

**Using a maintenance contribution model to predict the impact of maintenance on profitability**

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**Abstract**

The purpose of this paper is to study and present the impact of maintenance as one of the competitive factors in the business strategy. A financial maintenance contribution model is developed to illustrate that maintenance can have a significant impact on a firm's profitability. The model incorporates return on capital as a means to measure the effectiveness of maintenance activities. The results from simulation analysis indicate that variations in maintenance policies can impact return on capital and profitability of a business.

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*Keywords : Maintenance, return on capital, simulation.*

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## Introduction

Faced with increasing pressure to compete globally, companies are forced to look for ways to maintain or increase their existence in the marketplace. Philosophies such as just-in-time (JIT) production and total quality management (TQM) as well as technologies such as computer integrated manufacturing (CIM) and electronic data interchange (EDI) have been adopted and implemented in an effort to improve a company's competitive position. The impact of these philosophies and technologies are factored into the company's business strategy as the company struggles with how to please its current customers and attract new ones. Nevertheless, one activity that can have a major impact on the company's competitive position is often overlooked by top management. This activity is equipment maintenance.

The maintenance function is often overlooked by management as a competitive factor in the firm's business strategy. Most managers regard equipment maintenance as a necessary evil or a service whose sole purpose is to react in emergency situations. However, the maintenance function should be viewed by management as a resource that can be used strategically to improve productivity and profitability.

Maintenance provides management with an opportunity to improve productivity by supplying more capacity on a continuous basis. An increase in production capacity is achieved by properly managing maintenance activities in an effort to reduce equipment downtime due to failure. This in turn allows the company to be more flexible in its response to customers and market conditions. The potential to increase profitability arises as a result of the responsiveness and flexibility exhibited by the company in the marketplace. These opportunities do not exist if management ignores or improperly manages maintenance activities and allows production capacity to erode.

Likewise, management can improve profitability by focusing more attention on maintenance costs themselves. Since plant engineering and maintenance comprise approximately 20 to 40 percent of controllable manufacturing costs, management has the opportunity to increase profits by reducing these costs. Nevertheless, top management typically spends only 2 to 3 percent of its time on controlling maintenance costs that arise because of problems [Hora, 1987]. Instead of planning and managing

maintenance activities proactively, management controls maintenance expenses reactively.

The purpose of this study is to justify incorporating maintenance as a competitive factor in the business strategy. Support for this premise is based on profitability. A maintenance contribution model is developed which incorporates return on capital (ROC) as a means to measure the effectiveness of maintenance activities. A range of maintenance policies reflecting varying levels of activity are evaluated in terms of their impact on revenue, costs, profit, and ROC.

Revenue and costs are affected, in part, by the maintenance function's impact on equipment availability. By varying the level of maintenance activity, management can influence the percentage of time equipment is available for production (a measure of capacity). Equipment availability determines the amount of output achievable, which in turn impacts sales revenue (assuming everything produced is sold) and production costs. In addition, maintenance costs vary according to the level of maintenance activity. The revenue, production and maintenance costs for each maintenance policy are used to illustrate that maintenance can indeed have a significant impact on ROC; a measure of performance increasingly used by companies to evaluate their financial standing [Ruch et al., 1992]. A financial maintenance contribution model is developed in this study to illustrate that maintenance can in fact have a significant affect on a firm's profitability. The next section provides a review of the literature in this area. Details of the maintenance policies and contribution model are presented in section three. Section four presents the results and analysis of the results, and the final section provides conclusions.

### **Literature review**

Several authors conceptually describe the manner in which an improved maintenance program can increase equipment availability and productivity. The net effect is a positive impact on profitability due to increased revenues [Dunn, 1990], although most authors only evaluate the positive impact of lower maintenance costs on profit [Andrica, 1983; Bleuel, 1981; Kelly, 1980; Kelly and Eastburn, 1982]. Bleuel and Patton [1987] include the concept of revenue when they present maintenance as a support function utilized to achieve the production level required to generate the company's revenue and profit goals.

A numerical example of the impact of maintenance on revenue is presented by Ohl [1976]. The author incorporates a 2% increase in annual sales to achieve a 7.83% increase in pre-tax profit. Ohl points out that a 23.5% decrease in maintenance labor costs (indirect costs) would be required to achieve this same increase in pre-tax profit.

