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Generic Single Channel Multi Phase Waiting Line Model applied to Production Line for Productivity Improvement

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Abstract: *A service mechanism in a mass production type of manufacturing consists of service facilities which in turn contain parallel service channels. The prime objective of analyzing production line is to understand and analyze line performance which enables manager to identify bottlenecks affecting performance, contrained resources and predict system serviced cost and system waiting cost. This enables the manager to compute the total system cost at various levels of service which ensures optimal allocation of existing resources. This paper focuses on Single Channel Multi-Phase production line. The authors have developed a mathematical model for single channel multi-phase production line which is implemented in Visula Basic (VB). The production line configuration information such as machine name, cycle time, machine hour rate, shift busy period, production rate is centralized and stored in an XML file which is parsed using DOM (Document Object Model) parser for VB. A tool is developed for designing of a production line. WIP accumulation between different machines and individual machine idles times are determined. Finally, optimum level of service is determined from system service cost and system waiting cost. The model is generic and can be applied to any single channel, multi-phase production line.*

Keywords– *Extensible Markup Language, Manufacturing, Production Line,Single Channel Multi Phase Queues, Work In Process.*

I. Introduction

A production line is a line in which units move continuously through a sequence of stations. The main objective is to optimize line performance which can be attained by best allocation of task to an ordered sequence of stations subject to precedence constraints.

The main issues are associated with queuing, idle time among stations during the task achievement, WIP accumulation between machines which become obstacles to an efficient production line. Bottlenecks and congestion in queuing system has serious consequence. It has serious negative implication on both the system service cost and system waiting cost. The immediate consequence of the increase in idle time and WIP is corresponding increase in the operational cost. Further the failure to comply with the customer orders results in customer dissatisfaction and eventuallya loss of market share.

1.1 Problem Definition

In flow production type of manufacturing system in the production line, whenever existing demand exceeds capacity of the service facility, the items arriving cannot receive immediate service due to busy servers, which results in accumulation of WIP (Work In Process) between machines. Due to varying levels of production, the issues such as idle time of machines and WIP accumulation arise which hamper line performance. The main objective of generic model development is minimization of system service cost with respect to accumulated WIP and idle time of machines.

1.2 Objectives of the Work

- ✓ To reduce manufacturing lead time.
- ✓ To analyze idle time, WIP accumulation between machines and identify bottleneck resource.
- ✓ To analyze delays in production system with variable service times.
- ✓ To determine the level of service which minimizes total expected cost of service and the expected cost of waiting for that service.
- ✓ To analyze WIP in line for productivity improvement.
- ✓ To study system utilization and cost incurred, strike economic balance with minimum waste in system.

1.3 Assumptions made in Model Development

1. Mass production type of manufacturing system is assumed.
2. All jobs visit machines or work centers in the same sequence complying standard routing.

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3. The products are processed in a sequential order of machines in the production line.
4. Machine working conditions are reflected in cycle time of products.
5. All the parameters such as system service level, system service cost, and system waiting cost are computed for one working shift.
6. Cycle time is modified to take account of machine age using linear extrapolation.
7. Demand forecasting is the basis for the production level requirement.
8. Arrival rate of products at the first machine is assumed to be deterministic and finite.
9. First come first serve queue discipline is assumed.

II. Literature Survey and Prior Art

A lot of research work has been carried out to describe and solve more realistic generalized assembly line balancing problems. An exhaustive survey was carried out by Becker and Scholl on problems and methods in generalized assembly line balancing [1]. There is a substantial study on single channel waiting line system using various statistical approaches such as poisson arrivals and exponential service time. However, they are based on stochastic mathematical models [2]. A lot of literature exists on PLBP (Production Line Balancing Problem) where a technical constraint was carried out to minimize queuing problem and regulate the workers by applying hybrid models with an emphasis to reduce queuing and idle time. A new approach on traditional assembly line balancing problem is presented using 0-1 integer programming model to establish balance of assembly with minimum number of station and resources [3]. Andreas C. Nearchou has devised a novel method based on particle swarm optimization for simple assembly line balancing problems. Two criteria are simultaneously considered for optimization to minimize cycle time and maximize workload smoothing. [4]. In spite of lot of literature available on basic assembly line balancing, there remains a gap between requirements of real configuration problems and status of research. Most of the work focuses on just single or only few practical extensions at a time. Real world assembly system requires a lot of these extensions to be considered simultaneously. Nils Boysen et.al. have proposed a criteria for model selection according to characteristic practical settings and have highlighted relevant model extensions to reflect real world problems [5].

Rajendran and Alicke [6] carried out a study on the problem of dispatching in flow shops with bottleneck machines. Here, the objective is to develop dispatching rules for scheduling by taking into account the presence of bottleneck machines on the basis of TOC methodology. The measures of performance are the minimization of total flow time of jobs, the minimization of the sum of earliness and tardiness of jobs and the minimization of total tardiness of jobs are considered separately. The results of the experimental investigation show that the proposed dispatching rules emerge to be superior to the conventional dispatching rules. Murty [7] presented an Indian case study where in application of TOC-DBR leads to significant improvement in throughput. The implementation is carried out only for connecting rod line and flywheel housing line of engine division of company. This has resulted in an increase of about 50% in throughput of about 50% in the throughput without any additional investment. Besides this, there is considerable improvement in work in process inventory as well as machine utilization.

Frazier and Reyes [8] applied the TOC-DBR concept to obtain substantial improvement in its production performance in one of the high-tech manufacturing industry. The primary measures are used to assess the production performance are percentage of work orders complicated in the month, month end raw material inventory implementation period it is observed that WIP inventory is decreased to one third of its previous level, raw material inventory value is decreased by 30% and percentage of on time completion of jobs are increased by more than 20%. Chakravorty [9] explained the result obtained by implementing the Drum-Buffer-Rope (DBR) in a V-plant operation. The annual sales and performance measure before, during and after implementation of DBR are compared. It was found that the annual sales are increased by 4% inventory of finished window unit decreased by 67% and percentage of the orders reduced by 63%.

III. Mathematical Model for Generic Production Line

Let M_1, M_2. . . M_n be n machines in a multi-phase assembly. Let CT_{M1},CT_{M2},. . . CT_{Mn} be cycle times of a product on machines M_1, M_2. . . M_n, respectively. The following table depicts time duration at which different items enter and leave different machines.

