Preventive Maintenance

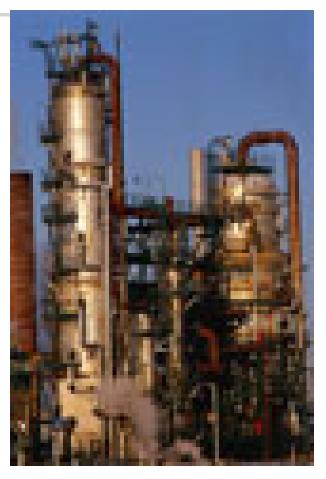
Chris Brammer Mike Mills

Why is preventive maintenance important?

- Reduce equipment downtime
- Reduce environmental and workplace hazards

To save money

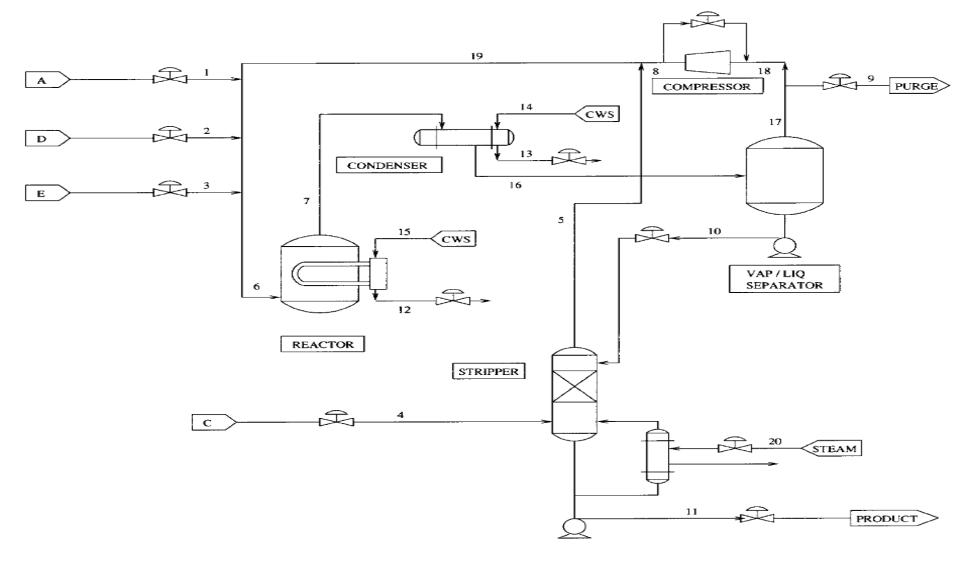




Project overview

- Build preventive maintenance scheduler
 - Assess potential losses
 - Find frequency of failure
 - Determine optimal maintenance policy
- Assist in Data Formation and Collection
 - Fortran Program Quang Nguyen
- Sample plant: Tennessee Eastman

Tennessee Eastman Process Plant



Theory

Maintenance types: Corrective (CM) Event driven (repairs) Preventive (PM) Time driven Equipment driven Opportunistic

Equipment failure modes

How does an equipment fail?

• Why does it fail?

Preventive maintenance...

Equipment Data

- Equipment type
- Failure type
- Mean time between failure
- Time needed for CM
- Time needed for PM
- PM interval
- Economic loss
- CM cost
- PM cost
- Inventory cost

Equipment Types

- Valves
- Pumps
- Compressor
- Reactor
- Flash Drum
- Heat Exchangers
- Stripping Column

Failure Types

- Fatigue
- Corrosion
- Wear
- Overload
- Contamination
- Misalignment



Mean time between failure...

- Log of equipment for particular time period
- Literature / Assumptions-Probability

MTBF

NS2 Shouldn't this be MTBF??? Nico Simons, 4/13/2007

Failure frequency

Equation:

$$t = MTBF \cdot \ln\left(\frac{1}{1-P}\right)$$

P = probability

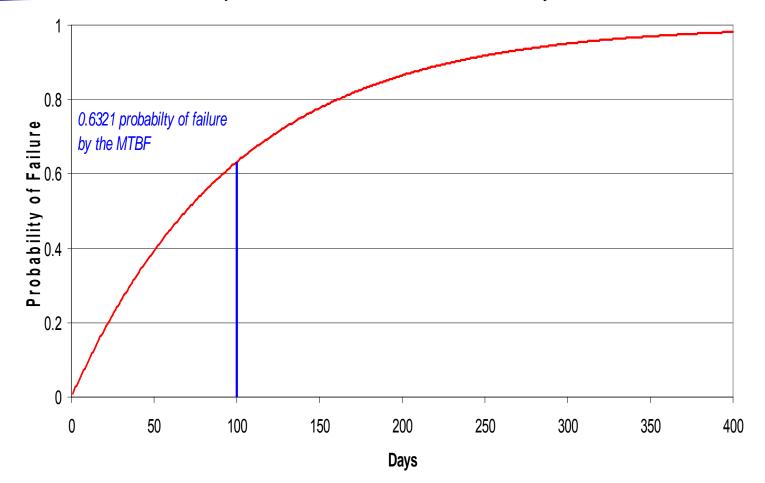
t= time of failure

MTBF = mean time between failure

•Exponential distribution for all failures

Exponential distribution (graph)

Exponential Distribution with MTBF of 100 days



Time Needed for CM & PM

Why?

Calculating Labor Costs

- Duration of Job
 - Scheduling

Preventative Maintenance Interval (PMI)

Based on MTBF

- High Frequency MTBF Shorter PM Interval
- Low Frequency MTBF Longer PM Interval
- Adjust to optimize cost
- Using a ratio of the MTBF

Economic Loss

- Losses occurred from reduced or halted process flows
- When CMs is performed

Equipment with failure that has not been Repaired

CM Cost

- Economic Loss (EL)
- Labor Costs (LC)
- Inventory Cost (IC)
- CM = EL + LC + IC

PM Cost

- Economic Loss (EL)
- Labor Costs (LC)
- Inventory Cost (IC)
- PM Interval (PMI)
- $\blacksquare \mathsf{PM} = \mathsf{EL} + \mathsf{LC} + \mathsf{IC}$
 - Per PMI

Inventory Cost

Inventory Cost – Opportunity Cost

$$IC = PC \cdot (1+i)^{MTBF} - PC$$

- PC = Parts Cost
- i = Interest Rate for investing money
- MTBF in years
- Not Accounted for Currently

PM Scheduler/Model

- Monte Carlo Simulation
- Optimize occurrence of PMs
 - Taking in to account the distributions of failure
 - PMs cost < Amount saved</p>
- Verify optimum with plots of total cost versus number of PMs

Monte Carlo Simulation

- Random Number Generation
 - Used to produce a random samples
 - Compile/Compute Data easily
 - Large sample size represents system
 - Analyze the results
- Optimization
 - Change the parameters
 - Repeat the simulation

A Perfect Model

- Equipment Data control
 - Generate PM's automatically
 - Determines equipments importance
- Employee Management
 - # of Employee's based on Failures
 - Employee skill determines job selection
- Inventory Control and Management
- Detail Repair Cost for Each Job
- Repair Instructions

Design of First Simulation

- Familiar tools
- Excel
- @Risk
- Only six pieces of equipment

Excel Simulation!

