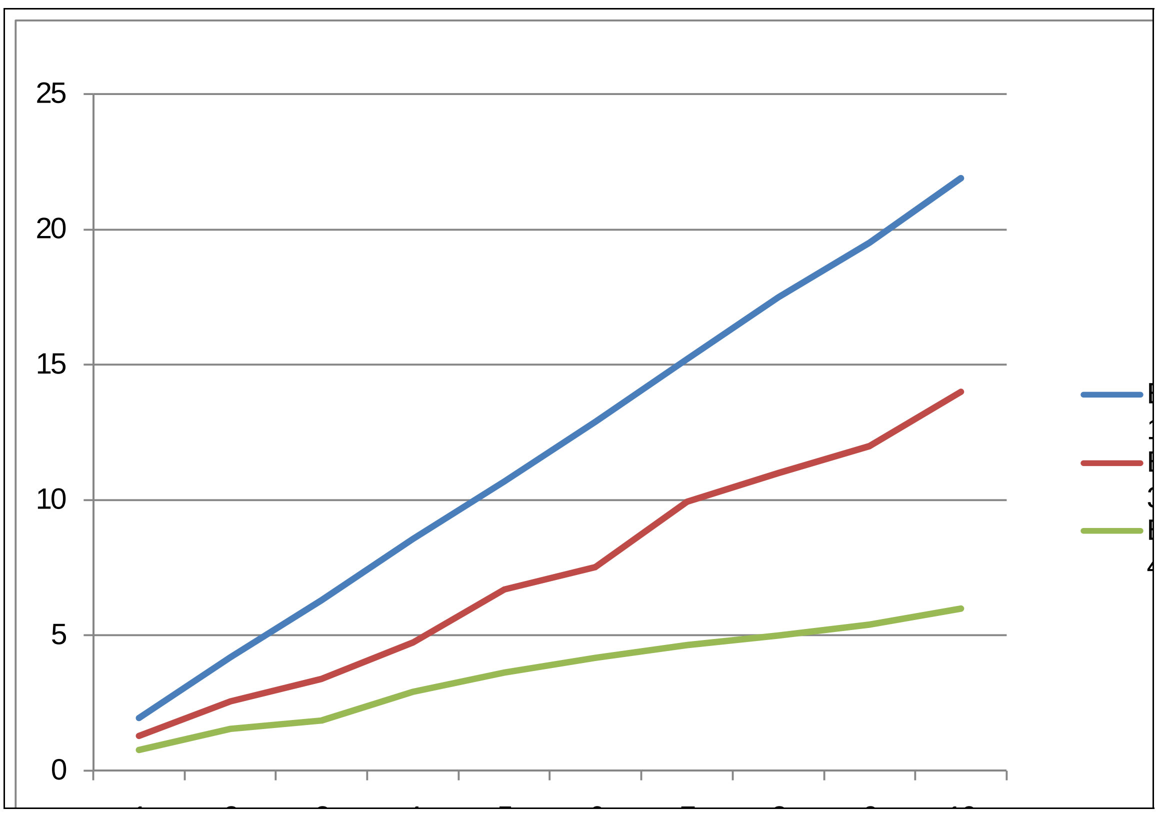
In this graph also we see a constantly increasing trend with increase in buffer allocation. Average wait also increased.

3) Average wait Vs Buffer capacity

Data table for graph:

	Buffer 11	Buffer 36	Buffer 47
1	1.94	1.28	0.76
2	4.19	2.56	1.55
3	6.29	3.39	1.85
4	8.57	4.73	2.91
5	10.7	6.69	3.62
6	12.9	7.53	4.17
7	15.2	9.93	4.64
8	17.5	11	5
9	19.5	12	5.4
10	21.9	14	6

Graph :



