Predictive Equipment Failure Methodology

With Sustainable Change

by

Douglas Kirk McDonald

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved July 2012 by the
Graduate Supervisory Committee:

Kenneth Sullivan, Chair
William Badger
William Verdini

ARIZONA STATE UNIVERSITY

December 2012

ABSTRACT

This dissertation examines an analytical methodology that considers predictive maintenance on industrial facilities equipment to exceed world class availability standards with greater understanding for organizational participation impacts. The research for this study was performed at one of the world's largest semiconductor facilities, with the intent of understanding one possible cause for a noticeable behavior in technical work routines.

Semiconductor manufacturing disruption poses significant potential revenue loss on a scale easily quantified in millions of dollars per hour. These instances are commonly referred to as "Interruption to production" (ITP). ITP is a standardized metric used across Company ABC's worldwide factory network to track frequency of occurrence and duration of manufacturing downtime. ITP, the key quantifiable indicator in this dissertation, will be the primary analytical measurement to identify the effectiveness of maintenance personnel's work routines as they relate to unscheduled downtime with facilities systems.

This dissertation examines the process used to obtain change in an industrial facilities organization and the associated reactions of individual organizational members. To give the reader background orientation on the methodology for testing, measuring and ultimately assessing the benefits and risks associated with integrating a predictive equipment failure methodology, this dissertation will examine analytical findings associated with the statement of purpose as it pertains to ITP reduction. However, the focus will be the exploration of behavioral findings within the organization and the development of an improved industry standard for predictive ITP reduction process implementation. Specifically, findings associated with organizational participation and learning development trends found within the work group.

TABLE OF CONTENTS

Page

CHAPTER

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Figure Page

Figure Page

Chapter 1

Introduction

Semiconductor Industry in Recent Times

Profitability is the primary objective for any business. For manufacturing companies, maximizing profitability means being able to meet consumer demand in the most cost effective manner. As shown in figure 1.1, a semiconductor manufacturing site's capital costs are among the highest of all industries (Damodaran 2011). During the life of the manufacturing site, profitability is a never ending pursuit.

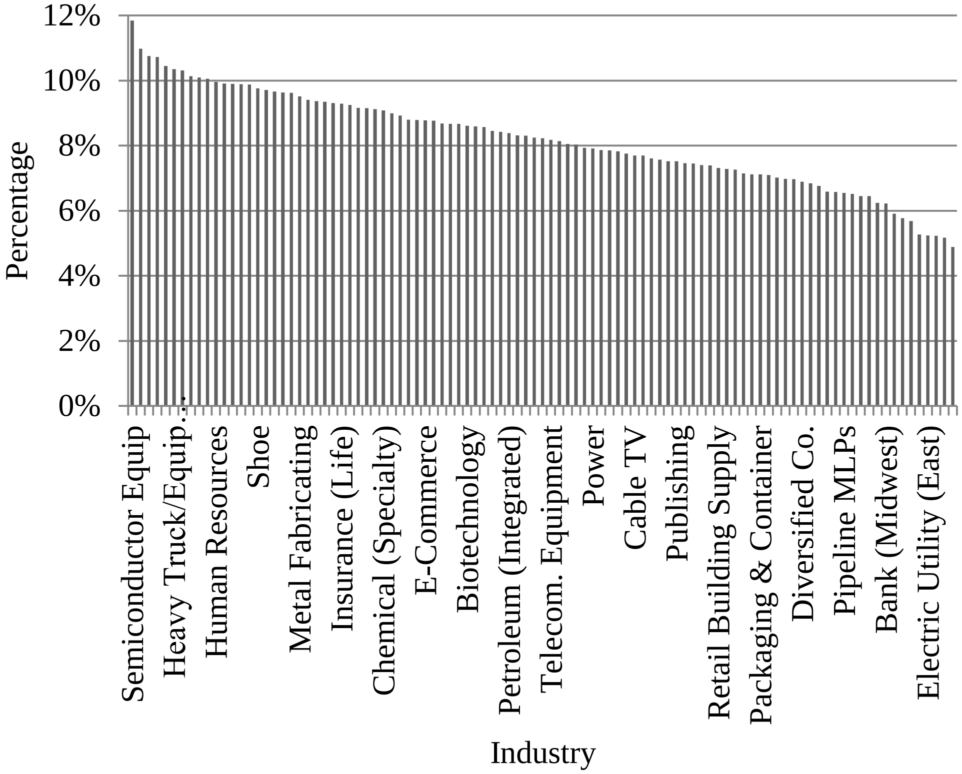
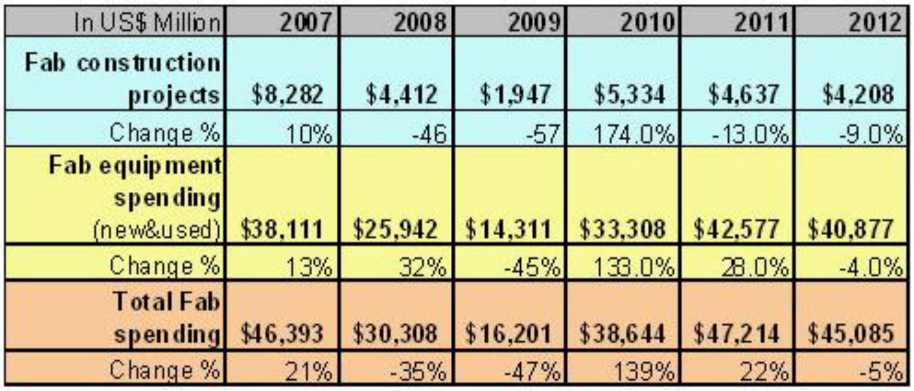


Figure 1.1. Average cost of capital expense by industry (Damodaran 2011)

As a result of exorbitant entry costs, semiconductor manufacturing sites have incurred a greater risk of insufficient equipment capacity. Historically, this was not a prominent issue and factories purchased the number of tools required to meet the most conservative estimate of equipment capacity (IEEE SEMI 1996). The ability to afford capital costs was much easier before the ".com" explosion of the late 1990s. Before 1990, semiconductor factories had the luxury of big profit margins and easy cash flow, which was required to bolster their capacity with new and redundant manufacturing tools to ensure output goals were met. Almost 15 years later, both the availability and ease of cash flow to purchase the very expensive capital equipment have been significantly reduced. With these financial constraints, and the fact that the average size of an industrial facility typically exceeds 200,000 square feet, maintenance challenges have the potential to bring higher risks of factory capacity reduction (Wroblaski 2010).

Figure 1.2 illustrates the historic average increase in capital expense required to support the semiconductor market demand for capital equipment.



In US$ Million	2007	2008	2009	2010	2011	2012
Fab construction projects	**$8,282**	**$4,412**	**$1,947**	**$5,334**	**$4,637**	**$4,208**
Change %	10%	-46	-57	174.0%	-13.0%	-9.0%
Fab equipment spending (new&used)	**$38,111**	**$25,942**	**$14,311**	**$33,308**	**$42,577**	**$40,877**
Change %	13%	32%	-45%	133.0%	28.0%	-4.0%
Total Fab spending	**$46,393**	**$30,308**	**$16,201**	**$38,644**	**$47,214**	**$45,085**
Change %	21%	-35%	-47%	139%	22%	-5%

Figure 1.2. United States semiconductor capital spending by year (Osborne 2011)

To minimize maintenance challenges and potential problems, as well as the associated costs, maintenance staffs need to be proactive in their maintenance and operations behaviors. This requires regular inspections, preparation, and team experience (with strong implicit knowledge). Facilities management industry expert Chuck Sullivan is the head of global operations at ProLogis. Sullivan cited that "preparation is the number one way to address maintenance challenges…having experienced teams closely follows" (Wroblaski 2010).