Assumptions made:

- Unlimited resources
- Immediate detection of failure
- No PM down time
- Equipment failure ——> shut down
- Equipment restored to new

Input Values

- Mean time between failures
- Time needed for CM
- Time needed for PM
- Initial runtime of equipment
- PM interval
- PM cost
- Cost of repair
- Economic Loss

Excel Table

														-	
		Equipment	Equipment	1	Name	ID Number	MTBF		MTPM		e Star PM	PM Cos		COD	Total Cost
		Specs	Number				(hrs)	(hrs)	(hrs)	(hour)	(hrs)	(\$)	(\$)	(\$)/hr	
		oposo		1 \	Valve 1	V1	8	3 4		0	1	6 10) 100	0 606.	6 <mark>\$8,733,319</mark>
Number	Number	Hour of the	Continous			Failure	Failed		Failure	PM	Under PN	PM		Total Downtime	
of Hours	of Davs					Probability			Count			Count		g Remaining	of Downtime
	,	-	(hrs)		Number		Y/N	Y/N		Y/N	Y/N		(hrs)	(hrs)	(hrs)
0	0	0			0.33333648	0.22119921				0		()	0	0 (
1	0	1		3	0.33333648	0.31271072				0		()	0	0 (
2	0	2		4	0.33333648	0.39346934	4 Yes	Yes		1		()	4	4 4
3	0	3		0	1	()	Yes		1		()	3	3 4
4	0	4		0	1	()	Yes		1		()	2	2 4
5	0	5		0	1	()	Yes		1		()	1	1 4
6	0	6		0	1	0.44750000)			1		()	0	0 4
/	0	/		1	0.89994635	0.117503097				1		()	0	0 4
8	0	8		2	0.89994635	0.22119921				1		())	0	0 4
9	0	9 10		3 1	0.89994635 0.89994635	0.31271072				1		l l		0	0 4
10	0			4	0.89994635	0.39346934				1		(ן ר	0	0 4
11 12	0			э 6	0.89994635	0.40473037				1 1 Yes	Yes		1	0	0 2
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13	0	13		1 2	0.13051049	0.221199217		Yes		י כ			1	4	2 ۱
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16	0	15		0	1		ן ר	Yes		2			1	2	2 (2)
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10	0	10		1	0.67311809	0.11750309	7			- 2			1		0 5
20	0			2	0.67311809	0.22119921				2			1		0 5
20	0			3	0.67311809	0.31271072				2			1	0	0 8
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During each hour for each piece of equipment:

- 1. Check current status of the equipment.
- 2. Determine equipment continuous runtime.
- 3. Generate new random number if needed.
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After simulation has run calculate total cost.

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				1		VI	c) 4	•	0		0 1	0	1000	000.0	\$0,733,319
Number of Hours	Number Number of Hours of Days			F	Random	Probability	Failed	Repair	Failure Count	PM	Under P	M PM Count	R	emaining	Total Downtime Remaining	of Downtime
			(hrs)		Number		Y/N	Y/N		<u>Y/N</u>	Y/N		<u>(</u> h	nrs)	(hrs)	(hrs)
0	0				0.33333648	0.221199217				0			0	0	0	0
1	0			3	0.33333648	0.312710721	Vee	Vee		U 1			0	0		0
2	C			4	0.33333648	0.39346934	res	Yes Yes	1	1			0	4	4	4
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-+ 5	C C			0 Û	· 1	0		Yes		1			0	1	1	. 4
6	C C			0	1	0		103		1			0	0		4
7	C	, U		1	0.89994635	0.117503097				1			0	0		4
8	Ċ) 8		2	0.89994635	0.221199217				1			0	0		4
9	C) 9		3	0.89994635	0.312710721				1			0	0	C	4
10	C) 10		4	0.89994635	0.39346934				1			0	0	C	4
11	C) 11		5	0.89994635	0.464738571				1			0	0	C	4
12	C) 12		6	0.89994635	0.527633447				1 Yes	Yes		1	0	C	4
13	C) 13		1	0.13051049	0.117503097				1			1	0	C	4
14	C) 14		2	0.13051049	0.221199217	Yes	Yes		2			1	4	4	. 8
15				0	1	0		Yes		2			1	3	3	8
16	C			0	1	0		Yes		2			1	2	2	8
17	C			0	1	0		Yes		2			1	1	1	8
18				0	1	0				2			1	0	0	8
19				1	0.67311809	0.117503097				2			1	0	C	8
20 21	C			2 3	0.67311809 0.67311809	0.221199217 0.312710721				2			1 1	0		8 8

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		Equipment Specs	Number	Name 1 Valve 1	ID Number V1	MTBF (hrs) {	(hrs)	MTPM (hrs)	Runtime S (hour))	Star PM (hrs) 1	PM Cos (\$) 6 10	(\$)	COD (\$)/hr 606.6	Total Cost \$8,733,319
Number	Number	Hour of the	Continous	Generate	Failure	Failed		Failure	PM	Under PN	PM		Total Downtime	
of Hours		Dav	Runtime	Random	Probability			Count			' Count	-	Remaining	of Downtime
	-	-	(hrs)	Number	0.00110001	Y/N	Y/N		Y/N	Y/N		(hrs)	(hrs)	(hrs)
0	0	0		2 0.3333364					2		C		0	0
1	0	1		3 0.3333364			Vee		1				0	0
2	0	2		4 0.3333364 0	8 0.39346934	+ Yes	Yes		1) 4) 2	4	4
3	0	3		0))	Yes Yes		1) 3) 9	3	4
4	0	4		0	1 (ן ר	Yes		1) <u> </u>	2	4
5	0	5		0		ן ר	165		1			י י ה ה		4
7	0	7		0.8999463	5 0.117503097	7			1		C C	, 0) 0		4
, 8	0	8		2 0.8999463					1		C C) ()		4
g	0	9		3 0.8999463					1		C C) ()	0	4
10	0	10		4 0.8999463					1		C) ()	0	4
11	0	11		5 0.8999463					1		C) 0	0	4
12	0	12		6 0.8999463					1 Yes	Yes	1	0	0	4
13	0	13		1 0.1305104	9 0.117503097	7			1		1	0	0	4
14	0	14		2 0.1305104	9 0.221199217	7 Yes	Yes	:	2		1	4	4	8
15	0	15		0	1 ()	Yes	:	2		1	3	3	8
16	0	16		0	1 ()	Yes	:	2		1	2	2	8
17	0	17		0	1 ()	Yes	2	2		1	1	1	8
18	0	18		0	1 ()		2	2		1	0	0	8
19	0	19		1 0.6731180	9 0.117503097	7		:	2		1	0	0	8
20	0	20		2 0.6731180				:	2		1	0	0	8
21	0	21		3 0.6731180	9 0.31271072 [,]	1		:	2		1	0	0	8

