ETM

ENGINEERING & TECHNOLOGY MANAGEMENT

Optimal Maintenance Plan within NCC (National Cement Company)

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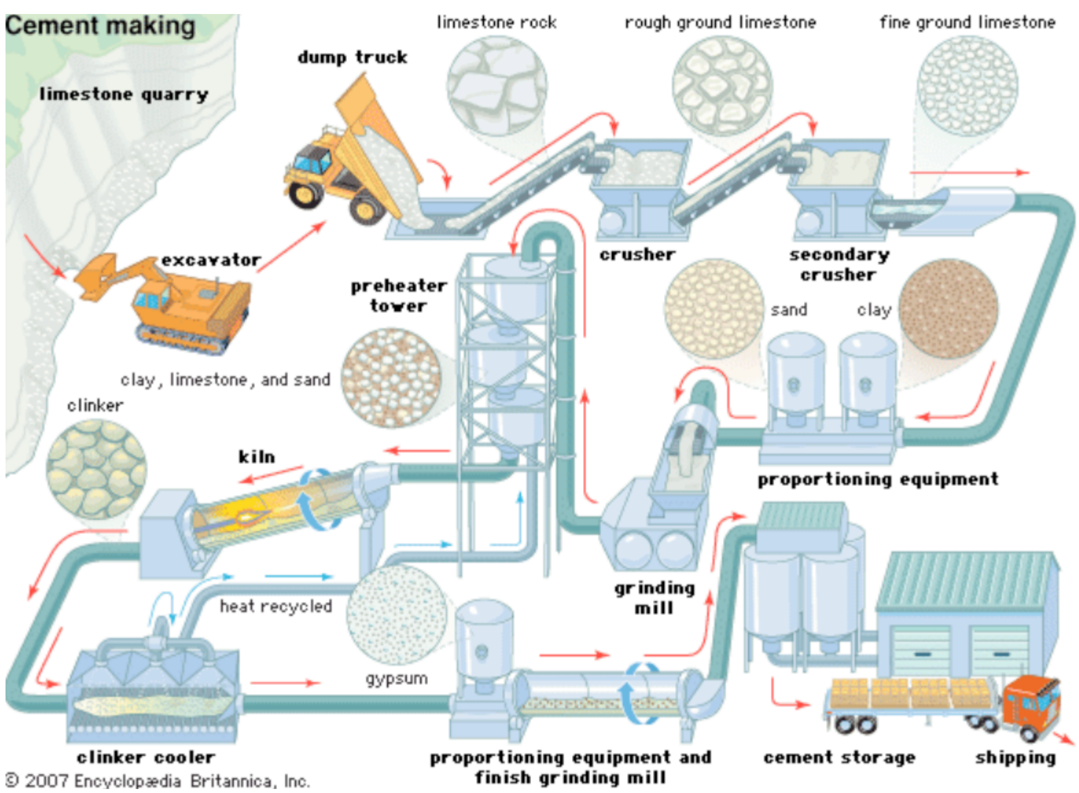
Abstract

The worst considered type of hold back within a manufacturing facility is an unexpected breakdown of machinery. Such breakdowns that would typically cost the most due to time lost during production. This report will explore the possibility of utilizing a mix of both Non-linear & Linear programing in excel to develop a basic staffing model to help develop an optimal preventive maintenance plan that will minimize breakdowns and the costs associated with them. The established model can help with the prevention of future failures within different equipment and minimize costs to allow for an increase in profit.

Introduction

National Cement Company (NCC) was established in 2006 and resides in Republic of Yemen. Estimated start-up cost was $250,000,000. NCC currently employs over 5000 employees, and is disbursed within the six-different locations worldwide. Image below is an illustration of the process life cycle that would simulate an NCC's facility [5].



As the industries increase in demands, the company falls behind in resources to help develop process to maintain a healthy growth.

There are a lot of different definitions of maintenance but within the industrial industry the best definition that could be found was written by B.S. Dhillon in his book, "Engineering Maintenance: A Modern Approach". He defines maintenance as "All actions appropriate for retaining an item/part/equipment in, or restoring it to, a given condition" [1]. All items used within a manufacturing facility are susceptible to wear and tear due to usability, time and the nature of task it performs. As there are many different possible reasons toward down time within manufacturing. The worst considered is an unexpected breakdown of machinery that would typically cost the most due to time lost, startup cost, repair cost and many other factors. Techniques such as preventative maintenance could be beneficial towards developing an optimal maintenance plan. This report will explore the possibility of utilizing linear programing in excel to develop a basic staffing model to achieve optimal preventive maintenance planning and minimize cost.