Graph: 5.10.3

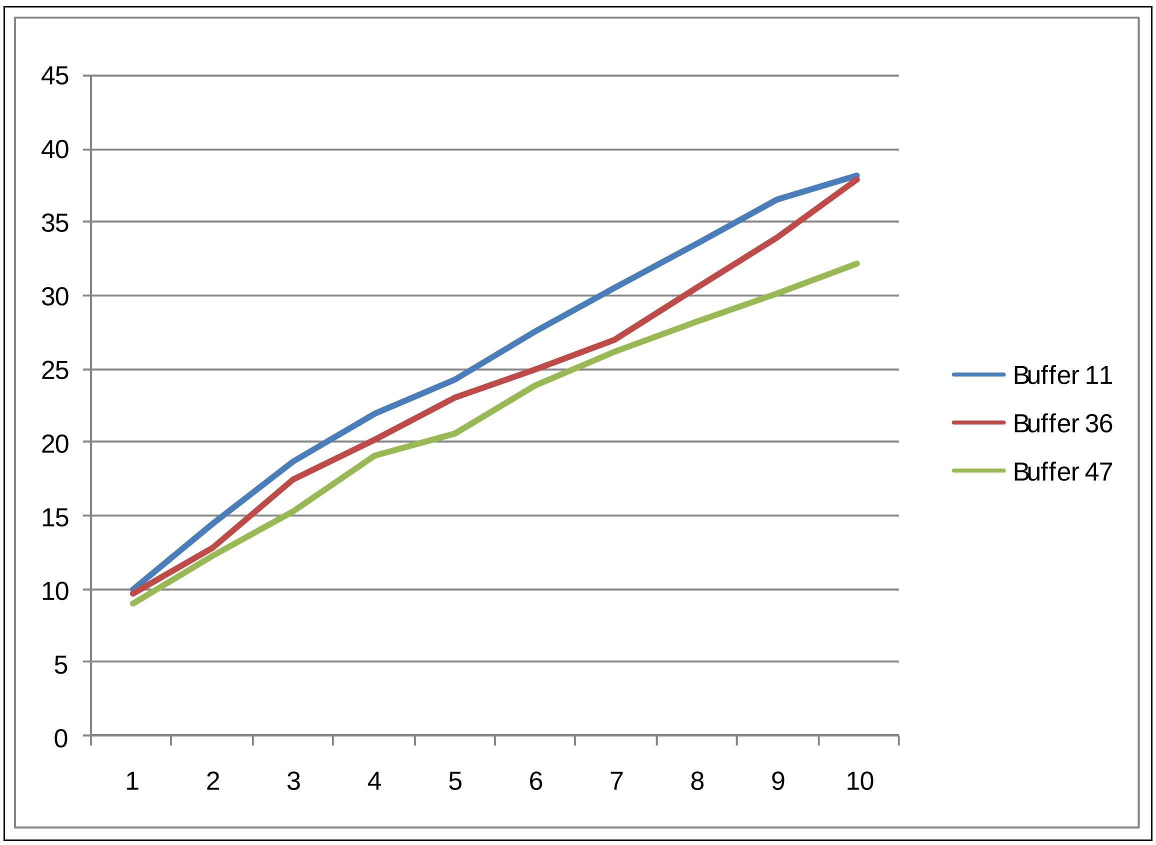
This also gives an increasing trend.

4) Maximum Wait Vs Buffer Capacity

Data table for graph :

	Buffer 11	Buffer 36	Buffer 47
1	9.98	9.7	9
2	14.5	12.9	12.3
3	18.7	17.4	15.3
4	22	20.2	19.1
5	24.3	23.1	20.6
6	27.6	25	23.9
7	30.6	27	26.2
8	33.6	30.5	28.2
9	36.5	34	30.2
10	38.2	37.9	32.2

Graph :