Item No.	**M_1**		**M_2**	
	IN	**OUT**	**IN**	**OUT**
1	0	CT_{M1}	CT_{M1}	$CT_{M1}+CT_{M2}$
2	CT_{M1}	$2CT_{M1}$	Max $[2CTM1, \sum_{i=1}^{2} CT_{Mi}]$	Max $[2CTM1, \sum_{i=1}^{2} CT_{Mi}] +$ $CTM2$

M_3		
Item No.	In	Out
1	$CT_{M1}+CT_{M2}$	$CT_{M1}+CT_{M2}+CT_{M3}$
2	Max $\{ Max\ [2CTM1, \sum_{i=1}^{2} CT_{Mi}], \sum_{i=1}^{3} CT_{Mi} \}$	Max $\{ Max\ [2CTM1, \sum_{i=1}^{2} CT_{Mi}], \sum_{i=1}^{3} CT_{Mi} \}+$ CT_{M3}

Generalizing the above process to the nth machine, the time at which the product enters nth machine is given by,

Max [Max [Max [. . . [Max $[2CTM1, \sum_{i=1}^{2} CT_{Mi}], \sum_{i=1}^{3} CT_{Mi}], \sum_{i=1}^{4} CT_{Mi}], \ldots .], \sum_{i=1}^{n} CT_{Mi}]$

Let it be denoted by M.

and the time at which the product leaves nth machine is given by

$$M + CT_{Mn}$$

where CT_{Mn} is the cycle time of the product on the nth machine.

The first product enters the first machine M_1 at time t=0 and leaves M_1 at time CT_{M1} where CT_{M1} is the cycle time of the product on machine M_1 . At this point of time M_2 is free. Hence the product is immediately processed on machine M_2 , where it enters M_2 at time CT_{M1} and leaves M_2 at a time $[CT_{M1} + CT_{M2}]$. Continuing in this manner, the first product enters nth machine at a time

$$\sum_{i=1}^{n-1} CT_{Mi}$$

and leaves nth machine at a time

$$\sum_{i=1}^{n-1} CT_{Mi} + CT_{Mn} = \sum_{i=1}^{n} CT_{Mi}$$

Hence the total time spent by the first product in an assembly line is

$$\sum_{i=1}^{n} CT_{Mi}$$

However, due to the differing cycle times of a product on different machines the situation is different for second and subsequent products. The second item enters the first machine at a time CT_{M1} and leaves it at a time $2CT_{M1}$ at which it is ready to be processed by machine M_2. However, M_2 becomes free at a time $CT_{M1}+ CT_{M2}$ after processing first item. Hence the second item can enter M_2 at the time given by,

$$\text{Max } \left[2CTM1 , \textstyle\sum_{i=1}^{2} CT_{Mi}\right] \qquad (1)$$

The second item leaves M_2 at a time give by

$$\text{Max } \left[2CTM1 , \textstyle\sum_{i=1}^{n} CT_{Mi}\right] + CT_{M1}$$

With the same argument the in and out times of second product on machine M_3 are given by

$$\text{Max} \left\{ \text{Max } \left[2CTM1 , \textstyle\sum_{i=1}^{2} CT_{Mi}\right] , \textstyle\sum_{i=1}^{3} CT_{Mi} \right\}$$

Generalizing the above procedure for the k^{th} item on the i^{th} machine, the waiting time is given by

$$\text{Max [Max [Max [. . . [Max } [2CTM1 , \textstyle\sum_{i=1}^{2} CT_{Mi}], \ \textstyle\sum_{i=1}^{3} CT_{Mi}], \textstyle\sum_{i=1}^{4} CT_{Mi}] , ...], \textstyle\sum_{i=1}^{k} CT_{Mi}]$$

We consider the following special cases.

Case 1 : $CT_{M1} < CT_{M2} < CT_{M3} < . . . . < CT_{Mi}$

In this case each machine is continuously busy processing the products. Hence the idle time of any machine is zero. However, it results in WIP accumulation between machines. In this case, in equ (1), second term will be maximum as shown below and hence selected in the expression.

$$CT_{M1} < CT_{M2}$$

Adding to CT_{M1} both the sides, we get

$$2CT_{M1} < CT_{M1} + CT_{M2}$$

$$2CT_{M1} < \textstyle\sum_{i=1}^{2} CT_{Mi}$$

Hence, $\text{Max } \left[2CTM1 , \sum_{i=1}^{2} CT_{Mi}\right] = \sum_{i=1}^{2} CT_{Mi}$

Applying the same logic to next station, we get

$$\begin{aligned} & \text{Max} \left\{ \text{Max } \left[2CTM1 , \textstyle\sum_{i=1}^{2} CT_{Mi}\right] , \textstyle\sum_{i=1}^{3} CT_{Mi} \right\} \\ = \ & \text{Max} \left\{ \textstyle\sum_{i=1}^{2} CT_{Mi} , \textstyle\sum_{i=1}^{3} CT_{Mi} \right\} \\ = \ & \textstyle\sum_{i=1}^{3} CT_{Mi} \end{aligned}$$

Calculation of accumulated system WIP per unit time. Waiting time of items between machines M_1 and M_2 is given by

$$\textstyle\sum_{i=1}^{2} CT_{Mi} - 2CT_{M1}$$

and between machines M_2 and M_3 is given by

$$\textstyle\sum_{i=1}^{3} CT_{Mi} - \left\{\textstyle\sum_{i=1}^{2} CT_{Mi} - CTM2\right\}$$

Continuing in this manner the system WIP is given by,

$$\left\{\textstyle\sum_{i=1}^{2} CT_{Mi} - 2CTM1\right\} + \left\{\textstyle\sum_{i=1}^{3} CT_{Mi} - (\textstyle\sum_{i=1}^{2} CT_{Mi} + CTM2)\right\} +$$

$$+ \left\{\textstyle\sum_{i=1}^{4} CT_{Mi} - (\textstyle\sum_{i=1}^{3} CT_{Mi} + CTM3)\right\} + ...$$

$= [\ CT_{M2} - CT_{M1}] + \left\{\sum_{i=1}^{3} CT_{Mi} - \sum_{i=1}^{2} CT_{Mi} - CTM2\right\} + \left\{\sum_{i=1}^{4} CT_{Mi} - \sum_{i=1}^{3} CT_{Mi} - CTM3\right\}$

$= [\ CT_{M2} - CT_{M1}] + [\ CT_{M3} - CT_{M2}] + [\ CT_{M4} - CT_{M3}]\ + \ldots\ldots + [\ CT_{Mk-1} - CT_{Mk-2}]\ + [\ CT_{Mk} - CT_{Mk-1}]$

$= CT_{Mk} - CT_{M1}$

Total WIP per unit time is equal to $Total_{WIP} = CT_{Mk} - CT_{M1}$

which depends only on cycle times of first and k^th machines and is independent of cycle time of intermediate machines.