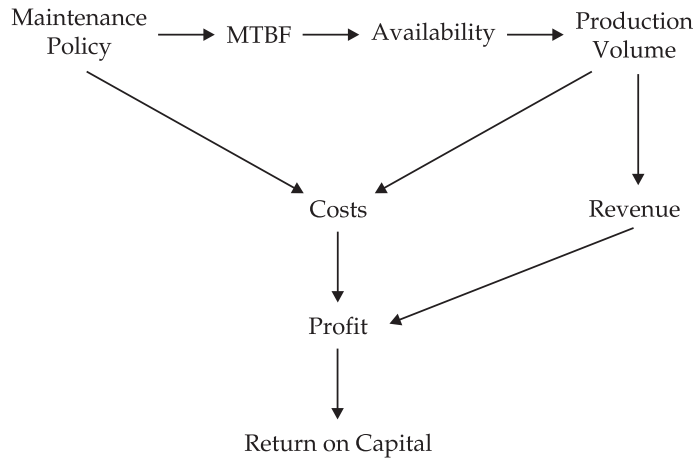
Several authors have used mathematical techniques to study the relationship between maintenance and profitability. Handlarski [1980] and Van Steelandt and Gelders [1981] present the concept of maximizing profitability while simultaneously maximizing availability. Handlarski compares two approaches to scheduling maintenance services while van Steelandt and Gelders evaluate the impact of various part replacement policies on availability and profit. The research presented in this paper is based on the development of a maintenance contribution model. The model utilizes simulation to generate costs and revenue for a variety of maintenance policies. The DuPont model then incorporates these outcomes from the simulation to determine ROC. Ahlmann [1984] conceptually presents the DuPont model as a means to study the impact of the maintenance function on ROC but does not use it for experimentation.

### **Models and methodology**

The maintenance activities within this study are categorized as either scheduled maintenance or emergency maintenance. Scheduled maintenance includes both preventive and predictive maintenance activities while emergency maintenance is performed only after equipment has failed. A universally recognized outcome of scheduled maintenance is a reduction in failures. Typically, an increase in scheduled maintenance decreases emergency maintenance. Nevertheless, scheduled maintenance may also require downtime and imposes costs upon the company. Although management can plan and control scheduled maintenance, a trade-off exists between scheduled and unanticipated emergency maintenance. As the level of scheduled maintenance activities increases, the downtime and costs eventually outweigh the downtime and costs incurred by emergency maintenance. A simulation analysis is used to evaluate these trade-offs for differing maintenance policies.

The maintenance contribution model is based on the fact that various maintenance policies incorporating a range of scheduled maintenance activities impact the number of times a piece of equipment fails. The change

in the number of failures changes the mean time between failures (MTBF) and downtime for repair, thereby impacting equipment availability. The change in availability allows the company to vary its output level, which in turn affects sales revenue and production costs. Maintenance costs are also affected as the level of emergency and scheduled maintenance activities vary. The changes in revenue and costs impact profit and ROC. Figure 1 illustrates these relationships.



(MTBF: Mean Time Between Failures)

**Figure 1**  
**The maintenance contribution model**

Two simulation models are used in this study to evaluate a variety of maintenance policies. The first simulation model is based on data collected from a firm in the metal fabrication industry. The simulation models three independent machines subject to failures. Jobs are generated for each machine over the course of a year according to data supplied by the company. As the machines process jobs, failures requiring downtime for repair occur. Varying levels of scheduled maintenance are added to the simulation in an effort to reduce failures. Data is collected within the simulation for production levels and downtime for emergency and scheduled maintenance. This information is then used to determine equipment availability and ROC.

The parameters for this simulation model are developed from the data collected at the metal fabrication company. Failure data are collected and used to identify the failure characteristics of each machine. By using the Kolmogorov-Smirnov test it is found that each data set is best represented by the Weibull distribution; a distribution often used to model equipment failures. The Weibull distribution is defined by a scale and shape parameter. The scale parameter represents MTBF and the shape parameter represents failure rate. A shape parameter of 1.0 represents a constant failure rate. However, as the shape parameter increases the probability of a failure occurring increases as well. The Weibull distribution for Machine 1 is characterized by a MTBF of 6,400 minutes (used as the scale parameter) and a shape parameter of 1.34. Machine 2 is characterized by a MTBF of 4,584 minutes and a shape parameter of 3.37, and Machine 3 is characterized by a MTBF of 10,187 minutes and a shape parameter of 2.43.