The contribution to the Facilities Management (FM) industry addressed in this dissertation deals with the premise that the healthier economy of the past allowed for reactive and less than optimal equipment maintenance programs. With the poor economic circumstances facing manufacturing sites around the world today, the pressures to reduce costs associated with equipment efficiency are growing. A method to quantifiably reduce equipment cost of ownership through sustained organizational behaviors that improve tool availability will be tested.

Importance of System Maintenance in a Slowing Economy

With a steady decline in the semiconductor industry's historic capital spending, it is critical that today's factories seize the opportunity to use the most effective equipment availability assumptions to reduce the amount of planned tool purchases. The objective is to increase manufacturing equipment availability by decreasing the number of times the equipment goes off-line for an unexpected event. The solution is to get more production out of fewer tools based on demonstrated and predicted output capability (IEEE SEMI 1996). Figure 1.3 illustrates the trend in semiconductor industry growth. Whenever product demand decreases, the priority to get more output from existing equipment increases, as demonstrated in the 2008 through 2010 timeframe.

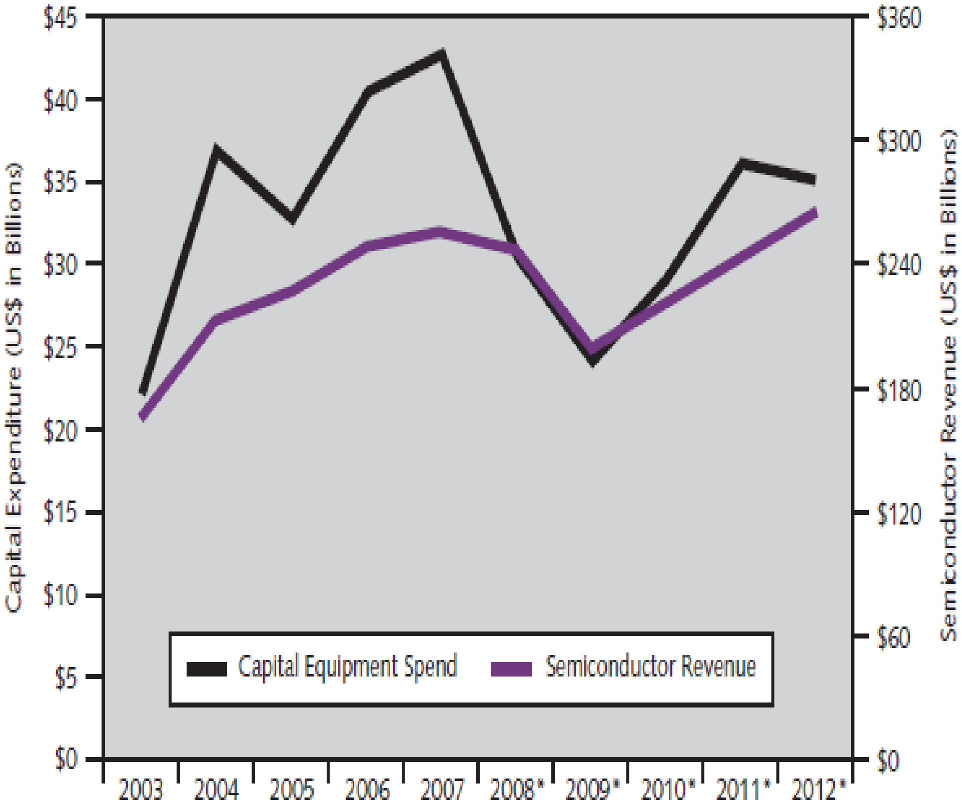


Figure 1.3. Semiconductor industry capital spending trend *years forecasted (Cullen 2009)

Maintenance of Equipment - Impact to Business

Prompted by the development of technology and higher demands for maintenance of increasingly complex equipment sets, a more effective and reasonable strategy for maintenance improvement is required. Semiconductor capital spending is expected to steadily decrease in the future (shown in figure

1.4). Worldwide wafer fab equipment spending decreased 48.1 percent in 2009. The year 2010 brought an expected scenario as spending increased, but the same projection suggests growth in capital spending will be reduced through 2014 (Stevens 2009).

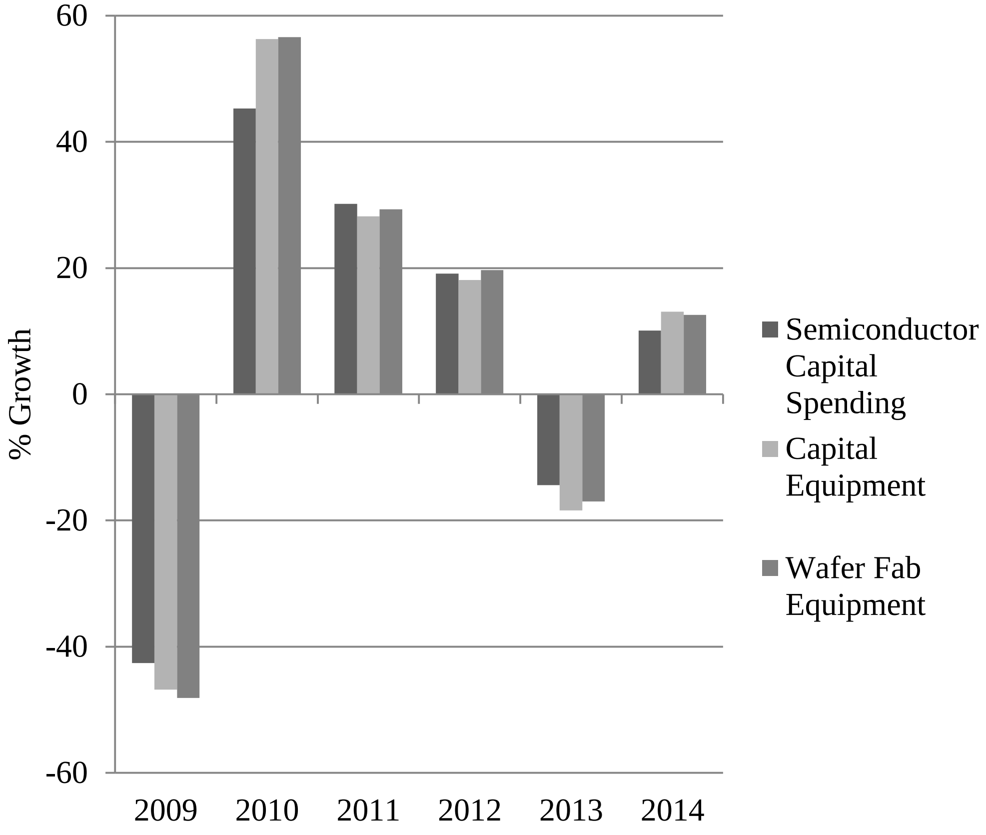


Figure 1.4. Predicted growth of semiconductor capital spending (Stevens 2009)

With reduced spending on capital, factories are forced to make their existing production equipment last longer. In the manufacturing environment, it is known that unexpected equipment failures usually have an effect on equipment operation and the quality of product handled by the equipment. Therefore, one of the major challenges for a maintenance team is to implement a strategy that successfully maximizes the availability and efficiency of the sustaining equipment systems by:

- controlling the rate of equipment deterioration,
- ensuring a safe and environmentally friendly operation
- minimizing the total cost of the operation

An effective equipment maintenance program means reduced downtime; this adds up to increased return on investment (Pass 2011). Consistent with this knowledge, preventive maintenance actions increase equipment lifetime and decrease breakdown frequency. In recent years, risk-based maintenance methodologies started to emerge with the intent of optimizing preventative maintenance frequency, thereby decreasing downtime and associated maintenance costs. Many of the methods based on risk assessment present a reasonable strategy toward equipment availability improvement. However, the methods can be complex and require computer applications for multi-variable computation.