Problem Statement

NCC has faced challenges with their maintenance planning, like working on repairing machinery when breakdown occurs. The past four years they have managed to average 21% above there given maintenance budget. The lack of planning and initiative has proven costly, so the company is searching for different approaches to better their ability to control their maintenance costs. The company has requested deeper research into justifying the importance and benefits to develop a basic staffing model to achieve optimal maintenance planning and minimize cost.

Literature Review

The increased emphasis on developing a coordinated and fully comprehensive maintenance plan has become the norm in most companies. An article reviewed focuses on non-linear optimization in the selection of Six Sigma Projects within Kraft Manufacturing. The goal for this study was to determine the optimal scheduling of projects to achieve maximum cost savings. When a project is completed the Net Present Value (NPV) of the yearly savings is given. If a project is only partially completed no cost savings is realized. Optimality would be achieved after the scheduling of projects was established to achieve the maximum cost savings given the current staffing level [2].

The articles “A production and maintenance planning model for the process industry" & “Integrating Preventative Maintenance Planning and Production Scheduling for a Single Machine” were found to have similarity with the problem presented to us at hand. They both applied different maintenance planning techniques that shared similarities with different assumptions as well as different approaches. The differences are that the first article covered the overall process within the industry while the later focused on different maintenance techniques on a single machine. Although Ashayeri, Teelen and Selen’s article seems to be comprehensive their assumption that the production rate remains constant and does not change throughout time contradicts their model. It is because they take into consideration capacity within a production line and demand of the product that would ultimately affect required production output as well as inventory and backorder.

Most articles reviewed did not cover the mix of both linear and non-linear maintenance application within a simpler manufacturing facility that does not utilize six sigma.

Methodology:

To develop a solution that would identify how to minimize staffing to achieve an optimal maintenance planning and minimize cost. **Figure 1**: describes the methodology flowchart approach.

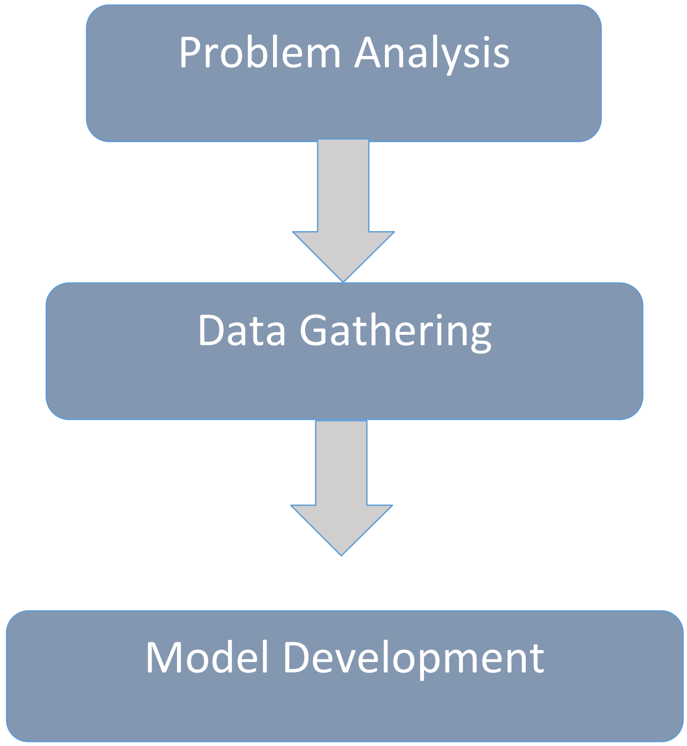


Figure 1: Methodology Flowchart

Problem Analysis:

The NCC has faced challenges with their maintenance planning, like working on repairing machinery when breakdown occurs. It is an attempt to minimize the overall breakdowns within the facility that leads-up to loss in profit. It would also include the number of required staff per shift for maintenance in comparison to what they already employ on a weekly basis. Optimized, sustainable maintenance strategies and improved performance and availability of production equipment depend on the detection and diagnosis of the root causes of poor performance and unplanned downtime [3].