Graph: 5.10.4

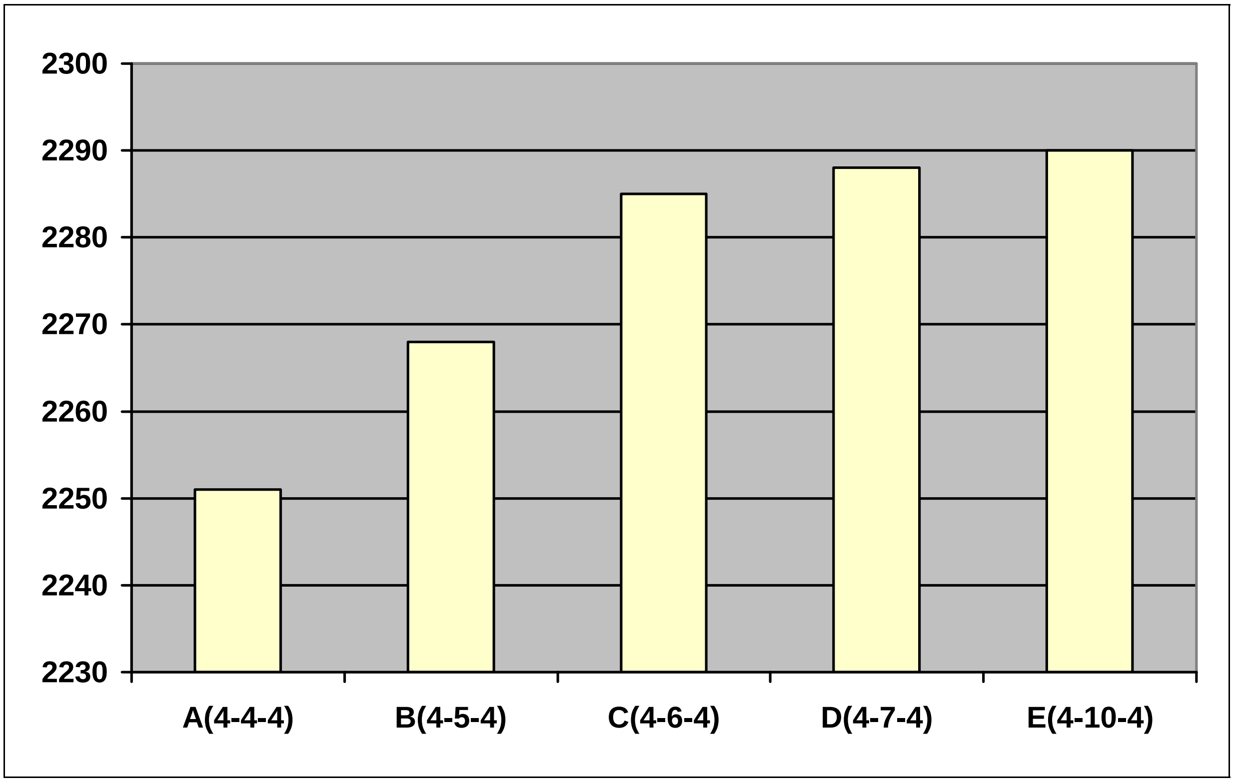
Here also we obtain a constant increasing graph

5) Throughput Vs Different Buffer Strategies

a) Data table for graph :

A(4-4-4)	B(4-5-4)	C(4-6-4)	D(4-7-4)	E(4-10-4)
2251	2268	2285	2288	2290

Graph :



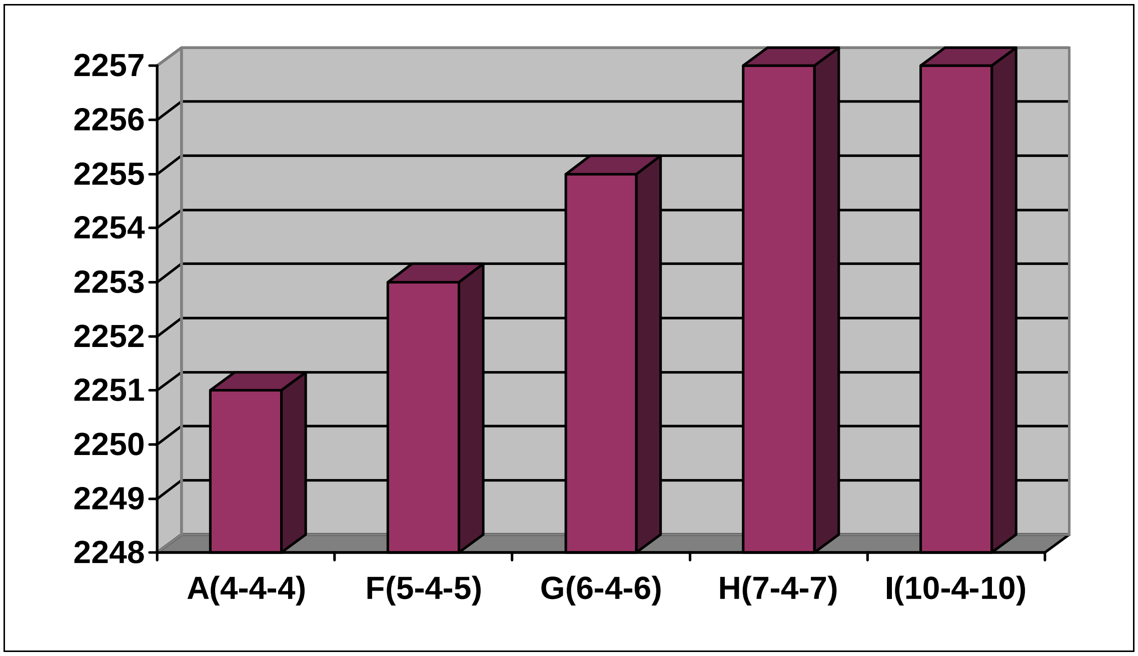
Graph: 5.10.5.a

As clear fro the numerical data and the graph after the strategy 4-6-4 there is not much percentage increase in throughput.