Case 2 : $CT_{M1} > CT_{M2} > CT_{M3} >\ldots\ldots\ldots > CT_{Mi}$
In this case each machine, except the first one is idle waiting for the product. Hence the WIP accumulation is zero. In this case in equ(1), first term will be maximum as shown below:

$CT_{M1} > CT_{M2}$

Adding to CT_{M1} both the sides, we get

$$2CT_{M1} > CT_{M1} + CT_{M2}$$

$$2CT_{M1} > \sum_{i=1}^{2} CT_{Mi}$$

Hence, Max $\left[2CTM1\,,\sum_{i=1}^{2} CT_{Mi}\right] = 2CTM1$

Applying the same logic to next station, we get,

$$\text{Max}\left\{\text{Max}\left[2CTM1\,,\sum_{i=1}^{2} CT_{Mi}\right],\sum_{i=1}^{3} CT_{Mi}\right\}$$
$$= \text{Max}\left\{2CTM1\,,\sum_{i=1}^{3} CT_{Mi}\right\}$$
$$= 2CTM1$$

Calculation of System Idle Time

The idle time of the machine M_1 is given by,

$2CT_{M1} - \sum_{i=1}^{2} CT_{Mi}$
$= 2CT_{M1} - CT_{M1} - CT_{M2}$
$= CT_{M1} - CT_{M2}$

The idle of the machine M_2 is given by,

$= \sum_{i=1}^{2} CT_{Mi} + CT_{M2} - \sum_{i=1}^{3} CT_{Mi}$
$= CT_{M1} + 2CT_{M2} - CT_{M1} - CT_{M2} - CT_{M3}$
$= CT_{M2} - CT_{M3}$

Hence the system idle time is given by,
Total System Idle Time = $CT_{M1} - CT_{Mk}$,

Which again depends on first and last machines only. For all other variations, the WIP accumulation and system idle time are dependent on all the intermediate stations

IV. Results And discussion

The model developed above is implemented in VB with MS-Access as backend. The structure of the database employed for this purpose is depicted in Fig 1.

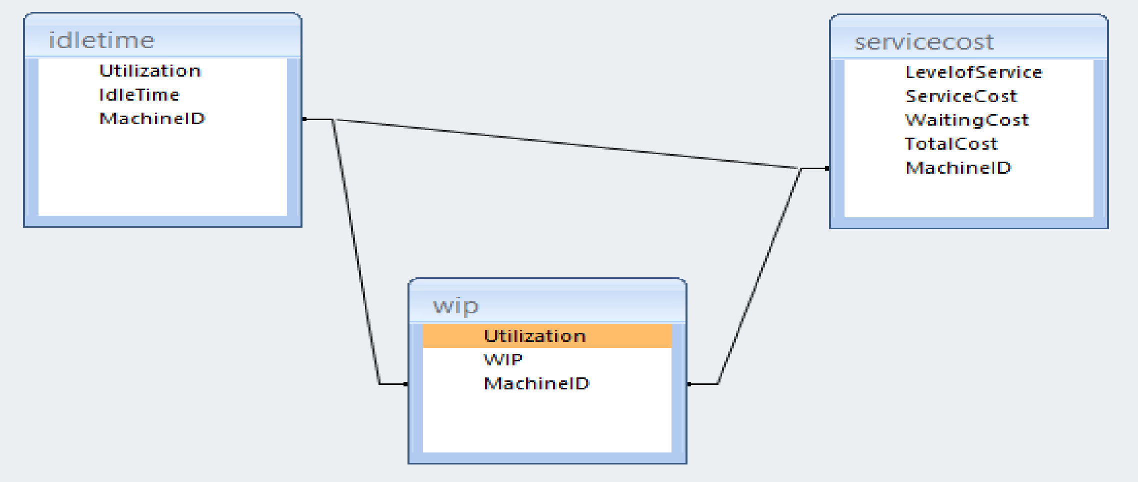


Fig.1 Structure of Database

The production line configuration information is stored in an XML file. A sample XML file is shown below. Figure 2 shows a GUI screen for analysis of production line. The production line can be designed by employig a simpe drag and frop operation as shown in Fig 3(a). Fig 3(b) presents a GUI for the modification of machine configuration information stored in an XML file. The XML file is automatically generated based on the parameters entered during the design phase. The structure of the XML file storing the machine configuration information is shown in Figure 4. The correpsonding Document Type Definition (DTD) for an XML document is shown in Figure 5.