The need for improved equipment availability does not stop inside the factory or with one set of equipment. During recent years, facilities systems have become increasingly more important to the holistic business environment for semiconductor manufacturing. In the semiconductor industry, shrinking product geometries result in greater facilities technology constraints and challenges for improved lab environment controls to sustain temperature, humidity, power, water purification and effective waste management. The high demand of strict operational environment controls within the cleanroom operations translates to one of two possible solutions: greater cost for redundant capital equipment or improved availability for existing equipment systems.

Equipment management is a critical element since capital equipment makes up about 40 percent of the average semiconductor manufacturer's total assets (Kwong 2004).

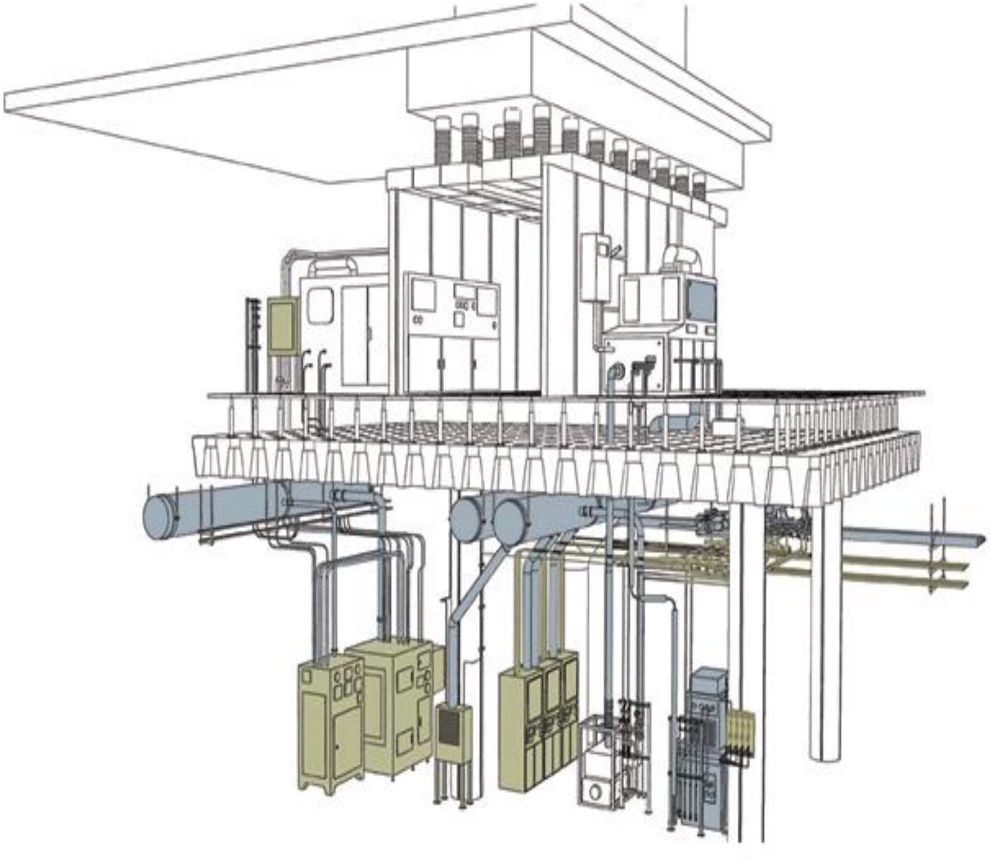


Figure 1.5. Diagram of facilities equipment supporting cleanrooms

Figure 1.5 is a rendering of the typical cross-section diagram of the facilities equipment in a typical bay/chase cleanroom manufacturing environment. The illustration gives perspective to the number of facilities systems integrated together to obtain a standard cleanroom environment. Notice the volume of support equipment that completely surrounds the cleanroom room bay laterally, above and below the cleanroom tunnel in figure 1.5.

Capital Equipment Growth in the Semiconductor Industry

During the 1980s and 1990s, when semiconductor manufacturing was realizing unprecedented growth, the overall semi-equipment business was outperforming the device manufacturing business.

Equipment capability was not constrained by the device technology as the challenge to manufacture required product geometries had not exceeded the equipment capability. In figures 1.6 and 1.7, analysts suggest that historic increasing sales performance with semiconductor equipment was attributed largely to the explosion of profitability in the chip business during the 1990s.

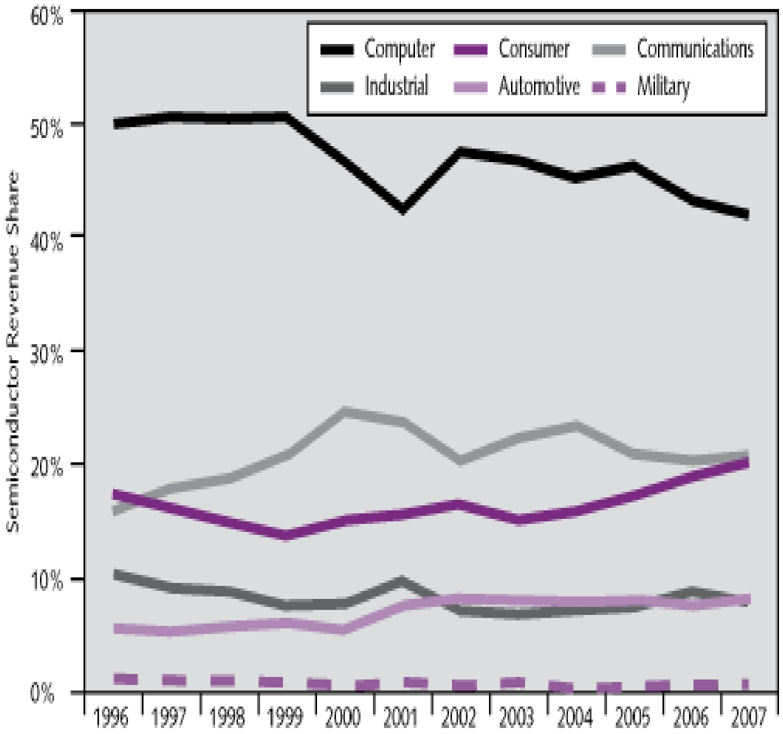


Figure 1.6. Semiconductor revenue share by end-use market (Cullen 2009)