Downtime for repair after a failure averages 360 minutes for Machine 1, 686.4 minutes for Machine 2, and 105 minutes for Machine 3. A triangular distribution is used in the simulation model to represent repair time.

Five maintenance policies for each machine are simulated over the course of a year to determine the policies' effect on reducing failures. The policies represent alternatives the company was considering at the time the data were collected.

*Policy 1.* Emergency maintenance only. This policy serves as the basis for comparison as scheduled maintenance is added.

*Policy 2.* Scheduled maintenance for each machine every two weeks.

*Policy 3.* Scheduled maintenance for each machine every week.

*Policy 4.* Scheduled maintenance for each machine twice weekly.

*Policy 5.* Scheduled maintenance for each machine every day.

Machines 1 and 2 are down 60 minutes each when a maintenance action is scheduled. Machine 3 is down 40 minutes for each scheduled maintenance action. The simulation model is replicated twenty times for 525,600 minutes (one year) per replication for each maintenance policy.

The output data collected during the simulation are used to determine revenue and production costs for each maintenance policy. In addition, the downtime for emergency maintenance and scheduled maintenance is factored by hourly maintenance costs supplied by the company

to determine the total maintenance cost. For this company the hourly emergency maintenance cost is 1.06 times greater than the hourly scheduled maintenance cost. These values are used in the DuPont model to calculate ROC for each policy. The simulation also provides machine availability for Machines 1, 2, and 3 for each maintenance policy. This data is used to determine whether scheduled maintenance makes a difference in available capacity. The ROC and availability results are discussed in the next section. Although these results are not statistically analyzed, they indicate that the impact of maintenance on a firm's financial standing warrants further study. The second simulation, described below, modifies and expands the first simulation to allow for statistical analysis of the results.

The second simulation model again focuses on the three machines and failure characteristics previously described. However, the arrival rate of jobs for processing on the machines is increased to observe the impact of various maintenance policies on availability and ROC under conditions of higher equipment utilization. In addition, ten units of work-in-process inventory are added to each machine queue at the start of the simulation to emulate a steady state manufacturing environment. Four maintenance policies are explored in this study.

*Policy 1.* Emergency maintenance only. This policy serves as the basis for comparison as scheduled maintenance is added.

*Policy 2.* Scheduled maintenance 6.25 times per year or every 20,000 minutes.

*Policy 3.* Scheduled maintenance 12.5 times per year or every 10,000 minutes.

*Policy 4.* Scheduled maintenance 25 times per year or every 5,000 minutes.

*Policies 2, 3 and 4* are chosen because the time between scheduled maintenance actions more closely coincide with the MTBF's of Machines 1, 2 and 3. Each maintenance policy is replicated twenty times for 124, 800 minutes per replication. This equates to one 8-hour shift, 5 days per week for 52 weeks.

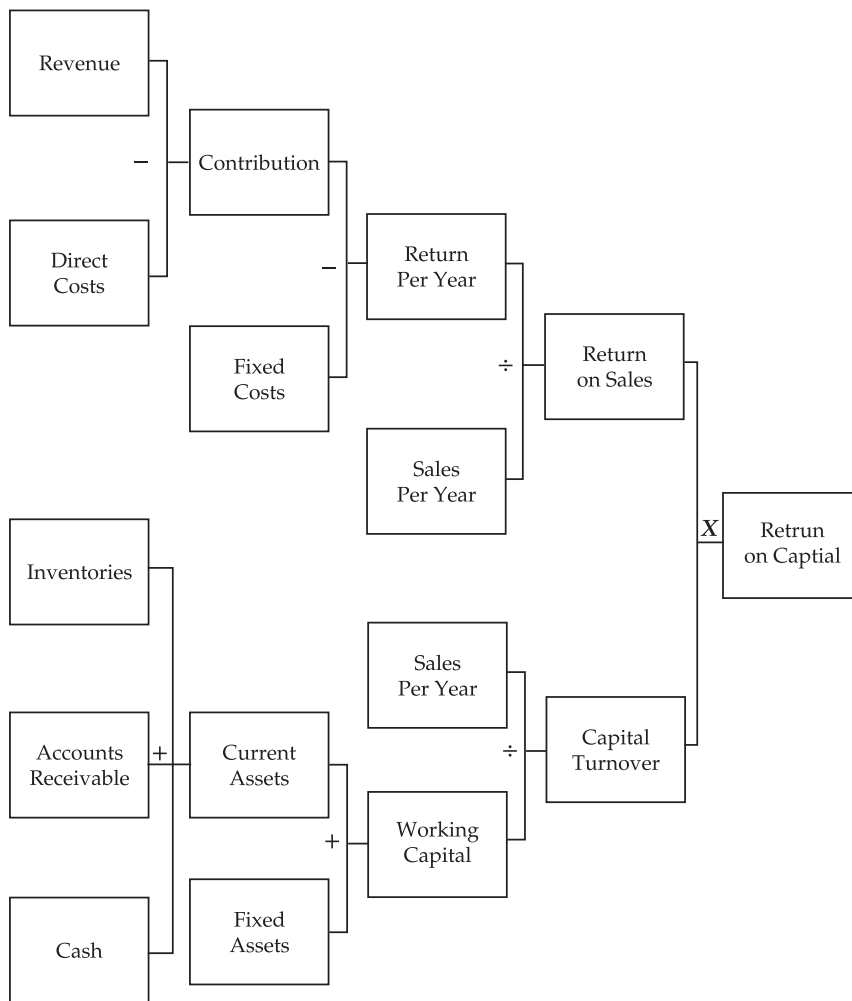
Data are collected from the simulation to independently calculate and statistically compare availability of each machine as well as ROC. The analysis of variance technique is used to determine if the maintenance