b) Data table for graph :

A(4-4-4)	F(5-4-5)	G(6-4-6)	H(7-4-7)	I(10-4-10)
2251	2253	2255	2257	2257

Graph :



Graph: 5.10.5.b

There is almost no increase in throughput

On the basis of above data we conclude that 4-6-4 in the best strategy.

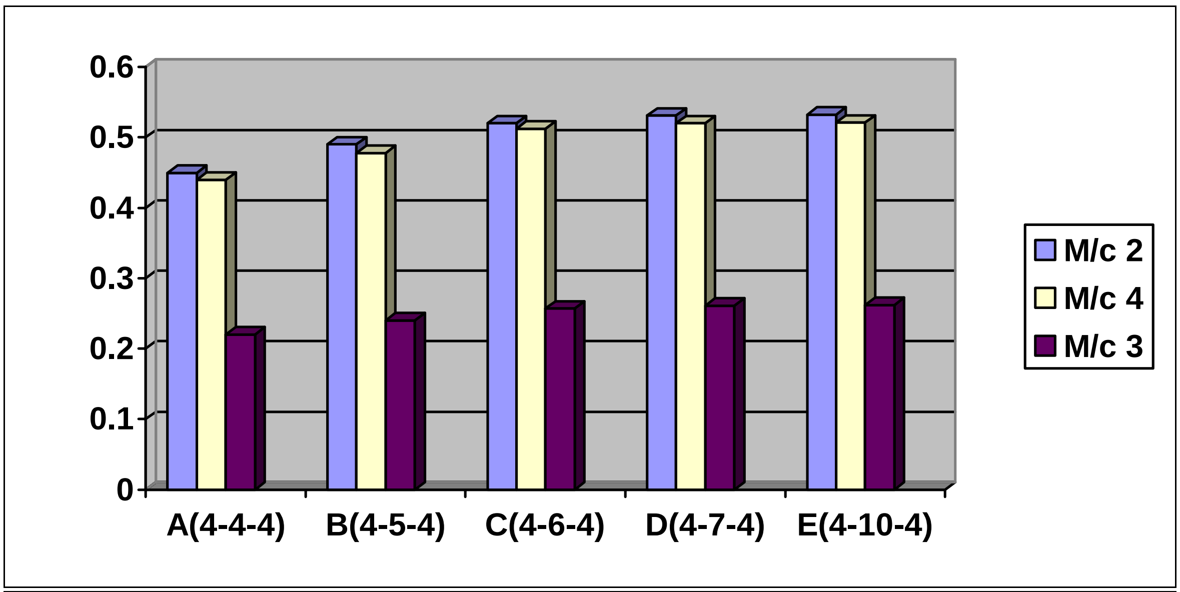
6) Machine utilization Vs Different Buffer strategies

Here we are considering only three machines and numerical data shows similar trend for all other machines as well.

a) Data table for graph :

	A(4-4-4)	B(4-5-4)	C(4-6-4)	D(4-7-4)	E(4-10-4)
M/c 2	0.45	0.49	0.52	0.531	0.532
M/c 4	0.44	0.478	0.512	0.52	0.521
M/c 3	0.22	0.24	0.257	0.261	0.262

Graph :