Data Gathering

The gathered data has been solely provided by the NCC. Although in a different time zone; the communication was generally made over the phone with a liaison that worked within the industrial department of the manufacturing facilities. The Literature reviews help derived to better develop an understanding of the industry. The information provided has been multiplied by an un-given factor to preserve confidentiality

Model Development

Staffing Model:

Management of NCC's goal is to minimize the number of staffing required to cover each shift and maintain efficiency. The decision variables are the numbers of staff (j) assigned to each shift (i). The requirements will repeat in 24-hours cycles, seven days a week. There is a maximum of 40 technicians available, 8 are senior and 32 are junior technicians. NCC's workday is broken down into six 4-hour shifts, and each technician workday covers two consecutive shifts. There must be at least one master and three junior technicians available for each shift [4].

Table: 1 *describes the staffing requirement demands for each shift.*

Data Set							
Shifts	**1**	**2**	**3**	**4**	**5**	**6**	
Time Periods	12:00am-4:00am	4:00am-8:00am	8:00am-12:00am	12:00pm-4:00pm	4:00pm-8:00pm	8:00pm-12:00am	**Total**
Staff Required	4	8	10	10	5	3	40

Table 1: Staff demands per shift

The high demand time for staffing is between shifts two through four. These shifts are operating business hours that require available maintenance staff to be on-hand for potential machinery breakdown. **Figure 2:** describes the optimization formulation for this staffing model based on the information provided to us from NCC.

Where:

x_j = Number of staff working shift *j*

d_i = Demand for staff in period i

$$A_{ij} = \begin{cases} 1\ \textit{If shift j call for work in period i} \\ \quad\quad\quad\quad \textit{Otherwise} \end{cases}$$

Minimize

$$\sum_{i=1}^{6} \sum_{j=1}^{40} d_i x_j$$

[Total Demand Staffing]

s.t.

$$\sum_{j=1}^{n} A_{ij} x_j \geq di$$

[Staffing Coverage in each period (hourly)]

$x_j \geq 0$ and integer, for j=1.....n [Non-Neg]

Figure 2: Staffing Optimization Formulation model

Some assumptions were made in-order for our model to be successful. The assumptions for the staffing model are as follows:

- Different breakdown seasons consist of high and low demands
- No overtime, sick day and vacations taken into account
- Master and junior technicians are treated equally (each shift has one master technician available)
- There is no limit of how many employee can work per shift, but we will assume 40 max employees
- Salary/Hourly wages are unknown, due to limited proprietary information

After formulating a linear programming model in excel to determine the minimal number of staffing required to cover each shift and maintain efficiency [4]. Shown in **Figures 3** is the corresponding staffing model.

	A	B	C	D	E	F	G	H	I	J
1	Maintenance Planning Staff Scheduling									
2										
3	**Data Set**									
4	Shifts	**1**	**2**	**3**	**4**	**5**	**6**			
5	Time Periods	12:00am-4:00am	4:00am-8:00am	8:00am-12:00am	12:00pm-4:00pm	4:00pm-8:00pm	8:00pm-12:00am	**Total**		
6	Staff Required	4	8	10	10	5	3	40		
7										
8	**Decision Variables**	12:00am	4:00am	8:00am	12:00pm	4:00pm	8:00pm			
9	Number of Staff	4	4	6	4	3	0			
10										
11	**Objective Function**							**Total**		
12	Minimize Number of staff per shift	1	1	1	1	1	1	21		
13										
14	**Constraints**							LHS		RHS
15	12:00am-4:00am	1	0	0	0	0	1	4	≥	4
16	4:00am-8:00am	1	1	0	0	0	0	8	≥	8
17	8:00am-12:00am	0	1	1	0	0	0	10	≥	10
18	12:00pm-4:00pm	0	0	1	1	0	0	10	≥	10
19	4:00pm-8:00pm	0	0	0	1	1	0	7	≥	5
20	8:00pm-12:00am	0	0	0	0	1	1	3	≥	3

Figure 3: Maintenance Planning Staffing Model Scheduling

The original number of staffing utilized to cover the 6 shifts was 40 technicians. The number of optimal technicians required, according to the model is 21 technicians, with no one starting work in shift 6. The optimal solution for this staffing model, achieves our objective goals. By minimizing the number of staffing, this will allow the company to optimally reduce the overall maintenance cost.