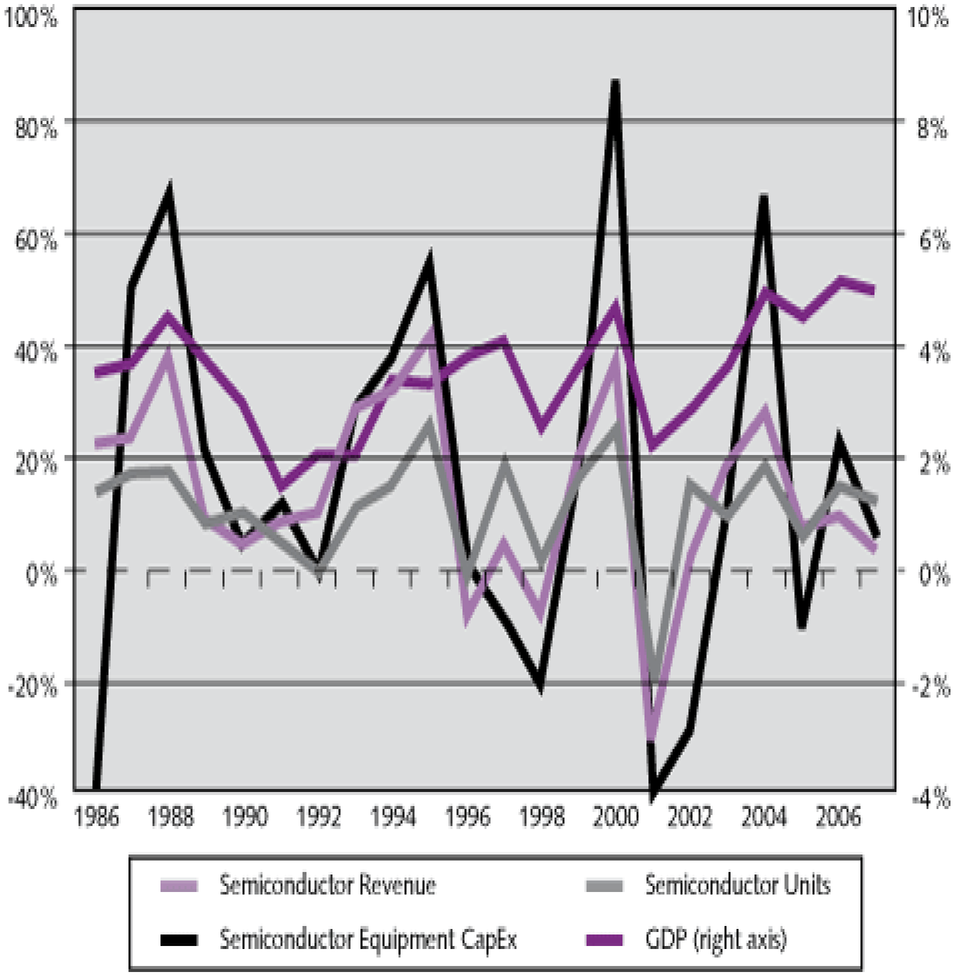


Figure 1.7. Annual percentage changes in worldwide semiconductor revenues (Cullen 2009)

The improving profitability enabled chipmakers to accelerate the reduction of the price of chips (Moore's Law) through capital equipment investment to support the next generation of manufacturing technology.

Moore's Law, originally stated in 1965, continues to drive the semiconductor industry more than 45 years later. Moore's law, expressed by Gordon Moore, one of the founders of Intel Corporation, states that every 18 to 24 months the capabilities of integrated circuits double and the price of such chips is reduced by about 50 percent. Technically, Moore's law is a "conjecture" or a roadmap guideline for semiconductor manufacturing technology planning and target-setting, rather than a real law (Intel 2008).

Figure 1.8 illustrates Moore's law with the relationship to the number of transistors per device (or chip) as a function over time.

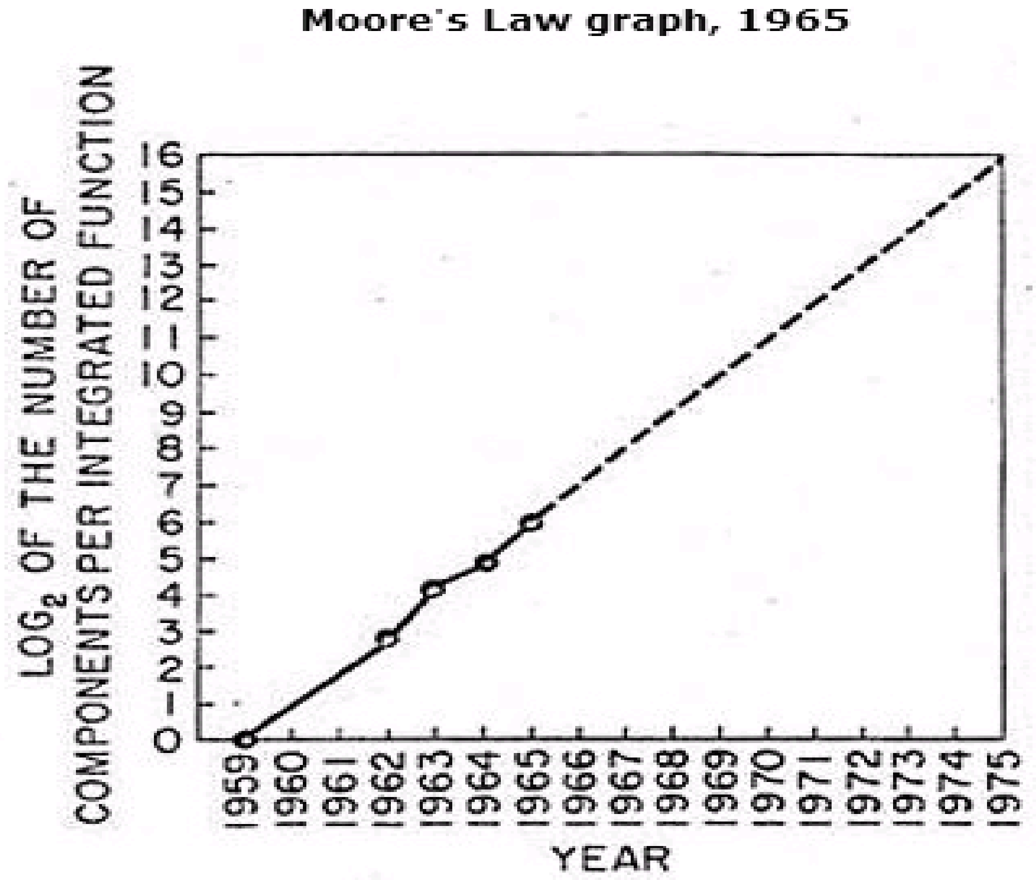


Figure 1.8. Moore's law graph (Intel 2008)

While industry analysts can point to the semiconductor industry's profitability peaking in about the year 2000, most agree the industry will not achieve those levels of growth and profit margin for generations to come. If this prediction is true, growth rates for the semiconductor equipment manufacturing business will be conservative at best with potential for falling below the device industry's expected growth rate.

Since the tech bubble burst in the early 2000s, cost conscious spending and increasing complexity for semiconductor manufacturing equipment performance (Moore's Law) have driven the demand for doing more with less, specifically, using existing production equipment to manufacture more complex devices.

Table 1.1 - Device makers return on capital - is a high level summary of survey responses from 15 major chip device manufacturers. The feedback demonstrates an average return on capital of nine percent in the first quarter of 2004, compared to the year 2000 average of 17 percent return on capital. Bank of America analysts expect average returns on future capital investments to hold steady in the 13 percent range (FitzGerald 2004).

Table 1.1. Device makers’ return on capital (FitzGerald 2004)

4 Quarter Moving Average Return on Capital		
	2000 Peak	2004
ALTR	35.16%	14.33%
AMD	17.77%	-2.16%
ADI	22.29%	10.82%
ATML	8.21%	-2.82%
IDTI	40.34%	0.74%
INTC	24.38%	14.60%
LLTC	26.12%	15.01%
LSI	10.35%	-4.74%
MCHP	18.76%	9.00%
MCRL	29.31%	2.79%
MU	17.98%	-2.34%
MXIM	26.17%	15.86%
STM	15.69%	2.13%
TXN	17.69%	10.35%
XLNX	17.81%	9.63%
TOTAL	20.54%	9.14%

Consistent with the economic environment across multiple industries around the world (with today's business challenges of limited spending and reduced loan availability), the expectation of diminishing return on investment and the reality of Moore's law will continue to drive production costs higher. As cost device manufacturing becomes increasingly reliant on equipment performance, the need for optimized equipment availability is evident. This means controlling the available time a piece of equipment is on-line and yielding high quality product. Keeping the manufacturing line in production with consistent quality output from all equipment is the key maintenance deliverable needed to offset the reduced profit margins and skew revenue toward previous performance standards. The production equipment must be managed in a standardized fashion to make it more available to production time. Another key attribute to the success of the equipment improvement program is to understand, and thereby reduce, variation within the performance of the production equipment.

Equipment Availability

A simple definition of availability for production equipment is the time a piece of equipment is able to work producing quality product divided by the time that same piece of equipment is required to work (Vorster 2007).