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		2																
Number of Hours		Hour of the Day	Runtime	Genera Rando	m	Failure Probability	Failed	Repair	Failure Count	PM	Under F	-11/1	PM Count	Ren	naining	Total Downtim Remaining	of	Downtime
		-	(hrs)	Numbe			Y/N	Y/N		Y/N	Y/N			(hrs)	(hrs)		rs)
0	0	0			333648	0.221199217				0			0)	0		0	0
1	0	1			333648					0			0)	0		0	0
2	0	2		4 0.333	333648	0.39346934	Yes	Yes		1			0)	4		4	4
3	0	3		0	1	0		Yes		1			0)	3		3	4
4	0	4		0	1	0		Yes		1			0)	2		2	4
5	0	5		0	1	0	1	Yes		1			0)	1		1	4
6	0	6		0	1	0				1			0)	0		0	4
7	0	7			994635					1			0)	0		0	4
8	0	8			994635					1			0)	0		0	4
9	0	9			994635					1			0)	0		0	4
10	0	10			994635	0.39346934				1			0)	0		0	4
11	0	11			994635					1			0)	0		0	4
12	0	12			994635	0.527633447				1 Yes	Yes		1		0		0	4
13		13)51049					1			1		0		0	4
14		14		2 0.130)51049	0.221199217	Yes	Yes		2			1		4		4	8
15		15		0	1	0		Yes		2			1		3		3	8
16	0	16		0	1	0		Yes		2			1		2		2	8
17	0	17		0	1	0		Yes		2			1		1		1	8
18	0	18		0	1	0				2			1		0		0	8
19	0	19			311809					2			1		0		0	8
20		=•			311809	0.221199217				2			1		0		0	8
21	0	21		3 0.673	311809	0.312710721				2			1		0		0	8

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Number	Number	Hour of the	Continous			Failure	Failed		Failure	PM	Under P	MPM			Total Downtime	
of Hours		Dav	Runtime			Probability		-	Count			" Count		-	Remaining	of Downtime
		-	(hrs)		mber		Y/N	Y/N		Y/N	Y/N		(h	nrs)	(hrs)	(hrs)
0	0	0			.33333648	0.221199217				0			0	0	0	0
1	0	1			.33333648	0.312710721)			0	0	0	0
2	0	2		4 0.	.33333648	0.39346934	Yes	Yes		1			0	4	4	4
3	0	3		0	1	0		Yes		1			0	3	3	4
4	0	4		0	1	0		Yes		1			0	2	2	4
5	0	5		0	1	0		Yes		1			0	1	1	4
6	0	6		0	1	0				1			0	0	0	4
1	0	(0.117503097				1			0	0	0	4
8	0	8			.89994635	0.221199217				1			0	0	0	4
9	0	9			.89994635	0.312710721				1			0	0	0	4
10	0	10			.89994635	0.39346934				1			0	0	0	4
11	0	11			.89994635	0.464738571				1	N/		0	0	0	4
12	0	12			.89994635	0.527633447				1 Yes	Yes		1	0	0	4
13		13			.13051049	0.117503097				1			1	0	0	4
14		14		20.	.13051049	0.221199217	Yes	Yes		2			1	4	4	8
15		15		0	1	0		Yes		2			1	3	3	8
16	0	16		0	1	0		Yes		2			1	2	2	8
17	0	17		0	1	0		Yes		2			T A	1	1	8
18	0	18		0	1	0 447500007				2			T A	0	0	8
19	0	19			.67311809	0.117503097				2			T A	0	0	8
20		20			.67311809	0.221199217				2			T A	0	0	8
21	0	21	l	3 0.	.67311809	0.312710721				2			1	0	0	8

Simulation Process

- 6. If runtime is greater than or equal to the time between PMs, mark equipment as PMed.
- 7. Determine equipment status.
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After simulation has run calculate total cost.

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				1		VI	<u> </u>	<u>, 1</u>	· (,	1	Ľ		,	1000	000.0	σ φ0,733,319
Number of Hours		Hour of the Day	Runtime	F	Random	Failure Probability	Failed	Repair	Failure Count	PM	Under	PM	PM Count	Re	emaining	Total Downtime Remaining	of Downtime
		-	(hrs)		Number	0.001100017	Y/N	Y/N		<u>Y/N</u>	Y/N			(hr	<u>s)</u>	(hrs)	(hrs)
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ו כ	0	ו ס		3 1	0.33333648	0.39346934	Voc	Yes	() I				ן ר	0		1 4
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6	0	6		0	1	0							Ċ)	0) 4
7	0	7		1	0.89994635	0.117503097				1			C)	0) 4
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9	0	9		3	0.89994635	0.312710721				1			C)	0	() 4
10	0	10		4	0.89994635	0.39346934				1			C)	0	() 4
11	0	11		5	0.89994635	0.464738571							C)	0	() 4
12	0	12		6	0.89994635	0.527633447				Yes	Yes		1	1	0	() 4
13		13		1	0.13051049	0.117503097							1	1	0	() 4
14		14		2	0.13051049	0.221199217	Yes	Yes	2	2			1	1	4	4	4 8
15		15		0	1	0		Yes	2	2			1	1	3		3 8
16	0	16		0	1	0		Yes	2	2			1	1	2		2 8
17	0	17		0	1	0		Yes	2	2			1	1	1		1 8
18		18		0	1	0			2	2			1	1	0) 8
19		19		1	0.67311809	0.117503097				2			1	1	0		8
20 21	0 0	-•		2	0.67311809 0.67311809	0.221199217 0.312710721			4	2			1	1 1	0 0) 8) 8

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		Equipment Specs		Name I Valve 1	ID Number V1	MTBF (hrs)	(hrs)	MTPM (hrs)	Runtime (hour) 0	e Star PM (hrs)	(\$)	ost COF (\$) 10	1000	COD (\$)/hr		Total Cost \$8,733,319
					VI	(,		0	I	0	10	1000		00.0	φ0,733,319
Number of Hours			Continous Runtime (hrs)	Generate Random Number	Failure Probability	Failed Y/N		Failure Count	PM Y/N	Under Pi Y/N	M PM Count		ntime aining	Total Down Remaining (hrs)		Total Hours of Downtime (hrs)
	0	-	· /	2 0.33333648	0.221199217		1/11		0	1/11		0	0	· · · ·	0	
1	0	1		0.33333648					0			0	0		0	0
2	0	2		0.33333648			Yes		1			0	4		4	4
3	0	3	() 1)	Yes		1			0	3		3	4
4	0	4	() 1	(5	Yes		1			0	2		2	4
5	0	5	() 1	()	Tes		1			0	1		1	4
6	0	6	() 1	(C			1			0	0		0	4
7	0	7		0.89994635	0.117503097	7			1			0	0		0	4
8	0	8		0.89994635	0.221199217	7			1			0	0		0	4
9	0	9	:	0.89994635	0.31271072	1			1			0	0		0	4
10	0	10	4	0.89994635	0.39346934	1			1			0	0		0	4
11	0	11	Į	5 0.89994635					1			0	0		0	4
12		12	e	6 0.89994635					1 Yes	Yes		1	0		0	4
13		13		0.13051049					1			1	0		0	4
14		14	2	2 0.13051049	0.22119921	7 Yes	Yes		2			1	4		4	8
15		15) 1	()	Yes		2			1	3		3	8
16	0	16	() 1	()	Yes		2			1	2		2	8
17	0	17	() 1	()	Yes		2			1	1		1	8
18		18) 1	()			2			1	0		0	8
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21	0	21		3 0.67311809	0.31271072	1			2			1	0		0	8

Simulation Process

- 6. If runtime is greater than or equal to the time between PMs, mark equipment as PMed.
- 7. Determine equipment status.
- 8. If the equipment is still under repair or maintenance than decrement the downtime remaining.
- 9. Determine total downtime.