Preventative Maintenance Planning Model:

As a company, its primary objective is to minimize cost and maximize the revenue. We have two issues within the NCC Company. A) Minimize the number of staff working each shift without affecting the productivity. B) Minimize the breakdown cost such as startup cost by optimizing the maintenance cost that includes preventive maintenance cost.

The company has a high productive season during the summer trimester, which means there is a higher number of machinery breaking down. Similarly, spring and fall are considered to have lower demand where the required productivity is less compared to summer.

Spring being the average of high and low season. During this model certain assumptions where made to meet the expectations of the company and they are as follows:

- The number of breakdowns occurring the following year are 5% less than the current year
- The costs of breakdown during a trimester does not change as the year goes on
- Preventative maintenance (PM) only occurs twice a month following that extra PM would follow the rule of diminishing returns
- When PM is employed they would only occur during the beginning of the month and middle of the month
- If PM occurs twice, the second PM will only yield a 75% benefit
- All breakdowns costs the same
- PM reduces the probability of breakdowns by 45% during the low productivity semester
- PM reduces the probability of breakdowns by 38% during middle productivity semester
- PM reduces the probability of breakdowns by 30% during the high productivity semester
- Cost of Employment is an estimated value as it was not provided

Given those assumptions the developed model is as follows:

Decision Variable

t = Time period from January to December

PM_t = Preventative maintenance (t)

X_t = # of breakdown in process during time period (t)

λ_t = Probability of breakdown during time period (t)

BC_t = Breakdown cost during period (t)

SC_t = startup cost during time period (t)

RC_t = Repair cost during time period (t)

LC_t = Loss of production during time period (t)

A_t = Probability of breakdown after PM during time period (t)

YC_t = Cost of employee during period (t)

Y_t = # of employee during period (t)

PMC_t = Cost of preventative maintenance

Objective Function

$$\text{Max} \sum \lambda_t \times BC_t - \sum \lambda_t \times BC_t \times PM_t \times A_t + \sum PMC_t \times PM_t + \sum Y_t \; YC_t$$

$$\sum BC_t = (SC_t + RC_t + LC_t) \times X_t$$

$$PM_t \begin{cases} 1 \; if \; PM \; occur \; on \; process \; during \; time \; period \; (t) \\ \qquad\qquad 0 \; otherwise \end{cases}$$

Constraints

$PM_t \leq 2 \quad \forall t$ [PM Can only Occur a max of twice a month]

$\sum_{t=1}^{4} PM_t \leq 4 \quad \forall t$ [PM Can only Occur a max of four times during trimester 1]

$\sum_{t=5}^{8} PM_t \leq 4 \quad \forall t$ [PM Can only Occur a max of four times during trimester 2]

$\sum_{t=9}^{12} PM_t \leq 4 \quad \forall t$ [PM Can only Occur a max of four times during trimester 3]

$\sum_{t=1}^{4} PM_t \leq 1 \quad \forall t$ [PM has to occur at least once during trimester 1]

$\sum_{t=5}^{8} PM_t \leq 1 \quad \forall t$ [PM has to occur at least once during trimester 2]

$\sum_{t=9}^{12} PM_t \leq 1 \quad \forall t$ [PM has to occur at least once during trimester 3]

$X_t \geq 0$ and integer, for t=1…n [Non- Negativity]

Now given the model table 2 would demonstrate the provided information that was achieved by contacting the NCC.

month	Probability Of Breakdown	Actual # of Breakdowns	1 if Preventative Maintenance occurs 0	if Preventative Maintenance	Cost of unit Breakdown In Production Loss	Startup Cost for Unit Breakdown	Repair Cost for Unit
January	0.95	5	0	0	$20,000.00	$1,000.00	$2,000.00
February	0.95	2	1	0	$20,000.00	$1,000.00	$2,000.00
March	0.95	5	0	0	$20,000.00	$1,000.00	$2,000.00
April	0.95	1	0	0	$20,000.00	$1,000.00	$2,000.00
May	0.95	11	0	0	$28,000.00	$1,500.00	$3,000.00
June	0.95	35	1	0	$28,000.00	$1,500.00	$3,000.00
July	0.95	9	0	0	$28,000.00	$1,500.00	$3,000.00
August	0.95	1	0	0	$28,000.00	$1,500.00	$3,000.00
September	0.95	30	1	0	$38,000.00	$2,000.00	$4,000.00
October	0.95	3	0	0	$38,000.00	$2,000.00	$4,000.00
November	0.95	27	0	0	$38,000.00	$2,000.00	$4,000.00
December	0.95	7	0	0	$38,000.00	$2,000.00	$4,000.00

Table 2: Probability & Costs of Breakdown

Given the probability of breakdowns for the upcoming year and the costs of breakdown it was simple to determine the overall costs of breakdown for the following year, which totaled up to be $5,053,650. That is given a probability of 5% decrease in total number of breakdowns for the following year compared to the original costs of breakdown of $5,307,000.