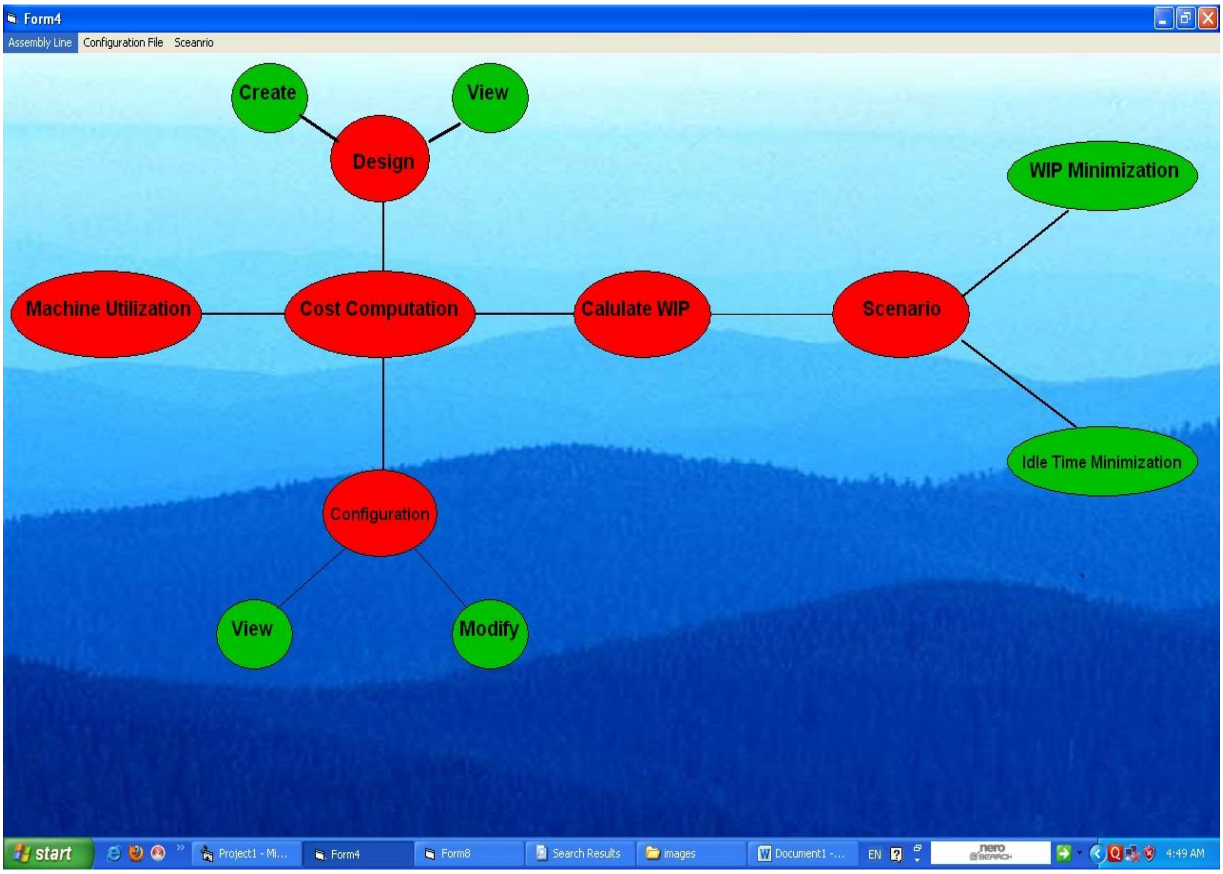
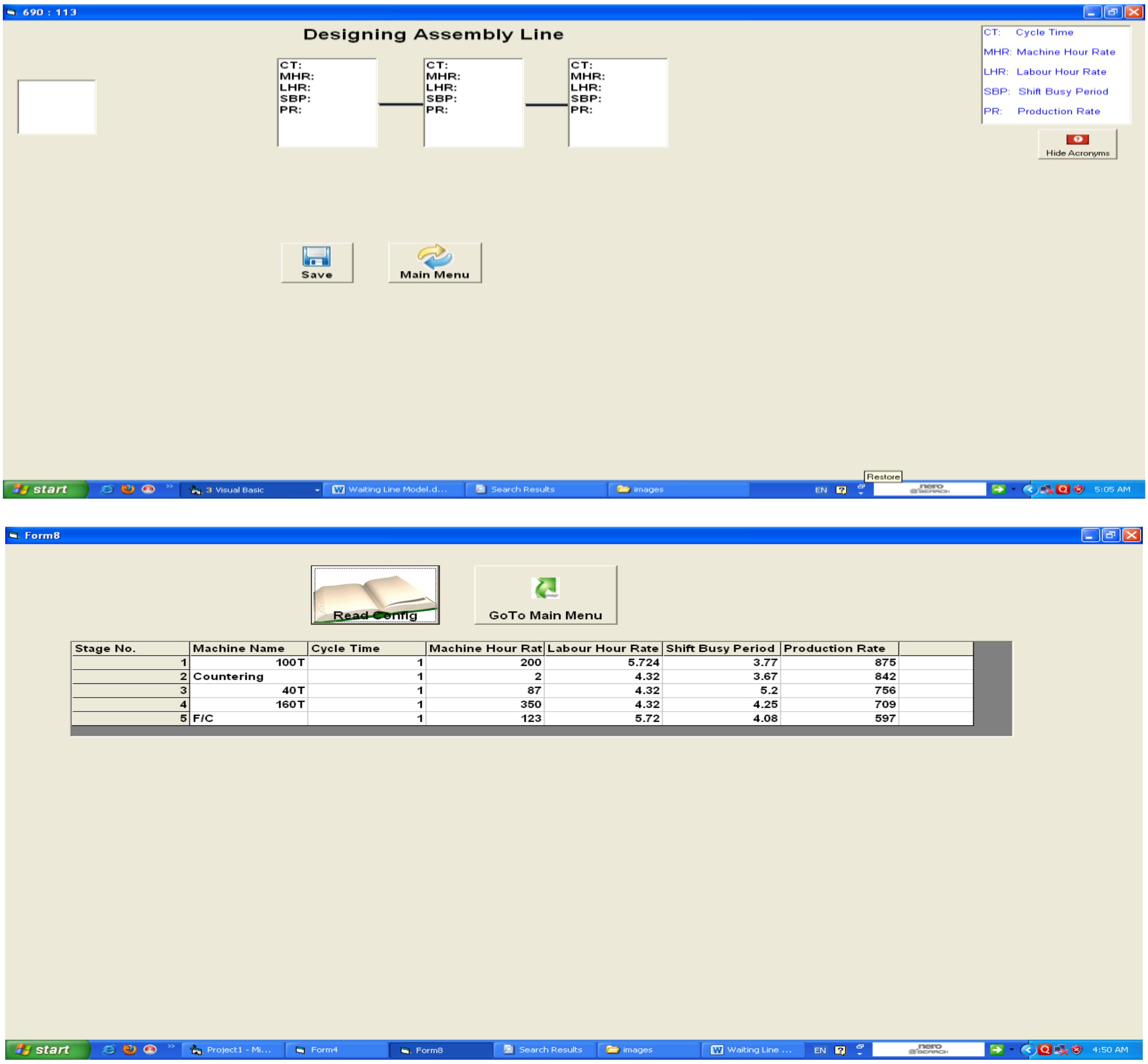


Fig.2 GUI Screen for the Analysis of Production Line



Designing Assembly Line

CT:
MHR:
LHR:
SBP:
PR:

CT: Cycle Time
MHR: Machine Hour Rate
LHR: Labour Hour Rate
SBP: Shift Busy Period
PR: Production Rate