Overall Equipment Effectiveness (OEE) is a capacity planning acceptance program model established by the Association for Manufacturing Technology (2002). The OEE philosophy suggests there are only two measurements for determining the effectiveness of equipment operation:

- the quality of product it produces must be high
- the time that it is available to run must be high

During the ".com" boom of the 1990s, there was an abundance of finance options available for capital investment opportunities. This affluence of funds provided an option to leverage capacity constraints with more equipment redundancy that could be used to offset production output limitations. However, increasing production capacity through increased equipment redundancy overwhelmed the need for strong diligence on maintenance behaviors, ultimately fostering less than optimal maintenance practices normally required to sustain world class production performance levels. Increasing manufacturing capacity through increased capital equipment also reduced management's visibility and prioritization to develop the true operational performance capabilities of existing equipment.

Today's economic reality is significantly more dire, demand for manufacturing goods is down and factories must come to terms with existing maintenance practices and behaviors in their organization, which are substantially below where they need to be. Today's equipment maintenance teams must deliver performance that maximizes the most available time that equipment is on-line and producing high yield next generation product technology.

Defining equipment availability can be simple if viewed in the correct context. A piece of equipment is operating to effective quality standards or it's not. IEEE defines availability as: "If a press operates at 80 strokes per minute but has a design cycle speed of 100 strokes per minute, it can be said that its performance rate is 80 percent. Similarly if it produces 90 good parts out of 100, it has a quality rate of 90 percent. If a business plans to run (load) the equipment for eight hours and it breaks down for two, its availability is 75 percent" (Godfrey 2002).

This explanation of overall equipment effectiveness, illustrated in figure 1.9, highlights the key components that make up the overall percentage of true equipment capability.

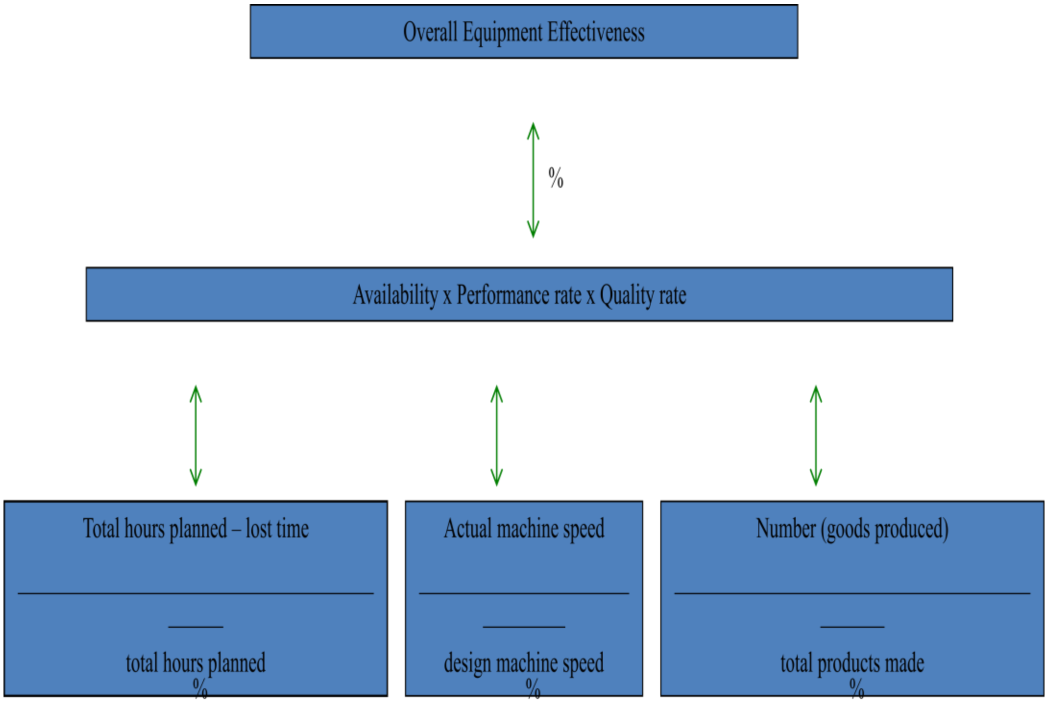


Figure 1.9. Overall equipment effectiveness (Godfrey 2002)

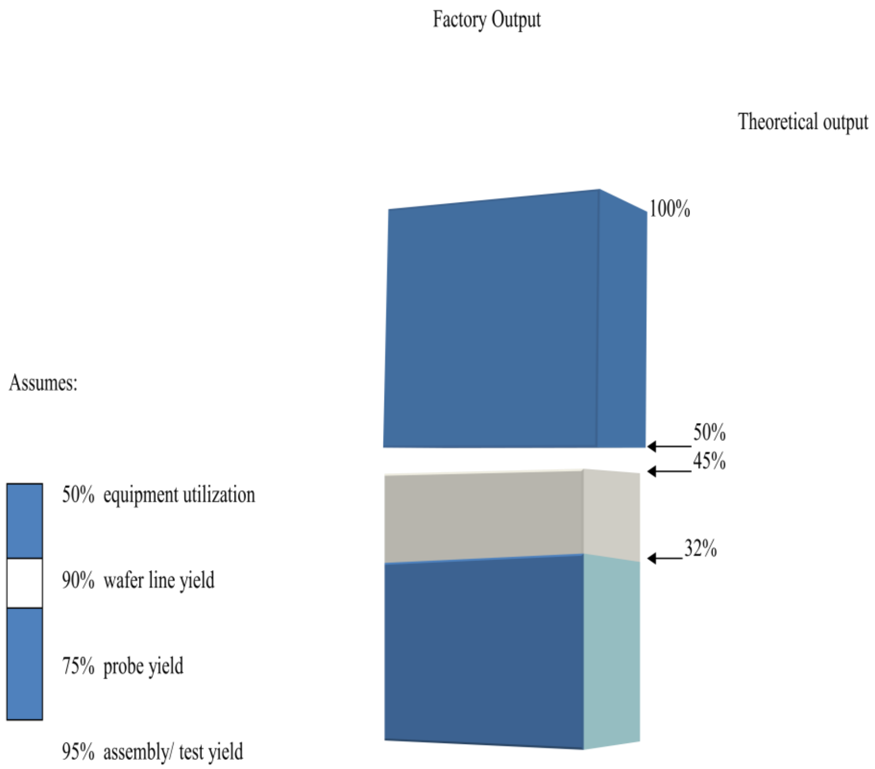


Figure 1.10. Factory output availability breakdown (Kanagal 1990)

Every manufacturing factory has its own availability challenges; IEEE suggests the semiconductor industry has a general breakdown (shown in figure 1.10). In this chart, the key observation is that equipment utilization of 50 percent is considered a common metric. To normalize that against an example in our daily life, imagine your personal vehicle or preferred method of transportation only being available for operation 50 percent of the time.

The utilization of equipment is determined by the time it is actually used divided by the time it is required and able to work (Vorster 2007).

If a piece of production equipment is on-line and available for manufacturing but is not utilized (or put into productive action), the business is not generating revenue. In fact, that scenario increases cost of ownership and drives a loss of profitability. The availability and utilization percentages are primary business factors for every production environment regardless of industry. An obvious example of the relationship with equipment utilization compared to the Average Selling Price (ASP) of semiconductor devices is demonstrated in figures 1.11 and 1.12. Figure 1.11 illustrates utilization versus ASP as it affects the relationship of Integrated Circuits (IC) and ASP.