Analysis and Results:

From the staffing model, to minimize the number of staffing required to cover each shift and also to maintain the efficiency, the final number that was suggested as an optimum number was 21 technicians working every day to meet up with the productivity requirements. After doing further analysis & research, the sensitivity analysis of the staffing model shows that the number of technicians can be reduced further to meet the optimum number for technicians without affecting the productivity.

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$9	Number of Staff 12:00am	4	0	1	0	0
$C$9	Number of Staff 4:00am	4	0	1	0	0
$D$9	Number of Staff 8:00am	6	0	1	0	0
$E$9	Number of Staff 12:00pm	4	0	1	0	0
$F$9	Number of Staff 4:00pm	3	0	1	0	1
$G$9	Number of Staff 8:00pm	0	0	1	1E+30	0

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$H$15	12:00am-4:00am LHS	4	0	4	2	4
$H$16	4:00am-8:00am LHS	8	1	8	6	2
$H$17	8:00am-12:00am LHS	10	0	10	2	6
$H$18	12:00pm-4:00pm LHS	10	1	10	1E+30	2
$H$19	4:00pm-8:00pm LHS	7	0	5	2	1E+30
$H$20	8:00pm-12:00am LHS	3	1	3	1E+30	2

Figure 3: Sensitivity Analysis Report for Maintenance Planning Staffing Model Scheduling

The demand for productivity during the last two shifts (04:00 PM & 08:00 PM) is low compare to the other high demanding shifts (regular business hours). Since the sensitivity analysis also shows that there can be an additional allowable decrease of another two technicians for the final shift (08:00PM). We can decrease the number of technicians working during the last shift by two. See **Figure 5** for the updated staffing model.

Data Set									
Shifts	1	2	3	4	5	6			
Time Periods	12:00am-4:00am	4:00am-8:00am	8:00am-12:00am	12:00pm-4:00pm	4:00pm-8:00pm	8:00pm-12:00am			
Staff Required	4	8	10	10	5	1			
Decision Variables	12:00am	4:00am	8:00am	12:00pm	4:00pm	8:00pm			
Number of Staff	4	4	6	4	1	0			
Objective Function							Total		
Minimize Number of staff per shift	1	1	1	1	1	1	19		
Constraints							LHS		RHS
12:00am-4:00am	1	0	0	0	0	1	4	≥	4
4:00am-8:00am	1	1	0	0	0	0	8	≥	8
8:00am-12:00am	0	1	1	0	0	0	10	≥	10
12:00pm-4:00pm	0	0	1	1	0	0	10	≥	10
4:00pm-8:00pm	0	0	0	1	1	0	5	≥	5
8:00pm-12:00am	0	0	0	0	1	1	1	≥	1

Figure 5 – Staffing model with updated value for the number of technicians

This decreased the total number of required technicians down to 19. Reference **Figure 5** for the updated sensitivity analysis report.

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$9	Number of Staff 12:00am	4	0	1	0	0
$C$9	Number of Staff 4:00am	4	0	1	0	0
$D$9	Number of Staff 8:00am	6	0	1	0	0
$E$9	Number of Staff 12:00pm	4	0	1	0	0
$F$9	Number of Staff 4:00pm	1	0	1	0	1
$G$9	Number of Staff 8:00pm	0	0	1	1E+30	0

onstraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$H$15	12:00am-4:00am LHS	4	0	4	0	4
$H$16	4:00am-8:00am LHS	8	1	8	6	0
$H$17	8:00am-12:00am LHS	10	0	10	0	6
$H$18	12:00pm-4:00pm LHS	10	1	10	1E+30	0
$H$19	4:00pm-8:00pm LHS	5	0	5	0	1E+30
$H$20	8:00pm-12:00am LHS	1	1	1	1E+30	0

Figure 5 – Sensitivity analysis for the updated staffing Model

The sensitivity analysis shows that there cannot be any further increase or decrease in the number of technicians. So the optimum number of technicians working every day to cover each shift is 19.