Stage No.	Machine Name	Cycle Time	Machine Hour Rat	Labour Hour Rate	Shift Busy Period	Production Rate
1	100T	1	200	5.724	3.77	875
2	Countering	1	2	4.32	3.67	842
3	40T	1	87	4.32	5.2	756
4	160T	1	350	4.32	4.25	709
5	F/C	1	123	5.72	4.08	597

Fig.3(a)-(b) GUI GUI for Design of Production Line

```
<AssemblyLine>
        <WorkStations>
                <WorkStation>
                        <stage>1</stage>
                        <MachineName>TurretLathe1</MachineName>
                        <CycleTime>9</CycleTime>
                        <MachineHourRate>300</MachineHourRate>
                        <LabourHourRate>100</LabourHourRate>
                        <ShiftBusyPeriod>6</ShiftBusyPeriod>
                        <ProductionRate>6.69</ProductionRate>
                </WorkStation>
                <WorkStation>
                        <stage>2</stage>
                        <MachineName>TurretLathe2</MachineName>
                        <CycleTime>9</CycleTime>
                        <MachineHourRate>300</MachineHourRate>
                        <LabourHourRate>100</LabourHourRate>
                        <ShiftBusyPeriod>5.5</ShiftBusyPeriod>
                        <ProductionRate>6.69</ProductionRate>
                </WorkStation>
                .
                .
                .
        </WorkStations>
</AssemblyLine>
```

Fig.4 XML File Storing Machine Configuration Information

```
<?XML version=”1.0” ?>
<!ELEMENT  AssemblyLine(WorkStations)>
<!ELEMENT WorkStations (WorkStation+)>
<!ELEMENT WorkStation (stage)>
<!ELEMENT stage (#PCDATA)>
<!ELEMENT WorkStation (MachineName)>
<!ELEMENT MachineName (#PCDATA)>
<!ELEMENT WorkStation (CycleTime)>
<!ELEMENT CycleTime (#PCDATA)>
<!ELEMENT WorkStation (MachineHourRate)>
<!ELEMENT MachineHourRate (#PCDATA)>
<!ELEMENT WorkStation (LabourHourRate)>
<!ELEMENT LabourHourRate (#PCDATA)>
<!ELEMENT WorkStation (ShiftBusyPeriod)>
<!ELEMENT ShiftBusyPeriod (#PCDATA)>
<!ELEMENT WorkStation (ProductionRate)>
<!ELEMENT ProductionRate (#PCDATA)>
```

Fig.5 Document Type Definition for an XML File Storing Machine Configuration Information.

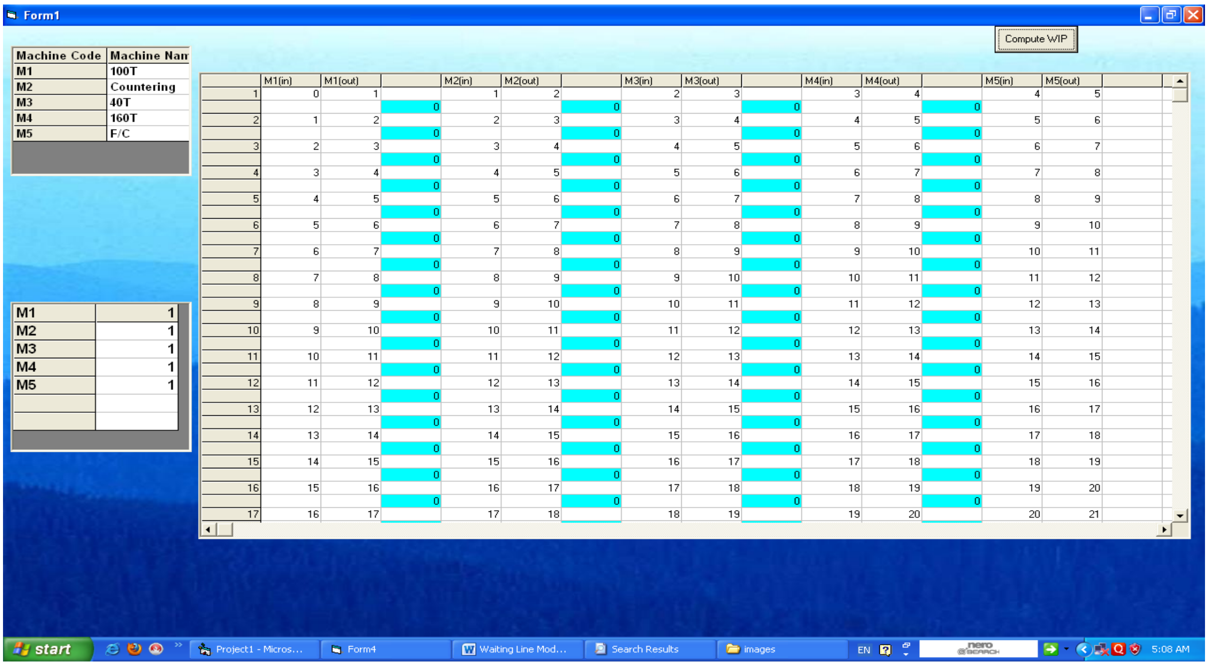
The XML file is parsed using Microsoft XML parser available as a dynamic link library, msxml6.dll. The VB code used for parsing is shown in Appendix A.

Fig. 6 and 7 show computation of WIP accumulation between various machines and machine idle times, respectively. Due to the varying cycle time of different machines there is a WIP accumultion between different machines and also there is some idle time at some work stations. The following two scenarios arise :

Scenario 1 : Idle Time Minimization.

Scenario 2 : WIP Minimization.

The probability of a machine remaining idle is inversely proportional to its utilization. If the cycle time of (n+1)th machine is greater than the cycle time of nth machine, idle time of (n+1)th machine will increase. On the contrary, if the cycle time of (n+1)th machine is less than the cycle time of nth machine, WIP accumulation between nth and (n+1)th machnines will increase. Hence it is observed that there is a trade off between minimization of WIP and minimization of idle time of machines in a production line. However, the total system cost which is the sum of the total waiting cost and the total service cost is found to be minimum for a certain level of service which is the economic level of WIP for the system under condideration.