After simulation has run calculate total cost.

Excel Table

		Equipment Specs	Equipment Number	Name 1 Valve 1	ID Number V1	MTBF (hrs) {	(hrs)	MTPM (hrs)	Runtime ((hour)	(hrs)	PM Cos (\$) 6 10	(\$)	COD (\$)/hr 606.6	Total Cost \$8,733,319
Number of Hours		Dav	Continous Runtime (hrs)	Generate Random Number	Failure Probability	Failed Y/N		Failure Count	PM Y/N	Under PM Y/N	1 PM Count		Total Downtime Remaining (hrs)	Total Hours of Downtime (hrs)
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7 8	0 0	7 8		1 0.8999463 2 0.8999463	5 0.221199217				1		() () (0	4
9 10 11	0	9 10 11		3 0.89994635 4 0.89994635 5 0.89994635	0.39346934	Ļ			1 1 1					4 4 4
12 13		12 13		6 0.89994633 1 0.13051049	5 0.527633447 9 0.117503097	,			1 Yes 1	Yes	1		0	4 4
14 15 16	0	14 15 16		2 0.13051049 0) 0.221199217 (Yes)	Yes Yes Yes	4	2 2 2		1 1 1		4 3 2	8 8 8
17 18	0	17 18		0 ·))	Yes		- 2 2		1	l 1 l C	1	8 8
19 20 21	0 0 0	19 20 21		1 0.67311809 2 0.67311809 3 0.67311809	0.221199217				2 2 2		1 1 1	C C C	0 0 0	8 8 8

Simulation Process

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			Continous	Generate	Failure		Under	Foiluro				Dountimo	Total Downtime	Total Hours
Number	Number	Hour of the	Runtime	Random	Probability	Failed		Failure Count	PM	Under PIV	PM Count			of Downtime
of Hours	of Days	Day	(hrs)	Number	Tiobability	Y/N	Y/N	Count	Y/N	Y/N	Count	(hrs)	(hrs)	(hrs)
	0	0	· · · · · ·	2 0.33333648	0.221199217		1/1 1)	171	() 0	0	(113)
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3	0	3		0 1	()	Yes		1		C) 3	3	4
4	0	4		0 1	()	Yes		1		() 2	2	4
5	0	5		0 1	()	Yes		1		() 1	1	4
6	0	6		0 1	()			1		() 0	0	4
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8	0	8		2 0.89994635	0.221199217	,			1		() 0	0	4
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20 21	0	20 21		2 0.67311808 3 0.67311809					<u>-</u>)		1			0 Q
21	0	21	I '	0.07011008	0.512/10/2	l		4	_			0	0	C

Simulation Process

- 6. If runtime is greater than or equal to the time between PMs, mark equipment as PMed.
- 7. Determine equipment status.
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After simulation has run calculate total cost.

Excel Table

	-	E au dia ma a sa t	Equipment	NI			MTBF	MTCM	MTPM	Runtime	Star	PM	PM Cos	1 COF	-	COD		Total Coat
		Equipment Specs	Number	INa	ame	ID Number	(hrs)	(hrs)	(hrs)	(hour)		(hrs)	(\$)	(\$)		(\$)/hr		Total Cost
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Number	Number	Hour of the	Continous			Failure	Failed		Failure	PM		Under PM	PM			Total Dov		Total Hours
of Hours			Runtime			Probability		Repair	Count				Count			Remainir	ng	of Downtime
	ol Baye	Day	(hrs)		umber		Y/N	Y/N		Y/N		Y/N		(hrs)		(hrs)		(hrs)
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1	0	1			0.33333648	0.312710721				0			C)	0		0	0
2	0	2		4 (0.33333648	0.39346934	Yes	Yes		1			C		4		4	4
3	0	3		0	1	0		Yes		1			C)	3		3	4
4	0	4		0	1	0		Yes		1			0)	2		2	4
5	0	5		0	1	0		Yes		1			0)	1		1	4
6	0	6		0	1	0 447502007				1)	0		0	4
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9 10	0	10			0.89994635	0.39346934				1					0		0	4
10	0	10			0.89994635	0.39340934				1					0		0	4
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13		13			0.13051049	0.117503097				1		103	1		0		0	4
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16		16		0	1	0		Yes		2			1		2		2	8
17	0	17		0	1	0		Yes		2			1		1		1	8
18	0	18		0	1	0				2			1		0		0	8
19		19		1 (0.67311809	0.117503097				2			1		0		0	8
20	0	20		2 (0.67311809	0.221199217				2			1		0		0	8
21	0	21		3 (0.67311809	0.312710721				2			1		0		0	8

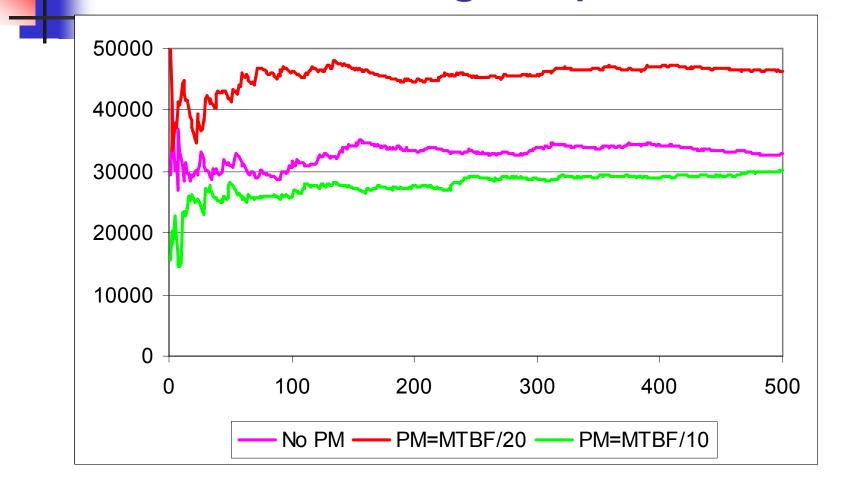
Running the Simulation

- Enter the equipment specifications
- Use @RISK and optimize values manually
- ... or use RISKOptimizer to optimize automatically
- Would be best to optimize one piece of equipment at a time

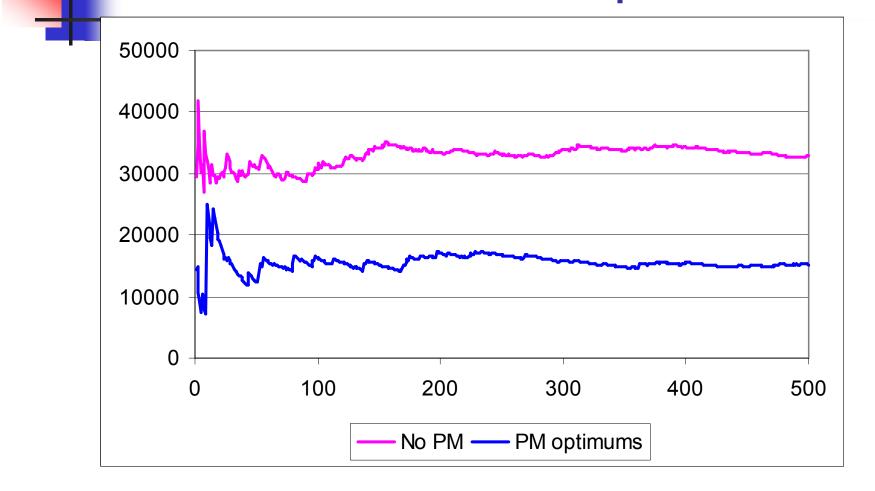
Methods

- Rough Estimates
- Determine Number of Samples Needed
- All PMs adjusted by common factor of each equipment's MTBF.
- From this rough optimum each PM is then optimized individually