Now looking at the Preventative maintenance plan given that the amount of staffing that should be employed is 19 employees to cover the daily shifts, the model developed will utilize that as a constant maintenance and compare it to the original 40 employees that are currently utilized.

The model developed shown in **Figure 5** shows the optimality and benefit that was gained by developing an optimal maintenance plan.

	January	February	March	April	May	June	July	August	September	October	November	December			
Decision Variable	0	1	0	0	0	1	0	0	1	0	0	0			
Objective Function	$118,750.00	$48,430.95	$118,750.00	$31,350.00	$349,125.00	$709,487.50	$287,375.00	$40,375.00	$935,309.52	$87,580.95	$1,138,100.00	$302,100.00		$4,166,733.93	
											Difference in overall costs from Original Breakdowns			$1,140,266.07	
Constraint													LHS		RHS
Preventative Maintenance in Month 1	1	0	0	0	0	0	0	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 2	0	1	0	0	0	0	0	0	0	0	0	0	1	<=	2
Preventative Maintenance in Month 3	0	0	1	0	0	0	0	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 4	0	0	0	1	0	0	0	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 5	0	0	0	0	1	0	0	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 6	0	0	0	0	0	1	0	0	0	0	0	0	1	<=	2
Preventative Maintenance in Month 7	0	0	0	0	0	0	1	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 8	0	0	0	0	0	0	0	1	0	0	0	0	0	<=	2
Preventative Maintenance in Month 9	0	0	0	0	0	0	0	0	1	0	0	0	1	<=	2
Preventative Maintenance in Month 10	0	0	0	0	0	0	0	0	0	1	0	0	0	<=	2
Preventative Maintenance in Month 11	0	0	0	0	0	0	0	0	0	0	1	0	0	<=	2
Preventative Maintenance in Month 12	0	0	0	0	0	0	0	0	0	0	0	1	0	<=	2
Preventative Maintenance in Semester 1	1	1	1	1	0	0	0	0	0	0	0	0	1	<=	4
Preventative Maintenance in Semester 2	0	0	0	0	1	1	1	1	0	0	0	0	1	<=	4
Preventative Maintenance in Semester 3	0	0	0	0	0	0	0	0	1	1	1	1	1	<=	4
Preventative Maintenance in Semester 1	1	1	1	1	0	0	0	0	0	0	0	0	1	>=	1
Preventative Maintenance in Semester 2	0	0	0	0	1	1	1	1	0	0	0	0	1	>=	1
Preventative Maintenance in Semester 3	0	0	0	0	0	0	0	0	1	1	1	1	1	>=	1

Figure 5: Optimal Preventative Maintenance Planning

The overall savings occurred from deploying preventative maintenance planning strategically throughout the different semesters resulted in approximate saving of $1.14 million from the original value. Which is a decrease in maintenance cost of 21.5% from the previous years maintenance costs as well as a 17.5% decrease in the upcoming predicted years costs. The overall cost of maintenance that was developed from the probability of breakdowns and the optimal amount of maintenance staff that should be utilized totaled to be approximately $4.166 million.

Since the Model is a non-linear model, it was not possible to develop a sensitivity analysis to further test the model.

Conclusion

In conclusion the utilizing linear programing in excel to develop a basic staffing model achieve optimal preventive maintenance planning and minimize cost. The worst considered is an unexpected breakdown of machinery that would typically cost the most due to time lost during production. Hence the problem is analyzed and the strategy to implement the model has been developed and delivered to the company. The overall cost has decreased to $4.166 million, which would generate a profit of approximately $1 million after the model has been performed.

Limitations & Future Research

The model itself has limitations in multiple areas, where the assumptions developed may be addressed in a more detailed method. Also the possibility of testing the model would help address any lacking within the constraints and where any of them need to be changed. Also the overall benefit of Preventative Maintenance is based on an assumption that was researched in our literature readings and was agreed upon by the beneficiary. Utilizing this model and testing it to be able to determine the actual value and benefit of Preventative Maintenance may prove extremely useful in validating the model. Also for future research developing the possibility of predictive maintenance that would be utilized and deployed to attempt avoiding any possible breakdowns could prove financially beneficial within the maintenance department.

References

[1] B. S. Dhillon, *Engineering Maintenance: A Modern Approach*. CRC Press, 2002.