policies significantly affect these performance measures. The DuPont model provides a means for the maintenance department to communicate alternative maintenance policies to top management. By taking operational information such as production levels and downtime and dollarizing them within the DuPont model, management can review the various maintenance options in terms of the company's financial performance.

The DuPont model is, however, not without its drawbacks. Financial ratios are limited since they can be distorted by a company's operating and accounting procedures. Although financial analysts do not always look upon the DuPont model favorably, its only purpose in this study is to provide evidence that maintenance significantly affects the company's financial standing. The DuPont model, as described by Weston and Brigham [1987, p. 255], is graphically represented in Figure 2.

The numerical values used within the DuPont model are modified from an example in Brigham and Gapenski [1987]. The values in this example are modified to achieve approximately a 9% return on capital as a base case when used with the company's hourly maintenance cost data. Changes in the ROC are due to the maintenance policies' impact on production levels which are used to calculate revenue and production costs. In addition, maintenance costs vary as the alternative policies are examined. Both production and maintenance costs are incorporated into the model as direct costs.

The capital portion of the DuPont model is not affected in this study. Nevertheless, management might expect to see a shift between inventories and cash. If the maintenance policy reduces the number of expected failures, less work-in-process and finished goods inventories are required to cover these unanticipated breakdowns. In addition, by planning and controlling more of its maintenance activities, management can reduce its investment in maintenance, repair, and operating inventories. These savings can be reflected in extra cash or invested in projects with a higher rate of return than inventories [Rishel, 1991]. The potential for additional cash may be important for a company since profit does not determine a company's solvency. Maintenance is one more factor a firm can incorporate into its cash planning practices as well as its overall business strategy.



**Figure 2**  
the Dupont model

**Results**

The results from the first simulation establish the fact that the maintenance policy can cause variations in availability and ROC. Table 1 contains these results for each machine and maintenance policy. As shown in the table, Machines 1 and 2 experience their highest ROC and equipment availability when scheduled maintenance is incorporated into the maintenance policy. However, the appropriate level of scheduled

maintenance is different for each machine. Machine 1 responds better when scheduled maintenance is performed weekly, whereas Machine 2 responds better when scheduled maintenance occurs twice weekly. Conversely, Machine 3 experiences the highest levels of availability and ROC when the emergency maintenance policy is in effect.

**Table 1**  
**Return on capital and availability results for simulation 1**

Level of scheduled maintenance	Return on Capital (percent)	Availability (percent)
Machine 1		
No scheduled maintenance	11.71	96.99
Two weeks	12.38	97.09
Weekly	12.45*	97.09*
Twice weekly	11.68	96.92
Daily	0.98	95.04
Machine 2		
No scheduled maintenance	10.90	96.86
Two weeks	12.25	97.07
Weekly	14.17	97.38
Twice weekly	20.72*	98.40*
Daily	9.23	96.39
Machine 3		
No scheduled maintenance	23.97*	99.90
Two weeks	18.92	99.81
Weekly	13.82	99.72
Twice weekly	-15.50	99.20
Daily	-104.47	97.66

\* Highest return on capital and availability

The emergency maintenance policy for Machine 3 is most effective because the machine is utilized at a much lower rate than Machines 1 and 2. Since a failure does not occur unless the machine is operating, and since Machine 3 has a MTBF of 10,187 minutes (based on operating time), there are few failures during the course of a year. There is not any advantage for the company to perform scheduled maintenance on this

machine because the time and expense for this activity outweighs that of the emergency maintenance policy.