Results – Rough Optimums



Results – Overall Optimums



Results Summary

- Average total cost using MTBF factor
 - No PMs \$32,883
 - MTBF/10 \$30,203
 - MTBF/20 \$46,373
- Individual PM optimums \$15,197
 - 3 valves 8 PMs / year for each
 - Stripping column <1 PM / year</p>
 - Heat exchanger 6 PMs / year
 - Pump 22 PMs / year

Advantages of Excel Simulation

- Easy to see how the simulation works
- Detailed analysis of results via @Risk
- Automatic optimization via @Risk

Limitations of Excel Simulation

- Number of cells in a worksheet
- No labor limitation considerations
- No failure types or priorities
- Difficult to add advanced features
- Computation time
- Computation time
- Computation time

Switched to Fortran Program

- No limit on number of equipment
 - 7 types, 19 pieces (Piping not considered)
- Addition of labor limitations
 - To an extent (Salary)
- Multiple failure types and priorities
- Easier to add more advanced features
- Significantly faster than Excel

Rules

- 1. Repair is classified by priority
- 2. Categories are described by the time one can afford before there is an unacceptable loss
- 3. Preventive maintenance is scheduled at regularly recurring intervals

Rules

- 4. If corrective maintenance occurred before schedule PM, PM is suspended.
- 5. Each week corrective maintenance actions schedule is planned ahead
- 6. Preventive maintenance on all major equipment is performed at downtime to minimize downtime

Rules

- Opportunistic maintenance, equipment dependencies, and delayed detection of failure are not considered
- 8. If there is an online backup of a piece of equipment determine the rules for when to switch to it

Priority Categories

Priority categories are established using a double entry matrix

	Cons	equence of	failure
Probability of subsequent catastrophic failure	High	Medium	Low
High	1	2	3
Medium	2	3	4
Low	3	4	5

Levels of Failures for Maintenance Concerns (following Tischuk, 2002)

Priority Categories

- Probability of subsequent catastrophic failure is based on how often a failure is expected to occur
- Consequences of failures is based on production loss, environmental hazards, and workplace safety all of which are ultimately associated with revenue

Equipment Data Determinations

- Mean time between failure
- Time needed for CM
- Time needed for PM
- PM interval
- Economic loss
- CM cost
- PM cost
- Priority

MTBF

Base on Average MTBF for type of equipment

Higher Probability – Smaller MTBF

Lower Probability – Larger MTBF

Time Needed for CM & PM

- CM
 - Assumption Based
 - Type of CM for each piece of equipment
- PM
 - Assumption Based
 - Type of PM for each piece of equipment
 - Safety work permits & simplicity of work



• $\frac{1}{2}$ MTBF $\rightarrow 1/80$ MTBF

Were Tested for Optimization

Done with an infinite work for at no cost.

Economic Loss

- During CM Cost per time
 - Based on Equipment Importance
- Un-repaired Equipment
 - Was 0.1% of the EL occurred during CM
- Cost per time x time = Economic loss

CM & PM Cost

CM Cost

Simply Cost of the Equipment

PM Cost

- Based on the Type of Equipment
 - Lubrication
 - Cleaning a Compressor impeller so vibrations will be minimized

Priority

- Used for planning
 - CM completed from Priority $1 \rightarrow 5$
 - PM completed after CM from Priority $1 \rightarrow 5$
- Delays
 - CM is completed at the first of the next week
 - PM is rescheduled for exactly seven days later

Priority (cont'd)

- If CM performed on equipment, next PM is ignored
- If CM is delayed more than 21 days, it is upgraded one level.
- After CM equipment is good-as-new.

Equipment Failure Spreadsheet

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,	Labor cost	1320000		2 V-1	Valve	Moderate Corrosion	1442	2		30	13
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1				6 V-1	Valve	Slight Wear	1325	2	2	30	13
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3	Valves	1002		8 V-1	Valve	Severe Corrosion	1054	5	2	30	13
Ļ	Compressor	381		9 V-1	Valve	Moderate Corrosion	949	4	2	30	13
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3	Heat Exchangers	1193	1	11 V-1	Valve	Severe Wear	1037	5	2	30	13
7	Reactor	1660	1	12 V-1	Valve	Moderate Wear	934	4	2	30	13
8	Stripper	2582		13 V-1	Valve	Slight Wear	840	4	-	30	13
9	Flash Drum	2208	1	14 V-1	Valve	Fatigue	1099	4	2	30	13
0	x factor	80	1	15 V-1	Valve	Severe Corrosion	782	5	2	30	13
1	Equipment Type	PMI	1	16 V-1	Valve	Moderate Corrosion	704	4	2	30	13
	Valves	13		17 V-1	Valve	Slight Corrosion	633	0	_	30	13
	Compressor	5		18 V-1	Valve	Severe Fatigue	810	5	2	30	13
4	Pumps	5	1	19 V-1	Valve	Slight Fatigue	625	4	2	30	13
5	Host Evchangers	16		20 1/ 1	Valva		۹77	F	2	30	12

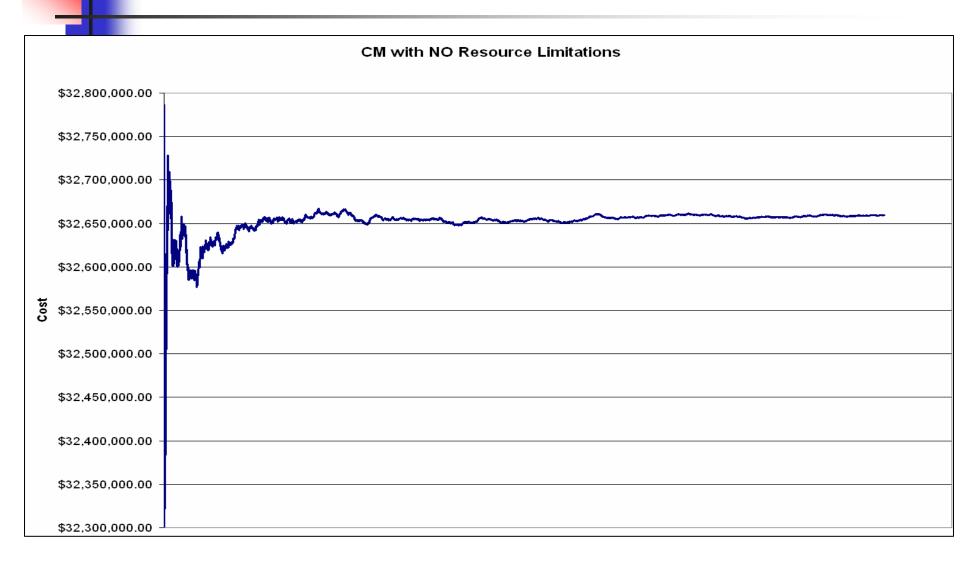
Fortran Model

- CM Model
 - Without Resource Limitations
 - Resource Limitation
 - Number of Workers
- CM & PM Model
 - Optimize
 - PMI
 - Number of Workers
- Will be analyzed at 1 & 3 years