[2] M. Tkáˇc and Š. Lyócsa, "On The Evaluation of Six Sigma Projects," *Quality and Reliability Engineering International*, August 2009.

[3] J. S. D'Aversa and J. F. Shapiro, "Optimal Machine Maintenance and Replacement by Linear Programming and Enumeration," *J Oper Res Soc*, vol. 29, no. 8, pp. 759–768, Aug. 1978.

[4] K. R. Baker, *Optimization Modeling with Spreadsheets*, 2 edition. Hoboken, N.J: Wiley, 2011.

[5] "cement: cement-making process," *Encyclopedia Britannica*. [Online]. Available: http://www.britannica.com/EBchecked/media/114022/The-cement-making-process-from-crushing-and-grinding-of-raw. [Accessed: 10-Mar-2015].

Appendix

			1 if Preventative	if Preventative	Cost of unit Breakdown	Startup Cost for Unit	Repair Cost for	Total Cost of							
month	Probability Of Breakdown	Actual # of Breakdowns	Maintenance occurs 0	Maintenance	In Production Loss	Breakdown	Unit	Breakdown 2014	Probability	PM Cost 1	# of Employee	Cost Per Employ	Cost of total Employee P	40 Employees	
January	0.95	5	0	0	$20,000.00	$1,000.00	$2,000.00	$115,000.00	0.45238095	$15,000.00	19	$500.00	$9,500.00	$20,000.00	
February	0.95	2	1	0	$20,000.00	$1,000.00	$2,000.00	$46,000.00	0.45238095	$15,000.00	19	$500.00	$9,500.00	$20,000.00	
March	0.95	5	0	0	$20,000.00	$1,000.00	$2,000.00	$115,000.00	0.45238095	$15,000.00	19	$500.00	$9,500.00	$20,000.00	
April	0.95	1	0	0	$20,000.00	$1,000.00	$2,000.00	$23,000.00	0.45238095	$15,000.00	19	$500.00	$9,500.00	$20,000.00	
May	0.95	11	0	0	$28,000.00	$1,500.00	$3,000.00	$357,500.00	0.38	$30,000.00	19	$500.00	$9,500.00	$20,000.00	
June	0.95	35	1	0	$28,000.00	$1,500.00	$3,000.00	$1,137,500.00	0.38	$30,000.00	19	$500.00	$9,500.00	$20,000.00	
July	0.95	9	0	0	$28,000.00	$1,500.00	$3,000.00	$292,500.00	0.38	$30,000.00	19	$500.00	$9,500.00	$20,000.00	
August	0.95	1	0	0	$28,000.00	$1,500.00	$3,000.00	$32,500.00	0.38	$30,000.00	19	$500.00	$9,500.00	$20,000.00	
September	0.95	30	1	0	$38,000.00	$2,000.00	$4,000.00	$1,320,000.00	0.3015873	$50,000.00	19	$500.00	$9,500.00	$20,000.00	
October	0.95	3	0	0	$38,000.00	$2,000.00	$4,000.00	$132,000.00	0.3015873	$50,000.00	19	$500.00	$9,500.00	$20,000.00	
November	0.95	27	0	0	$38,000.00	$2,000.00	$4,000.00	$1,188,000.00	0.3015873	$50,000.00	19	$500.00	$9,500.00	$20,000.00	
December	0.95	7	0	0	$38,000.00	$2,000.00	$4,000.00	$308,000.00	0.3015873	$50,000.00	19	$500.00	$9,500.00	$20,000.00	Total Costs
			Total Cost Given %5 Decrease in Upcoming Year ->			$5,053,650.00	$4,813,650.00	$5,067,000.00	<- Total Cost of breakdowns					$240,000.00	$5,307,000.00
	January	February	March	April	May	June	July	August	September	October	November	December			
Decision Variable	0	1	0	0	0	1	0	0	1	0	0	0			
Objective Function	$118,750.00	$48,430.95	$118,750.00	$31,350.00	$349,125.00	$709,487.50	$287,375.00	$40,375.00	$935,309.52	$87,580.95	$1,138,100.00	$302,100.00		$4,166,733.93	
											Difference in overall costs from Original Breakdowns			$1,140,266.07	
Constraint													LHS		RHS
Preventative Maintenance in Month 1	1	0	0	0	0	0	0	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 2	0	1	0	0	0	0	0	0	0	0	0	0	1	<=	2
Preventative Maintenance in Month 3	0	0	1	0	0	0	0	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 4	0	0	0	1	0	0	0	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 5	0	0	0	0	1	0	0	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 6	0	0	0	0	0	1	0	0	0	0	0	0	1	<=	2
Preventative Maintenance in Month 7	0	0	0	0	0	0	1	0	0	0	0	0	0	<=	2
Preventative Maintenance in Month 8	0	0	0	0	0	0	0	1	0	0	0	0	0	<=	2
Preventative Maintenance in Month 9	0	0	0	0	0	0	0	0	1	0	0	0	1	<=	2
Preventative Maintenance in Month 10	0	0	0	0	0	0	0	0	0	1	0	0	0	<=	2
Preventative Maintenance in Month 11	0	0	0	0	0	0	0	0	0	0	1	0	0	<=	2
Preventative Maintenance in Month 12	0	0	0	0	0	0	0	0	0	0	0	1	0	<=	2
Preventative Maintenance in Semester 1	1	1	1	1	0	0	0	0	0	0	0	0	1	<=	4
Preventative Maintenance in Semester 2	0	0	0	0	1	1	1	1	0	0	0	0	1	<=	4
Preventative Maintenance in Semester 3	0	0	0	0	0	0	0	0	1	1	1	1	1	<=	4
Preventative Maintenance in Semester 1	1	1	1	1	0	0	0	0	0	0	0	0	1	>=	1
Preventative Maintenance in Semester 2	0	0	0	0	1	1	1	1	0	0	0	0	1	>=	1
Preventative Maintenance in Semester 3	0	0	0	0	0	0	0	0	1	1	1	1	1	>=	1