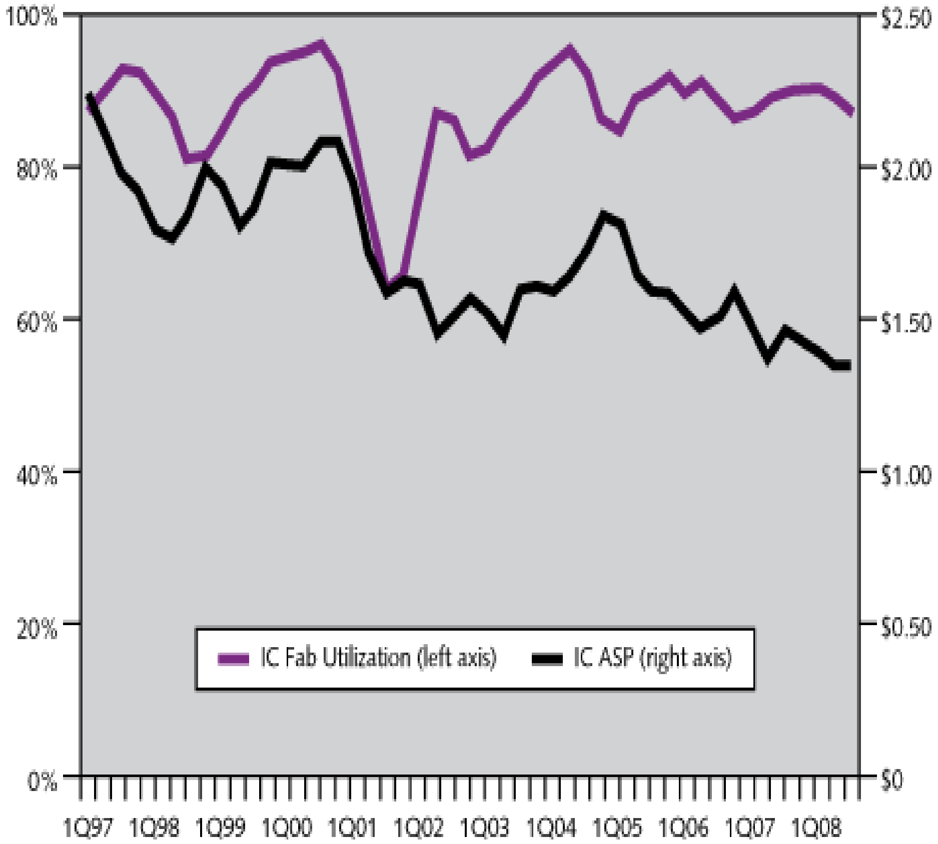


Figure 1.11. IC-wafer fab utilization (percent) and IC average selling prices in U.S. dollars. (Sources: In-Stat, SIA, January 2009)

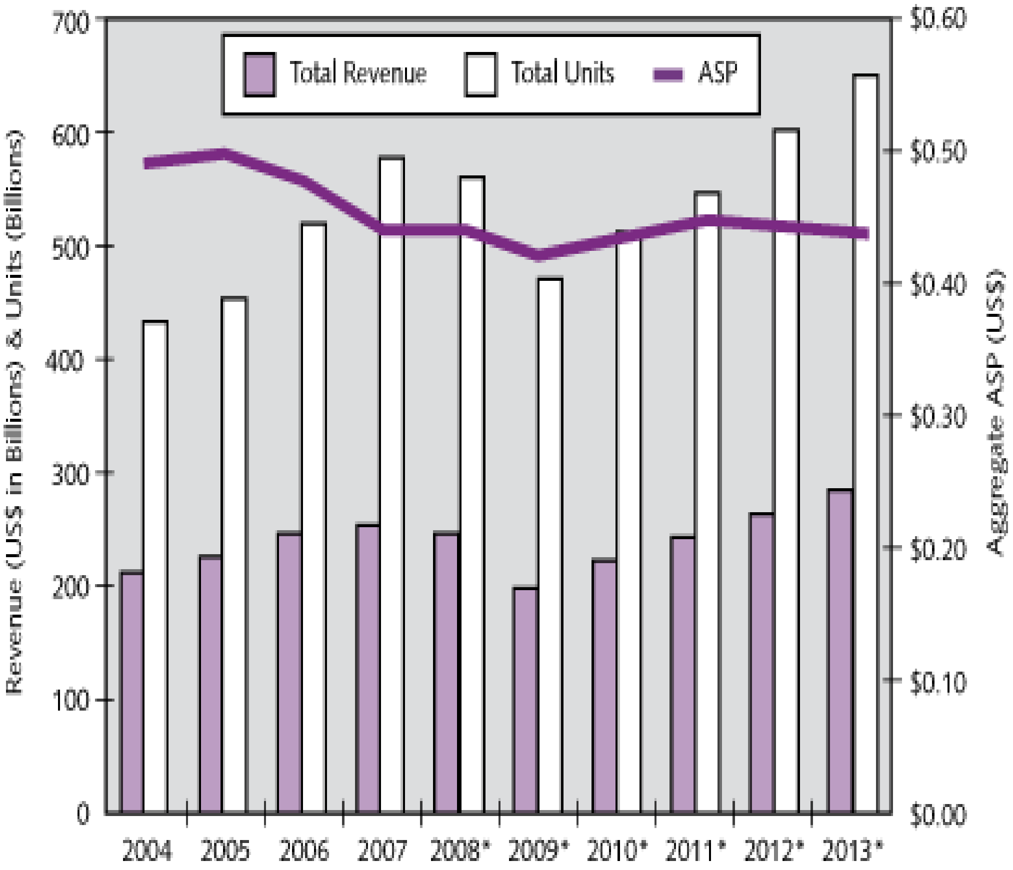


Figure 1.12. Worldwide semiconductor revenue with forecasts, 2004–2013. (Source: In-Stat, January 2009)

Figure 1.12 specifically demonstrates findings for the relationship of worldwide semiconductor revenue historic and forecasted compared to the ASP trend.

The primary area of interest among these business comparisons on utilization versus ASP is recognizing that utilization becomes more effective (increases) as ASP decreases. The bottom line message in understanding this comparison realizes that the more revenue the business is able to establish with its product, the more opportunity there is to manufacture at a reduced price due to greater manufacturing volume capability and the associated economic scale.

This concept is backed by Moore's Law, which states that the continuous increase in demand for semiconductor products will result in devices that are increasingly smaller (i.e., more per silicon wafer), which equals greater economy of scale. The industry's shift from 200 millimeter silicon wafers to 300 millimeter silicon wafers enabled a step function in productivity that doubled the output of the production line. Today, most factories have increased the size of their platform silicon wafers to a standard of 300 millimeters for that very reason.

With 300 millimeter wafers, a new manufacturing challenge was presented - the increased weight of a batch of wafers. Consistent with Moore's law, defect sensitivity also increased, requiring ultra-clean product handling. Today all high volume semiconductor factories utilize robots for product transport with virtually zero human physical involvement (Bonora 2001).

Full automation for product transfer has been considered pervasive in recent years; only a few years ago hundreds of people were required to effectively operate the tools and handle the product by loading and unloading the manufacturing equipment. Any inefficiency associated with an operator's response or work practices drastically affected tool utilization and was considered the single greatest opportunity for improvement.

Figure 1.13 Illustrates the potential confusion a manufacturing operator may have following the expectations of knowing where to take the product in a typical semiconductor device manufacturing flow. The challenge for humans to consistently and efficiently move product from station to station with the effectiveness of a preprogrammed robot is virtually impossible.