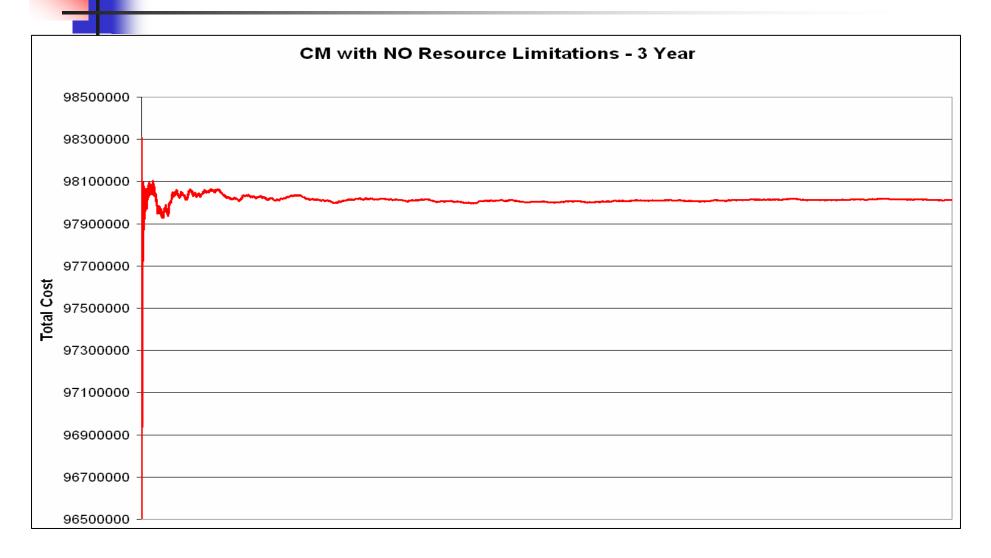
Fortran Model

- Does Not Consider...
 - Inventory Cost or Parts Available
 - Cost on an hourly/job basis
 - Employee Management
 - Which Job working
 - Employees are on Salary

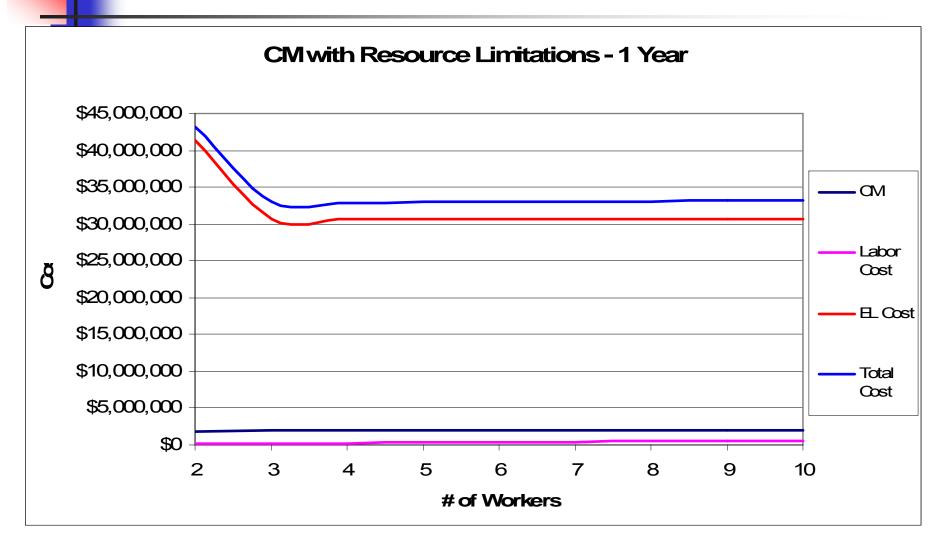
1 Year CM Model No Resource Limitations



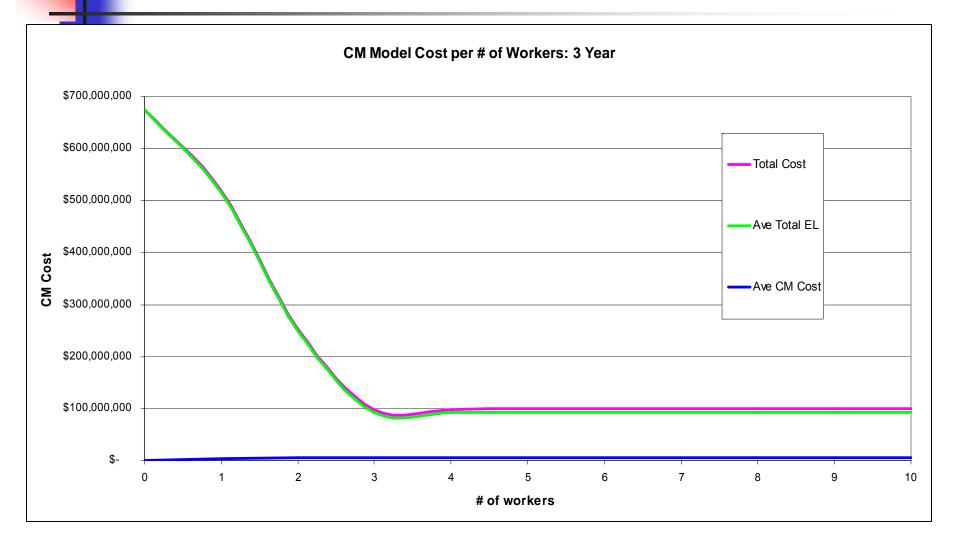
3 Year CM Model No Resource Limitations



1 Year CM Model With Resource Limitations



3 Year CM Model With Resource Limitations



Comparison of the CM Models

	CM Models		
Years	Model	# of Workers	Total Cost
1	CM Model - No Resource Limitations	Infinite	\$32,670,224
1	CM Model - With Resource Limitations	4	\$32,892,092
3	CM Model - No Resource Limitations	Infinite	\$98,026,767
3	CM Model - With Resource Limitations	3	\$98,657,573