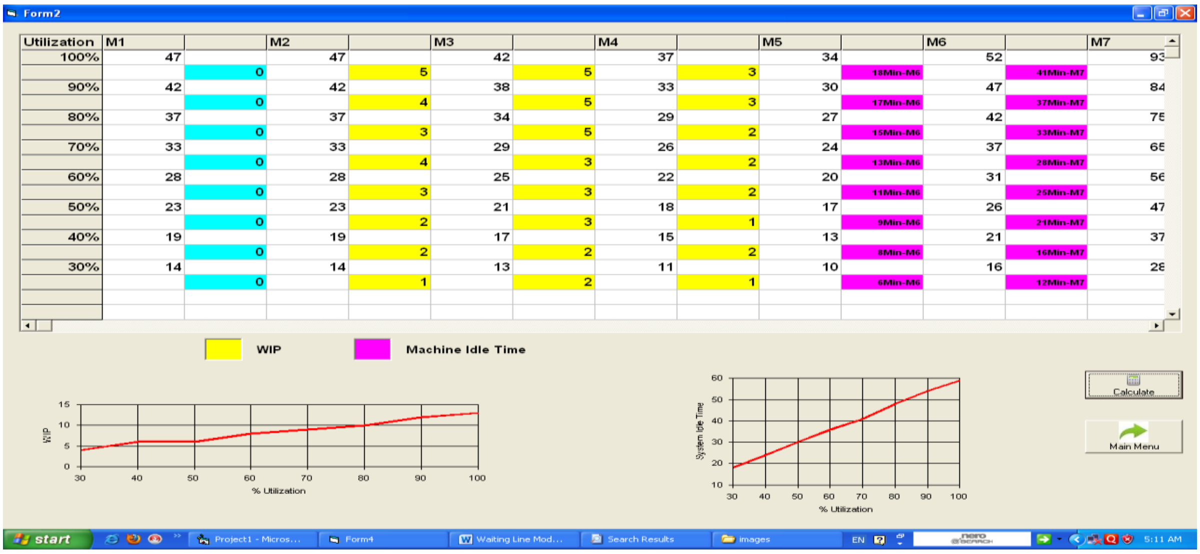


Machine Code	Machine Nam
M1	100T
M2	Countering
M3	40T
M4	160T
M5	F/C

M1	1
M2	1
M3	1
M4	1
M5	1

	M1(in)	M1(out)		M2(in)	M2(out)		M3(in)	M3(out)		M4(in)	M4(out)		M5(in)	M5(out)	
1	0	1		1	2		2	3		3	4		4	5	
			0			0			0			0			
2	1	2		2	3		3	4		4	5		5	6	
			0			0			0			0			
3	2	3		3	4		4	5		5	6		6	7	
			0			0			0			0			
4	3	4		4	5		5	6		6	7		7	8	
			0			0			0			0			
5	4	5		5	6		6	7		7	8		8	9	
			0			0			0			0			
6	5	6		6	7		7	8		8	9		9	10	
			0			0			0			0			
7	6	7		7	8		8	9		9	10		10	11	
			0			0			0			0			
8	7	8		8	9		9	10		10	11		11	12	
			0			0			0			0			
9	8	9		9	10		10	11		11	12		12	13	
			0			0			0			0			
10	9	10		10	11		11	12		12	13		13	14	
			0			0			0			0			
11	10	11		11	12		12	13		13	14		14	15	
			0			0			0			0			
12	11	12		12	13		13	14		14	15		15	16	
			0			0			0			0			
13	12	13		13	14		14	15		15	16		16	17	
			0			0			0			0			
14	13	14		14	15		15	16		16	17		17	18	
			0			0			0			0			
15	14	15		15	16		16	17		17	18		18	19	
			0			0			0			0			
16	15	16		16	17		17	18		18	19		19	20	
			0			0			0			0			
17	16	17		17	18		18	19		19	20		20	21	