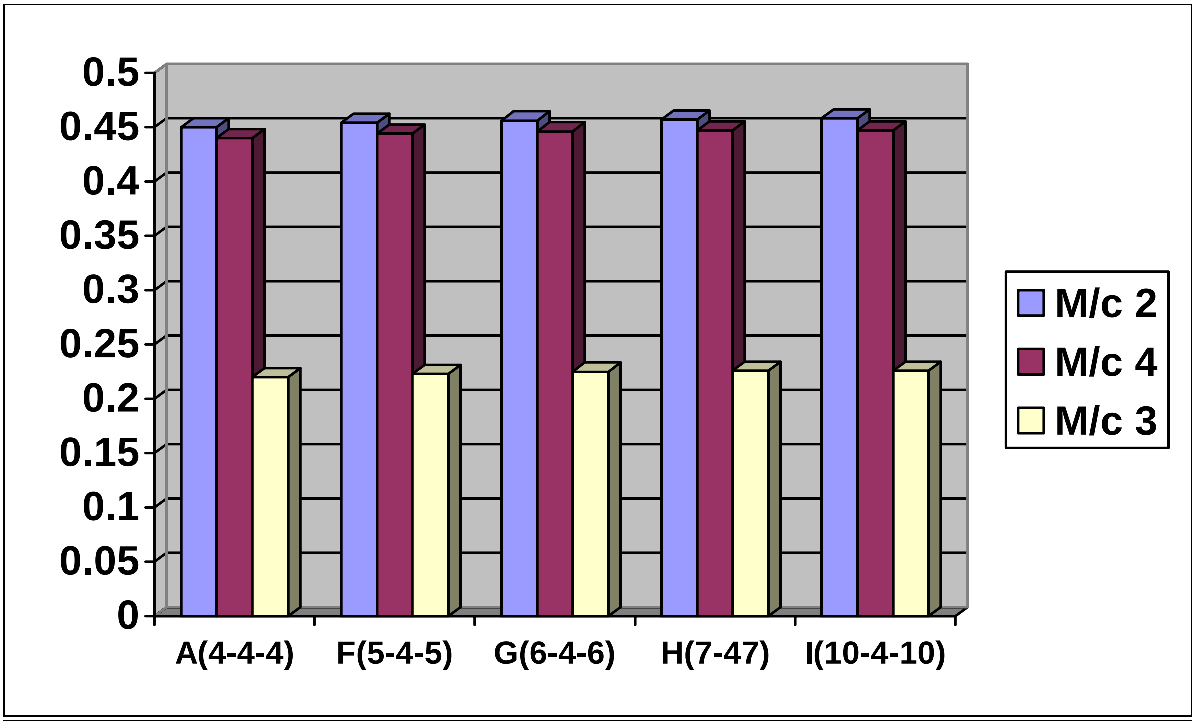
Graph: 5.10.6.a

As we can see from the numerical data that we have maximum machine utilization at 4-10-4, but we also observe that after 4-6-4 percentage increase in utilization is very low

b) Data table for graph:

	A(4-4-4)	F(5-4-5)	G(6-4-6)	H(7-47)	I(10-4-10)
M/c 2	0.45	0.454	0.456	0.457	0.458
M/c 4	0.44	0.444	0.446	0.447	0.447
M/c 3	0.22	0.223	0.225	0.226	0.226

Graph :



Graph: 5.10.6.b

Considering this case there is no such clear increase in machine utilization.

5.11 CONCLUSION FROM THIS MODEL

On the basis of above graphs and tables we propose 4-6-4 as the best strategy for this model in terms of throughput and cost efficiency.

Chapter 6

CONCLUSION

6. CONCLUSION:

During this project we came to know about the importance of buffer allocation in flow shop. How the buffer allocation strategies affect throughput and performance of the entire industry. We learnt the use of the software- Extend (v-4.0). This is a very powerful tool for simulation. We had the chance to get industrial data from BlowPlast ltd., Mumbai. We made a simulation model in Extend and analyzed the data provided to us. We allocated buffer at strategic positions in the flow line. Then the buffer capacity of each buffer was optimized keeping economy and space constraints in view. After analytical and graphical analysis we concluded that the buffer allocation of 4-6-4 is best suited for their flow shop.

Chapter 7

REFERENCES

7. REFERENCES:

1. EL-Rayah, T.E, “The effect of inequality of inter-stage buffer capacities and operation time variability on the efficiency of production line system”, IJPR Vol. 17, No.1, 2003.
2. Anderson, D.R and Moodie, C.L, “Optimal Buffer Storage Capacity in Production line systems”, IJPR, Vol. 7, No. 3, 2004.
3. Kay.E, “buffer stocks in Automatic Transfer Lines”, IJPR, Vol. 10, No. 2, 2003.
4. Sjeskin, T.J, “Allocation of Interstage storage along an automatic production line”, AIIE Trans Vol. 8, No. 1, 2003.
5. Okamura.K and Yamashinr.H, “Analysis of In-Process Buffer for Multi-stage Transfer line Systems”, IJPR, Vol. 21, No. 8, 2005.
6. Wijngard.J, “The effect of Inter-stage Buffer storage on the output of two unreliable Production Units in series, with different Production retes”, AIIE Trans, Vol. 11, No. 1, 2002.