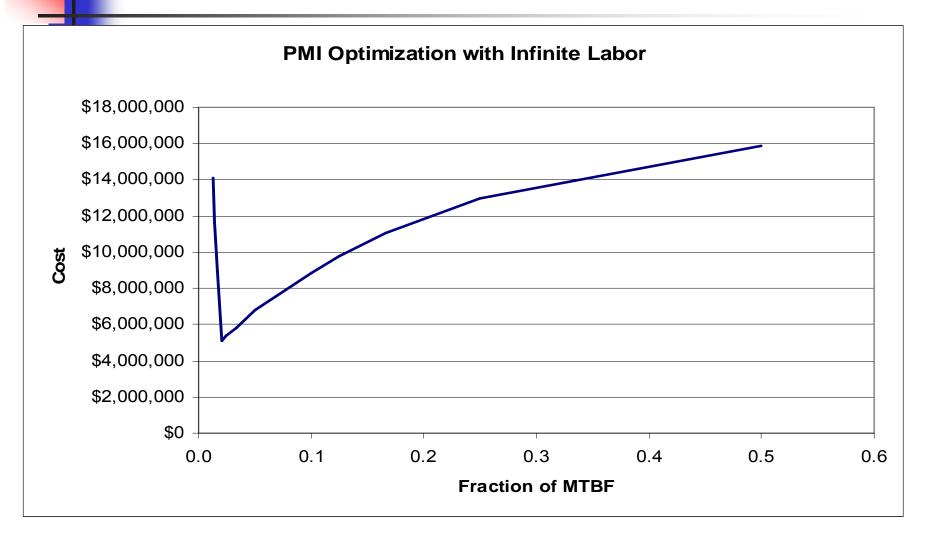
- 1 Year Difference \$221,868
- 3 Year Difference \$630,806

CM & PM Model – PMI optimization

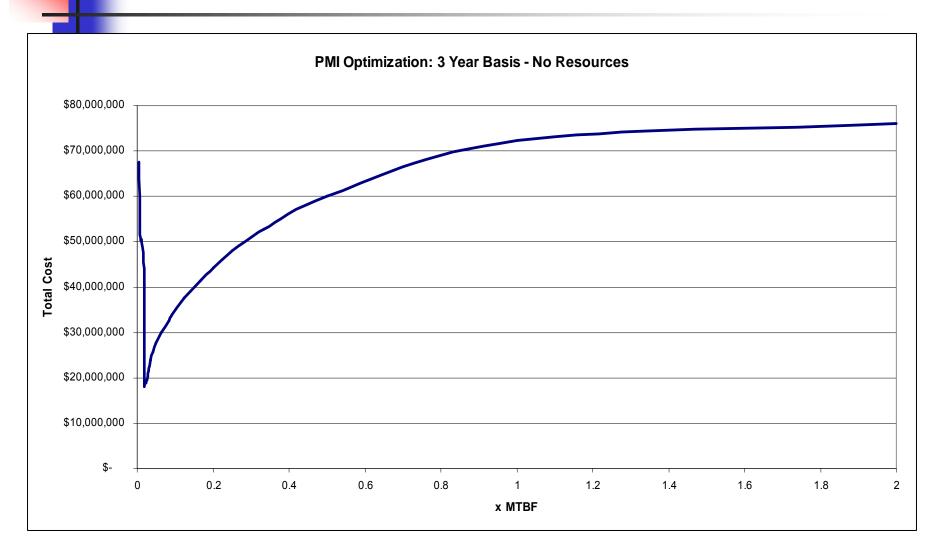
Use of Infinite Labor

- No Labor Cost
- Ran Model with PMI Ranges
 - \blacksquare Ranging from $\mathscr{V}_2 \to 1/80$ the MTBF
- Low Cost??

PMI optimization – 1 Year



PMI optimization – 3 Year



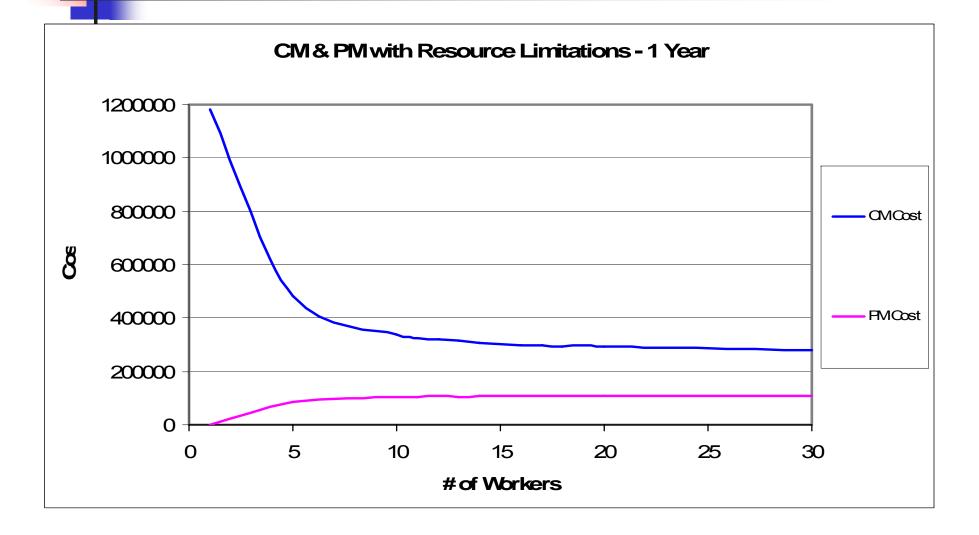
Workforce Optimization CM & PM Model

Use the Optimal PMI Found

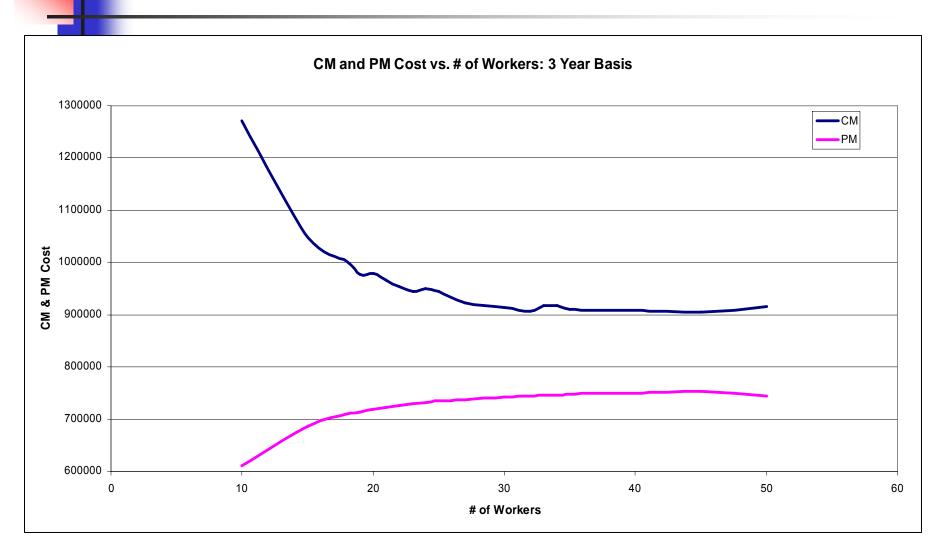
Vary the number of workers

Low Costs??