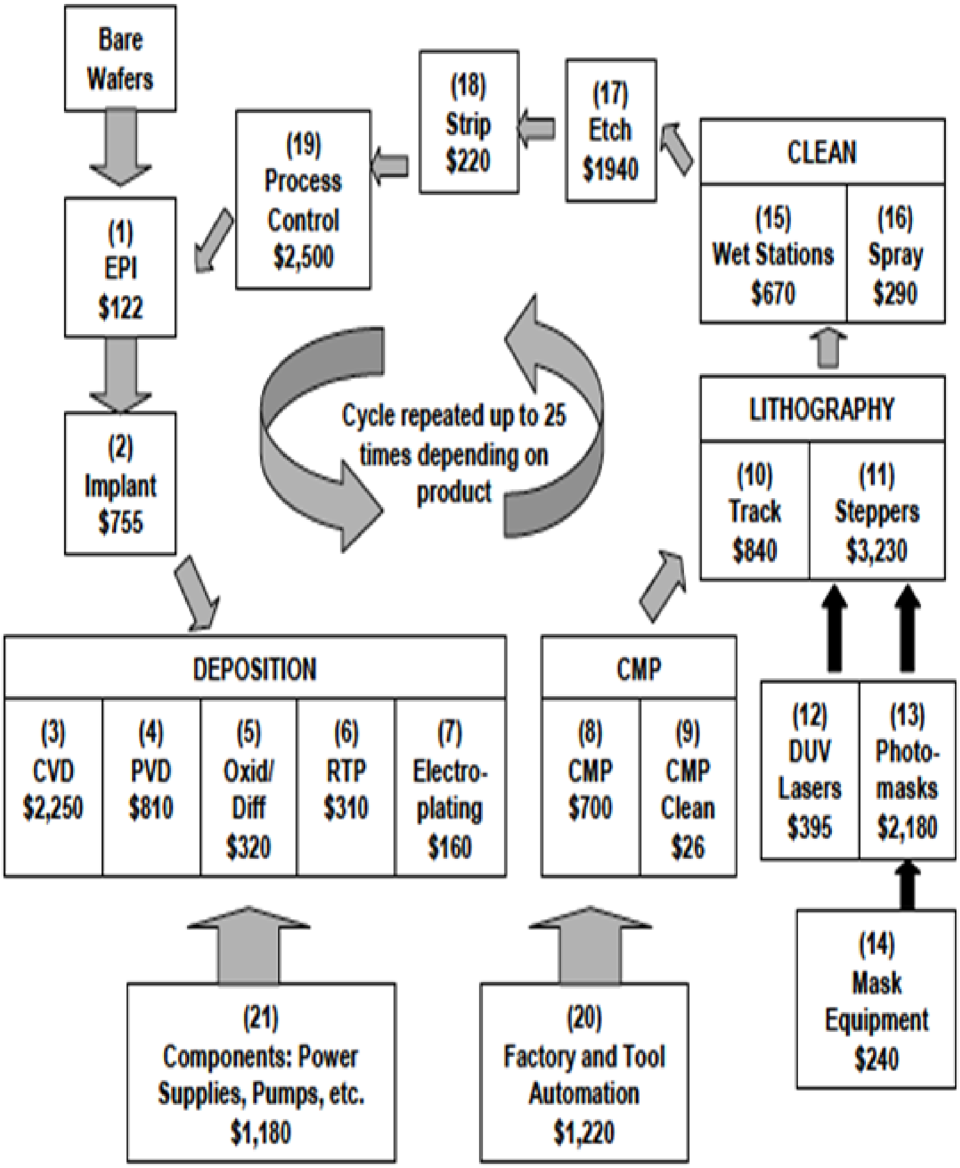


Figure 1.13. Equipment flow chart (FitzGerald 2004)

Only a very small percentage of the semiconductor workforce is now required to run operations versus the hundreds needed a few years ago. Today a small team of operators sits outside the cleanroom manufacturing area in a remote operations control center. The operators oversee and monitor automation for the robot's priorities of transporting, loading and unloading product.

The benefit to increased equipment utilization is made more obvious in figure 1.14, where the labor required to move product is captured in overall labor tasks. The illustration demonstrates where automation systems have taken over high duration labor tasks in recent years. With approximately 50 percent of the overall time for labor tasks being reduced and allocated to automated robots, the result is improvement in overall manufacturing cycle time and significant improve equipment utilization. Increasing the automation improvement, with consistent and predictable scheduling and transportation of product through the tools, eliminated the need for equipment operators to manually perform these functions (Jefferson 1995).

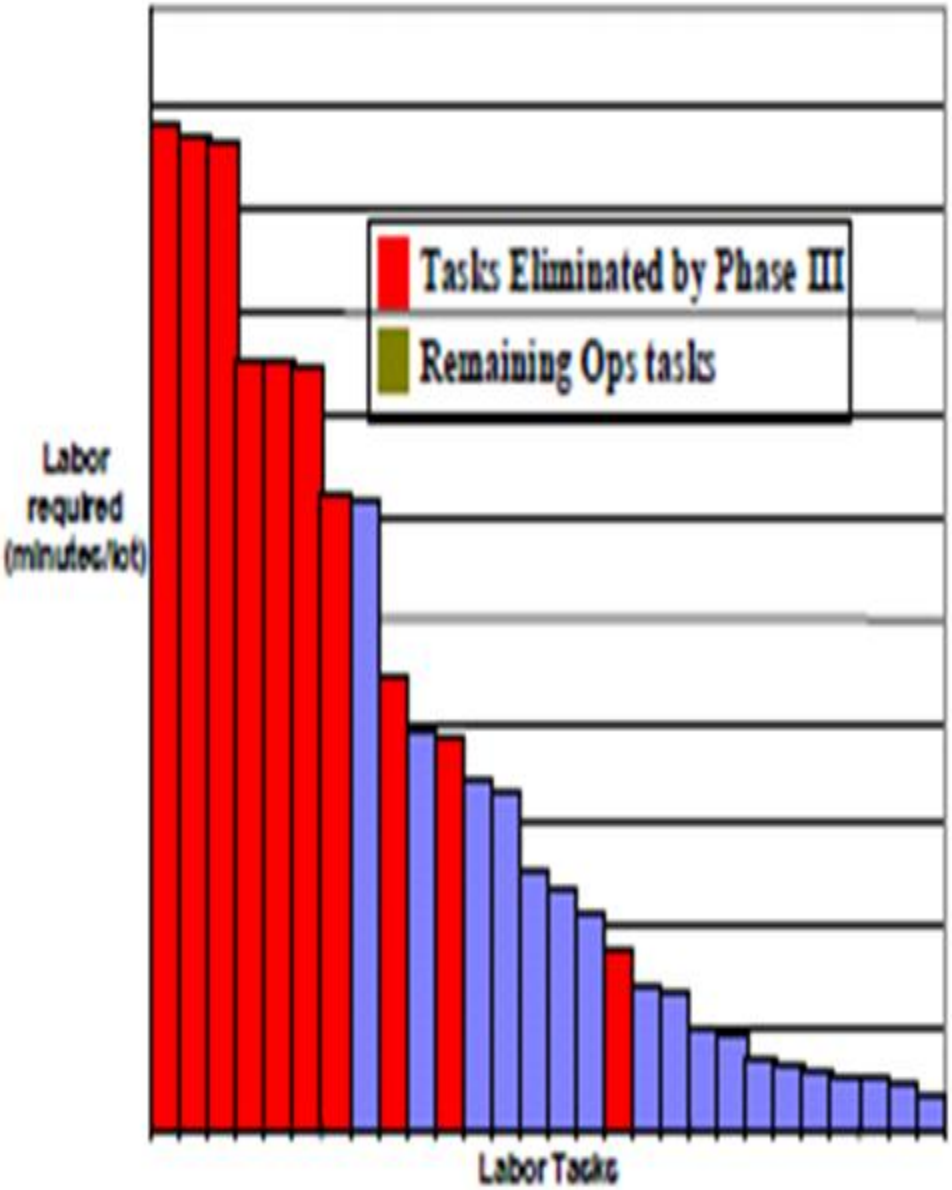


Figure 1.14. Pareto of labor tasks (Jefferson 1999)

Utilization of equipment through robotic automation has optimized how effective systems are operated. The remainder of this dissertation focuses on contributions to promote optimization of equipment availability. Maintenance actions remain to be highly human labor intensive as hundreds of people are required to resource the various tasks associated with this business function.