Cell	Name	Original Value	Final Value	Integer
$B$19	Decision Variable January	0	0	Integer
$C$19	Decision Variable February	1	1	Integer
$D$19	Decision Variable March	0	0	Integer
$E$19	Decision Variable April	0	0	Integer
$F$19	Decision Variable May	0	0	Integer
$G$19	Decision Variable June	1	1	Integer
$H$19	Decision Variable July	0	0	Integer
$I$19	Decision Variable August	0	0	Integer
$J$19	Decision Variable September	1	1	Integer
$K$19	Decision Variable October	0.000001	0	Integer
$L$19	Decision Variable November	0	0	Integer
$M$19	Decision Variable December	0	0	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$N$25	Preventative Maintenance in Month 1 LHS	0	$N$25<=$P$25	Not Binding	2
$N$26	Preventative Maintenance in Month 2 LHS	1	$N$26<=$P$26	Not Binding	1
$N$27	Preventative Maintenance in Month 3 LHS	0	$N$27<=$P$27	Not Binding	2
$N$28	Preventative Maintenance in Month 4 LHS	0	$N$28<=$P$28	Not Binding	2
$N$29	Preventative Maintenance in Month 5 LHS	0	$N$29<=$P$29	Not Binding	2
$N$30	Preventative Maintenance in Month 6 LHS	1	$N$30<=$P$30	Not Binding	1
$N$31	Preventative Maintenance in Month 7 LHS	0	$N$31<=$P$31	Not Binding	2
$N$32	Preventative Maintenance in Month 8 LHS	0	$N$32<=$P$32	Not Binding	2
$N$33	Preventative Maintenance in Month 9 LHS	1	$N$33<=$P$33	Not Binding	1
$N$34	Preventative Maintenance in Month 10 LHS	0	$N$34<=$P$34	Not Binding	2
$N$35	Preventative Maintenance in Month 11 LHS	0	$N$35<=$P$35	Not Binding	2
$N$36	Preventative Maintenance in Month 12 LHS	0	$N$36<=$P$36	Not Binding	2
$N$37	Preventative Maintenance in Semester 1 LHS	1	$N$37<=$P$37	Not Binding	3
$N$38	Preventative Maintenance in Semester 2 LHS	1	$N$38<=$P$38	Not Binding	3
$N$39	Preventative Maintenance in Semester 3 LHS	1	$N$39<=$P$39	Not Binding	3
$N$40	Preventative Maintenance in Semester 1 LHS	1	$N$40>=$P$40	Binding	0
$N$41	Preventative Maintenance in Semester 2 LHS	1	$N$41>=$P$41	Binding	0
$N$42	Preventative Maintenance in Semester 3 LHS	1	$N$42>=$P$42	Binding	0
$B$19:$M$19=Integer					