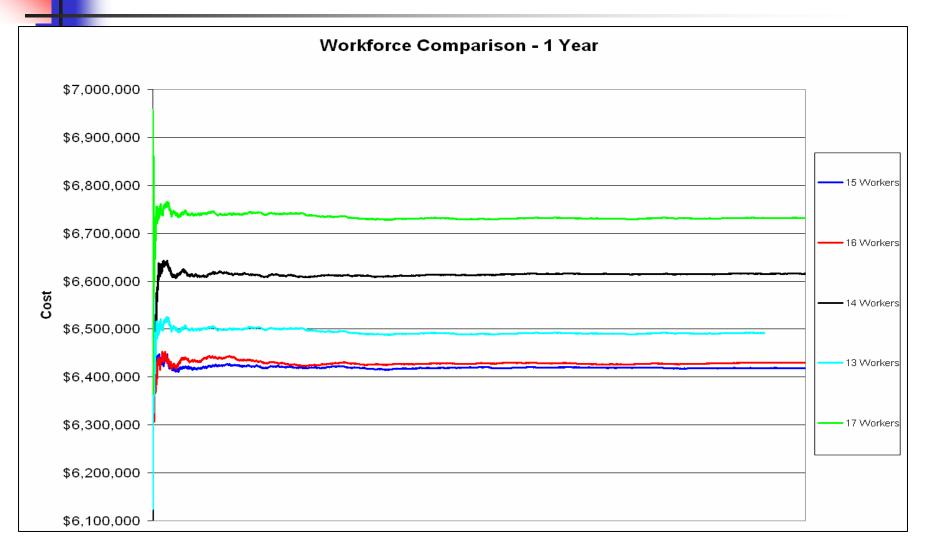
CM & PM Model (1-Year) CM, EL, PM, & Total Costs



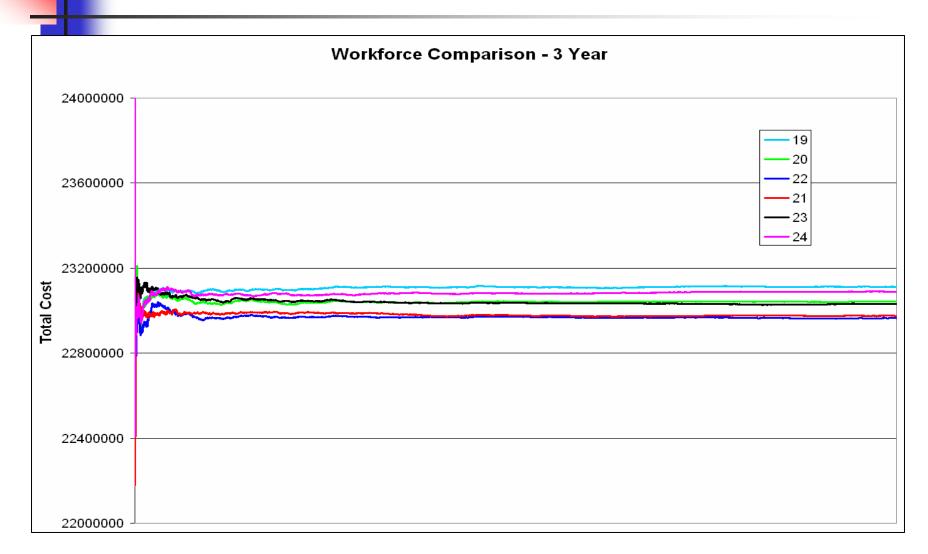
CM & PM Model (3-Year) CM, EL, PM, & Total Costs



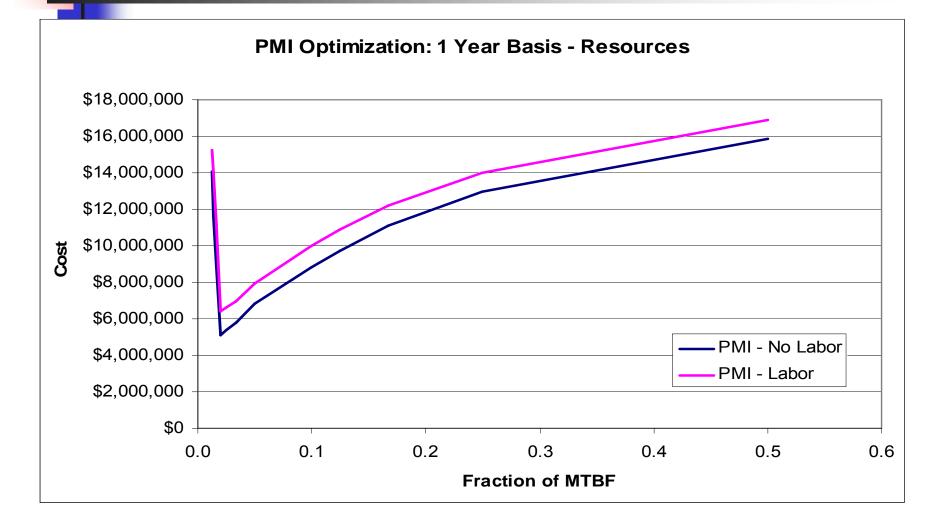
Verification of Number of Workers PM & CM Model (1 Year)



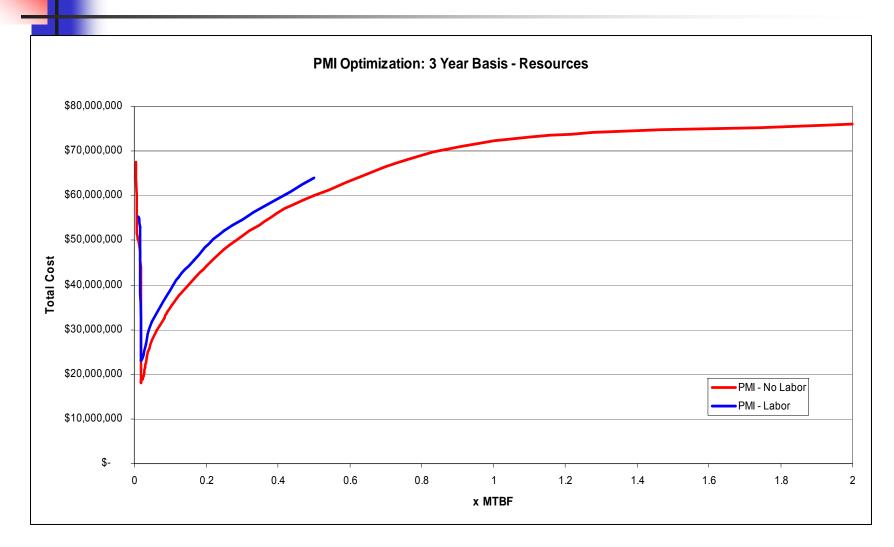
Verification of Number of Workers PM & CM Model (3 Year)



Does the PMI change based on a different work force?



Does the PMI change based on a different work force?



Model Comparison

	All Models		
Years	Model	# of Workers	Total Cost
1	CM Model - No Resource Limitations	Infinite	\$32,670,224
1	CM Model - With Resource Limitations	4	\$32,892,092
1	PM & CM Model	15	\$6,421,160
3	CM Model - No Resource Limitations	Infinite	\$98,026,767
3	CM Model - With Resource Limitations	3	\$98,657,573
3	PM & CM Model	22	\$23,027,813

- 1 Year Saving using PM Model
 - **\$**26,470,932
- 3 Year Savings using PM Model
 - **\$75,629,760**

Conclusions

- Easy to see PM significantly reduces
 Cost
 - Best CM Model vs. PM & CM Model
 - Savings of \$26.5 million for 1 year
 - Savings of \$75.6 millions for 3 year

Improvements

Questions?



REFERENCES:

- Guidelines for process equipment reliability data with data tables.
 American Institute of Chemical Engineers. 1989.
- Guidelines for Design Solutions for Process Equipment Failures. American Institute of Chemical Engineers. 1998.