Based on the production orders provided by the company for these machines, the simulation results show that only Machine 1 is incapable of processing all of its orders during the year. Nevertheless, the production levels do not vary significantly among maintenance policies. Alternatively, Machines 2 and 3 are not fully utilized throughout the year. Therefore, these two machines can process all orders to completion. These results imply that the differences seen in ROC among the five policies are solely due to variations in maintenance costs. Revenue and production costs do not change since the production levels for Machines 2 and 3 do not vary, and those for Machine 1 do not vary significantly.

These implications are explored in more detail and a statistical analysis is performed on the results in the second simulation. Because the production orders for the first simulation do not provide an opportunity to evaluate the impact of maintenance on revenue and production costs, a steady stream of jobs is generated for production by each machine. The simulation of Machines 1, 2, and 3 at high levels of utilization expands the study by providing more insight into the relationships between maintenance, availability, and ROC. Table 2 contains availability and ROC results and their statistical significance for the second simulation.

**Table 2**  
Statistical analysis and results for return on capital and availability

Number of scheduled maintenance actions (frequency)	Return on Capital (percent)	Availability (percent)
Machine 1		
0.00	A 27.25	A 91.35
6.26	A 28.65	A 91.35
12.50	A 28.90*	A 92.55*
25.00	A 27.20	A 91.30
Machine 2		
0.00	A 20.80	A 87.08
6.25	BA 23.65**	BA 88.91**
12.50	B 25.00	B 89.74
25.00	B 25.25	B 89.99*

(Table 2 Contd.)

Number of scheduled maintenance actions (frequency)	Return on Capital (percent)	Availability (percent)
Machine 2		
0.00	A 31.05	A 93.95
6.25	B 33.05	B 95.29
12.50	C 34.60	C 96.34
25.00	C 35.70*	C 97.03*

\* Highest return on capital and availability

\*\* Means with different letters are significantly different from each other for  $p < 0.05$

The most important outcome in this simulation is for Machine 3. The increased utilization of Machine 3 requires the adoption of a scheduled maintenance policy to achieve the highest levels of availability and ROC. This implies that a change in utilization of equipment requires a reevaluation of the appropriate maintenance policy; otherwise the company may not be attaining the highest availability and ROC possible.

Production levels, and therefore revenue and production costs, vary for all three machines. Only the variations in revenue among maintenance policies is statistically tested for significance. Machine 3 is the only machine that exhibits any significant differences between revenue. Although Machines 1 and 2 produce production levels that are not statistically different, the variations among revenue and the results for Machine 3 imply that the potential exists to increase production when the appropriate maintenance policy is in effect. The results for the availability measure substantiate this premise.

All three machines are available for production a higher percentage of time when scheduled maintenance is in effect. The highest availability level is significantly higher than the availability level when there is no scheduled maintenance for both Machines 2 and 3. Likewise, the ROC figures show the same results. In this simulation the ROC is a result of changes in both revenue and direct costs. Although the level of the ROC is not necessarily indicative of what a company can achieve by properly managing maintenance, the fact remains that maintenance does have a significant impact on ROC in some cases. These results illustrate that a company may be hurting itself competitively if the maintenance function is not incorporated as part of its business strategy.

## Conclusions

Although this study may not utilize the cost structure nor the failure characteristics of every company, it does demonstrate that every company should be cognizant of the impact equipment maintenance can have on its financial standing. Top management must start factoring maintenance into their strategies to enhance their competitive positions. The results indicate that by properly utilizing the maintenance function a company can potentially increase its production and revenue through higher levels of availability. This is important for those companies that are capacity constrained. Alternatively, by adopting a maintenance policy appropriate to its equipment, a company can reduce maintenance costs and production costs by reducing disruptions to the production process. Regardless of which financial ratios a company uses, the bottom line is an improvement in profitability.

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