Fig.6 Computation of WIP Accumulation Between Various Machines

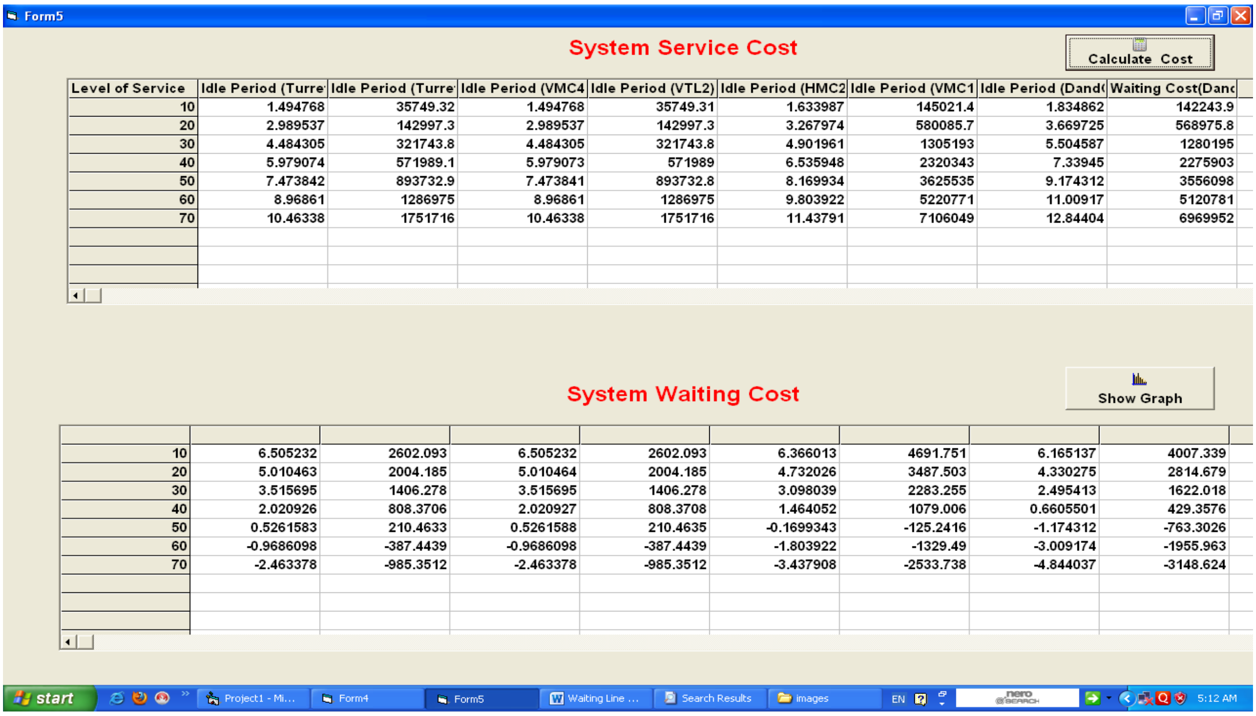


Utilization	M1		M2		M3		M4		M5		M6		M7
100%	47		47		42		37		34		52		93
		0		5		5		3		18Min-M6		41Min-M7	
90%	42		42		38		33		30		47		84
		0		4		5		3		17Min-M6		37Min-M7	
80%	37		37		34		29		27		42		75
		0		3		5		2		15Min-M6		33Min-M7	
70%	33		33		29		26		24		37		65
		0		4		3		2		13Min-M6		28Min-M7	
60%	28		28		25		22		20		31		56
		0		3		3		2		11Min-M6		25Min-M7	
50%	23		23		21		18		17		26		47
		0		2		3		1		9Min-M6		21Min-M7	
40%	19		19		17		15		13		21		37
		0		2		2		2		8Min-M6		16Min-M7	
30%	14		14		13		11		10		16		28
		0		1		2		1		6Min-M6		12Min-M7	

🟨 WIP 🟪 Machine Idle Time

Fig.7 Computation of Machine Idle Times

Computation of system service cost and system idle cost is depicted in Fig. 8. For the present system under consideration, the total system cost is found to be minimum at level of service 30 as shown in Fig. 9. Fig. 10 depicts the two scenarios discussed above for a hypothetical production Line.



System Service Cost

Level of Service	Idle Period (Turre	Idle Period (Turre	Idle Period (VMC4	Idle Period (VTL2)	Idle Period (HMC2	Idle Period (VMC1	Idle Period (Dand(	Waiting Cost(Danc
10	1.494768	35749.32	1.494768	35749.31	1.633987	145021.4	1.834862	142243.9
20	2.989537	142997.3	2.989537	142997.3	3.267974	580085.7	3.669725	568975.8
30	4.484305	321743.8	4.484305	321743.8	4.901961	1305193	5.504587	1280195
40	5.979074	571989.1	5.979073	571989	6.535948	2320343	7.33945	2275903
50	7.473842	893732.9	7.473841	893732.8	8.169934	3625535	9.174312	3556098
60	8.96861	1286975	8.96861	1286975	9.803922	5220771	11.00917	5120781
70	10.46338	1751716	10.46338	1751716	11.43791	7106049	12.84404	6969952

System Waiting Cost

10	6.505232	2602.093	6.505232	2602.093	6.366013	4691.751	6.165137	4007.339
20	5.010463	2004.185	5.010464	2004.185	4.732026	3487.503	4.330275	2814.679
30	3.515695	1406.278	3.515695	1406.278	3.098039	2283.255	2.495413	1622.018
40	2.020926	808.3706	2.020927	808.3708	1.464052	1079.006	0.6605501	429.3576
50	0.5261583	210.4633	0.5261588	210.4635	-0.1699343	-125.2416	-1.174312	-763.3026
60	-0.9686098	-387.4439	-0.9686098	-387.4439	-1.803922	-1329.49	-3.009174	-1955.963
70	-2.463378	-985.3512	-2.463378	-985.3512	-3.437908	-2533.738	-4.844037	-3148.624

Fig.8 Computation of System Service Cost and system Waiting Cost.

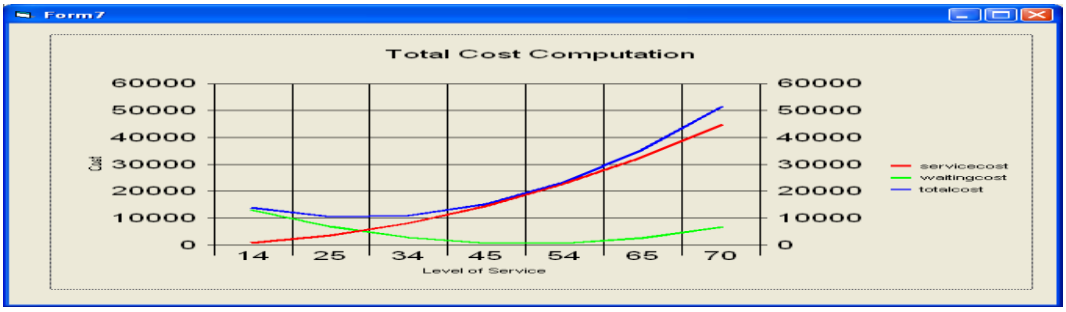
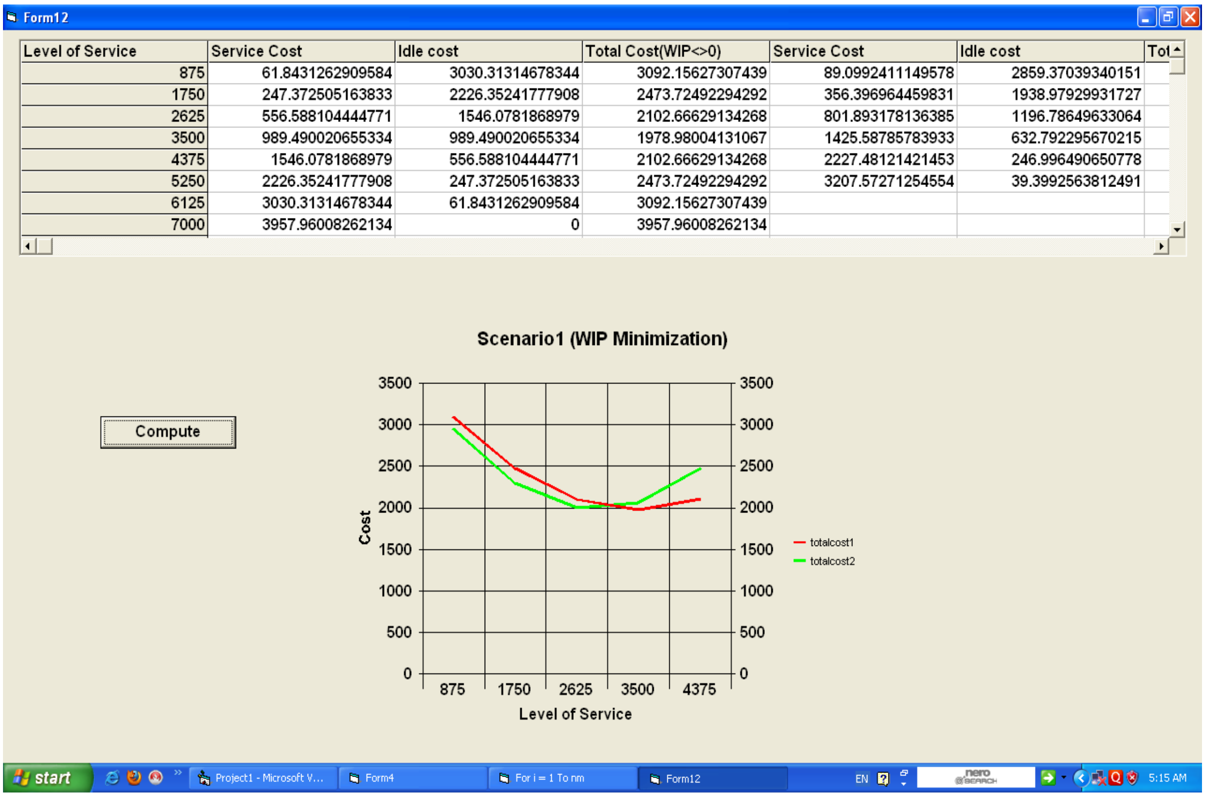


Fig.9 Computation of Total System Cost



Level of Service	Service Cost	Idle cost	Total Cost(WIP<>0)	Service Cost	Idle cost	Tot
875	61.8431262909584	3030.31314678344	3092.15627307439	89.0992411149578	2859.37039340151	
1750	247.372505163833	2226.35241777908	2473.72492294292	356.396964459831	1938.97929931727	
2625	556.588104444771	1546.0781868979	2102.66629134268	801.893178136385	1196.78649633064	
3500	989.490020655334	989.490020655334	1978.98004131067	1425.58785783933	632.792295670215	
4375	1546.0781868979	556.588104444771	2102.66629134268	2227.48121421453	246.996490650778	
5250	2226.35241777908	247.372505163833	2473.72492294292	3207.57271254554	39.3992563812491	
6125	3030.31314678344	61.8431262909584	3092.15627307439			
7000	3957.96008262134	0	3957.96008262134			

Fig.10 Two Scenarios for hypothetical Production Line.

V. Conclusion and Scope for Future Work

In the present work, the authors have developed and implemented a generic model for a single channel multi-phase production line. A GUI is presented for the design of an assembly line which stores the machine configuration information in an XML file. A DTD for the XML file is presented. WIP accumulation between various machines and individual machine idle times are determined. Optimum level of service is determined from system service cost and the system waiting cost. The model is generic and can be applied to any single channel multi-phase production line.

Based upon the cycle time of each work station, the service rate is determined and if the machine is kept busy on the basis of these derived times, the line is perfectly balanced to zero WIP level. In future, by setting the production line with various levels of WIP and analysing the utilization of resources, the cost impact can be assessed as a measure towards productivity improvement. To account for constrained resources which results in bottleneck, provision for time buffer or capacity buffer can be considered to attain synchronized manufacturing. Our future work focuses on fuzzifying input parameters to implement a mofre realistic model.

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Appendix A
Parsing of XML file using Microsoft XML Parser

```
Dim objXML As MSXML2.DOMDocument
 Dim objElem As
MSXML2.IXMLDOMElement
 Dim objSub As
MSXML2.IXMLDOMElement
    If con.State = adStateClosed Then
     con.Open
"Provider=Microsoft.Jet.OLEDB.4.0;Data
Source=C:\waitingline.mdb;Persist Security
Info=False"
    End If
    Set objXML = New
MSXML2.DOMDocument
    If Not objXML.Load(fname) Then
        Err.Raise
objXML.parseError.errorCode, ,
objXML.parseError.reason
    End If
    Set objElem =
objXML.selectSingleNode("WorkStations")
    ' iterate its sub-nodes
    cnt = 0
    For Each objSub In
objXML.selectNodes("//WorkStation")
        Set objElem =
objSub.selectSingleNode("MachineName")
        cnt = cnt + 1
        mname(cnt) = objElem.Text
        Set objElem =
objSub.selectSingleNode("CycleTime")
        ct(cnt) = objElem.Text
    Next
    cnt = 0
     For Each objSub In
objXML.selectNodes("//WorkStation")
        Set objElem =
objSub.selectSingleNode("MachineHourRate
")
        cnt = cnt + 1
        mhr(cnt) = objElem.Text
    Next
    cnt = 0
      For Each objSub In
objXML.selectNodes("//WorkStation")
        Set objElem =
objSub.selectSingleNode("LabourHourRate")
        cnt = cnt + 1
        lr(cnt) = objElem.Text
    Next
    cnt = 0
    For Each objSub In
objXML.selectNodes("//WorkStation")
        Set objElem =
objSub.selectSingleNode("ShiftBusyPeriod")
        cnt = cnt + 1
        avg_busy_period(cnt) = objElem.Text
    Next
    cnt = 0
    For Each objSub In
objXML.selectNodes("//WorkStation")
        Set objElem =
objSub.selectSingleNode("ProductionRate")
        cnt = cnt + 1
        prod(cnt) = objElem.Text
    Next
    nm = cnt 'No of machines
    If (prod(1) > 1 And prod(1) < 10) Then
     llimit = 10
     ulimit = 70
     con.Execute "Delete from servicecost"
     For i = 10 To 70 Step 10
      con.Execute "INSERT INTO
servicecost(LevelofService) VALUES(" & i
& ")"
     Next
    End If

    If (prod(1) > 10 And prod(1) < 100) Then
     llimit = 100
     ulimit = 700
      con.Execute "Delete from servicecost"
     For i = 100 To 700 Step 100
      con.Execute "INSERT INTO
servicecost(LevelofService) VALUES(" & i
& ")"
     Next
    End If

    If (prod(1) > 100 And prod(1) < 1000)
Then
     llimit = 1000
     ulimit = 7000
      con.Execute "Delete from servicecost"
     For i = 1000 To 7000 Step 1000
      con.Execute "INSERT INTO
servicecost(LevelofService) VALUES(" & i
& ")"
     Next
    End If
```