Moore’s law cites equipment capability as a constraint for semiconductor evolution as equipment must increasingly demonstrate the ability to manufacture smaller geometry parameters. While defect sensitivity does sometimes drive the need for newer, cleaner running equipment, the need for maintenance teams (working on the tools) to be increasingly vigilant about their practices is the first line of defense and the most controllable attribute to enable productivity and yield improvements.

Tables 1.2, 1.3, and 1.4 are real capital spending budgets for the world’s largest semiconductor manufacturers. Recognize that the normalized average spending per year does not significantly differ from company to company. Also notice that most capital spending remains constant and only deviates by time versus by company. It is also interesting to note that the spending variation ebbs for a year or two then increases consistently during the third year – proof of accuracy with Moore’s Law.

Table 1.2. Capital spending budgets (FitzGerald, 2004)

	2004E	2003	2002	2001	2000	04 vs 03
Samsung	4,333	3,308	1,825	2,880	2,609	31%
Intel	3,800	3,700	4,700	7,300	6,700	3%
UMC	2,300	600	1400	1800	2800	283%
TSMC	2,200	1,250	1,580	2,200	4,750	76%
STMicroelectronics	2,200	1,221	996	1,700	3,300	80%
SMIC	1,950	492	897	0	0	296%
Sony	1,774	1,370	760	1,439	2,316	29%
AMD	1,500	586	705	703	805	156%
NEC	1,438	826	494	929	1,820	74%
Micron	1,433	1,048	781	1,253	1,300	37%
Hynix	1,400	744	435	480	1,600	88%
Toshiba	1,381	1,036	504	650	1,382	33%
Texas Instruments	1,300	800	802	1,790	2,800	63%
Renesas	1,286	782	685	0	0	64%
Matsushita	1,238	614	512	744	1,148	102%
Nanya Tech	1,140	600	300	300	780	90%
Infineon	1,050	1,025	654	1,687	2,181	2%
Winbond	970	131	104	175	453	642%
Grace Semiconductor	800	500	600	100	0	60%
Chartered	700	221	420	550	911	217%
IBM	600	800	1,000	2,100	1,900	-25%
PowerChip	600	300	268	163	313	100%
Anam	550	200	200	280	370	175%
Eipida	495	389	317	0	0	27%
Mosel	450	250	400	200	400	80%
Total	**$.36,888**	**$ 22,793**	**$ 21,339**	**$.29,423**	**$.40,638**	**62%**
Year-Year change	62%	7%	-27%	-28%		

Table 1.3. Cap-Ex forecast versus actual spending (FitzGerald 2004)

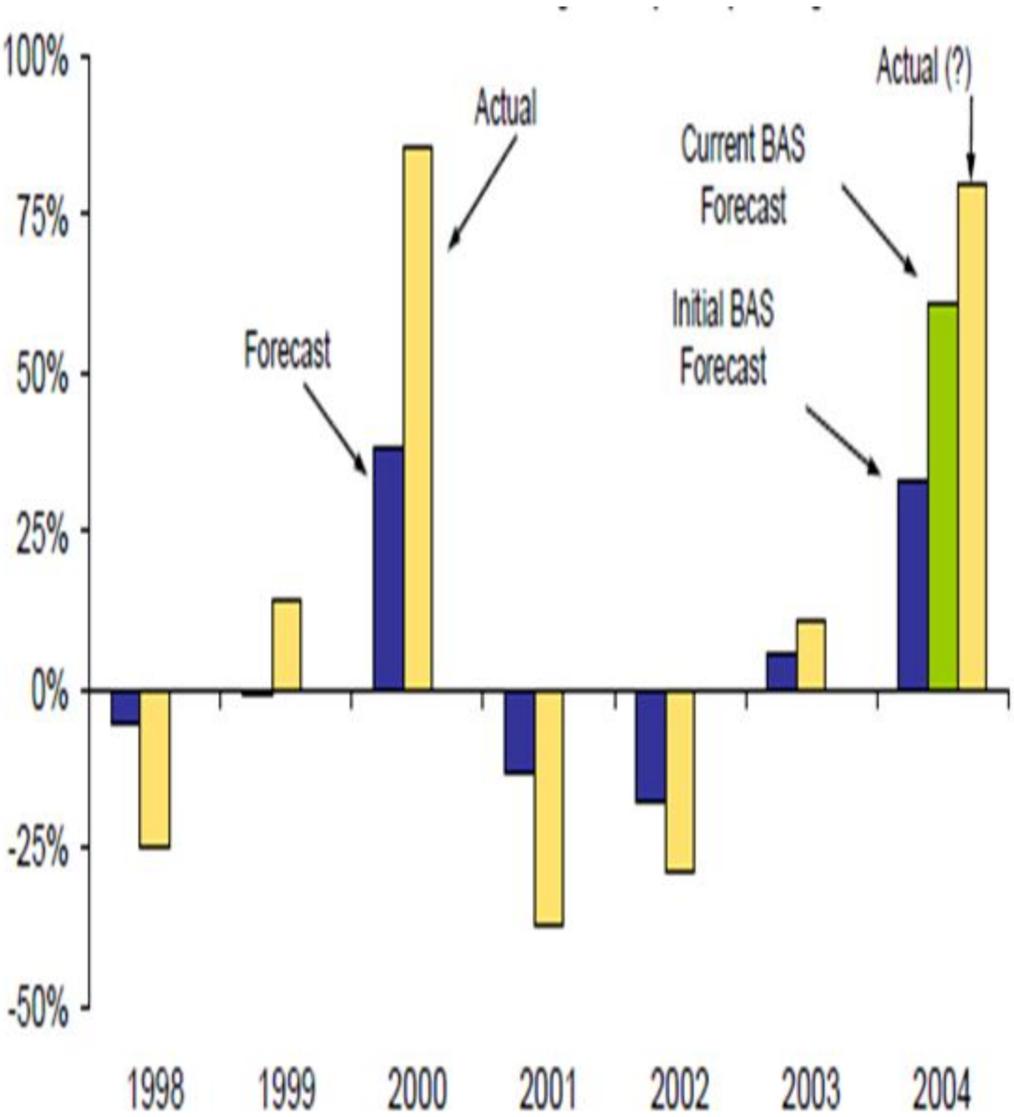


Table 1.4. Cap-Ex spending by region (FitzGerald, 2004)

	2004	2003	2002	2001	2000
United States	8,633	6,934	7,947	13,146	13,505
Percent Growth	24.5%	-12.7%	-39.5%	-2.7%	
Japan	7,612	5,017	3,447	3,762	6,666
Percent Growth	51.7%	45.5%	-8.4%	-43.6%	
Taiwan & China	10,410	4,123	5,549	4,938	9,496
Percent Growth	152.5%	-25.7%	12.4%	-48.0%	
Singapore	700	221	420	550	911
Percent Growth	216.7%	-47.4%	-23.6%	-39.6%	
Korea	6,283	4,252	2,460	3,640	4,579
Percent Growth	47.8%	72.8%	-32.4%	-20.5%	
Europe	3,250	2,025	1,650	3,387	5,481
Percent Growth	60.5%	22.8%	-51.3%	-38.2%	
Top 25 Worldwide Total	36,888	22,572	21,473	29,423	40,638

Moore’s law has demonstrated a repeatable cycle of capital spending, driving the need to recognize that existing equipment availability is a constant challenge through each technology generation. Training an organization of people to understand and integrate new equipment erudition and the associated technology tool is the role of a world class maintenance organization that will forever be in demand. With the exorbitant entry costs to the semiconductor market, due to capital equipment costs, semiconductor companies must turn their focus to equipment performance on the manufacturing line and within the associated facilities support systems to stay financially competitive (have the best possible profit margins). Continuous performance improvement of existing equipment is rarely pushed to the limit; future manufacturing requirements in an oppressed economic environment must embrace the goal of extending the production equipment lifecycle between generations - associated with Moore’s Law (King 1996). Figure 1.15 demonstrates the average cycle time for equipment lifecycle based on Moore’s law.

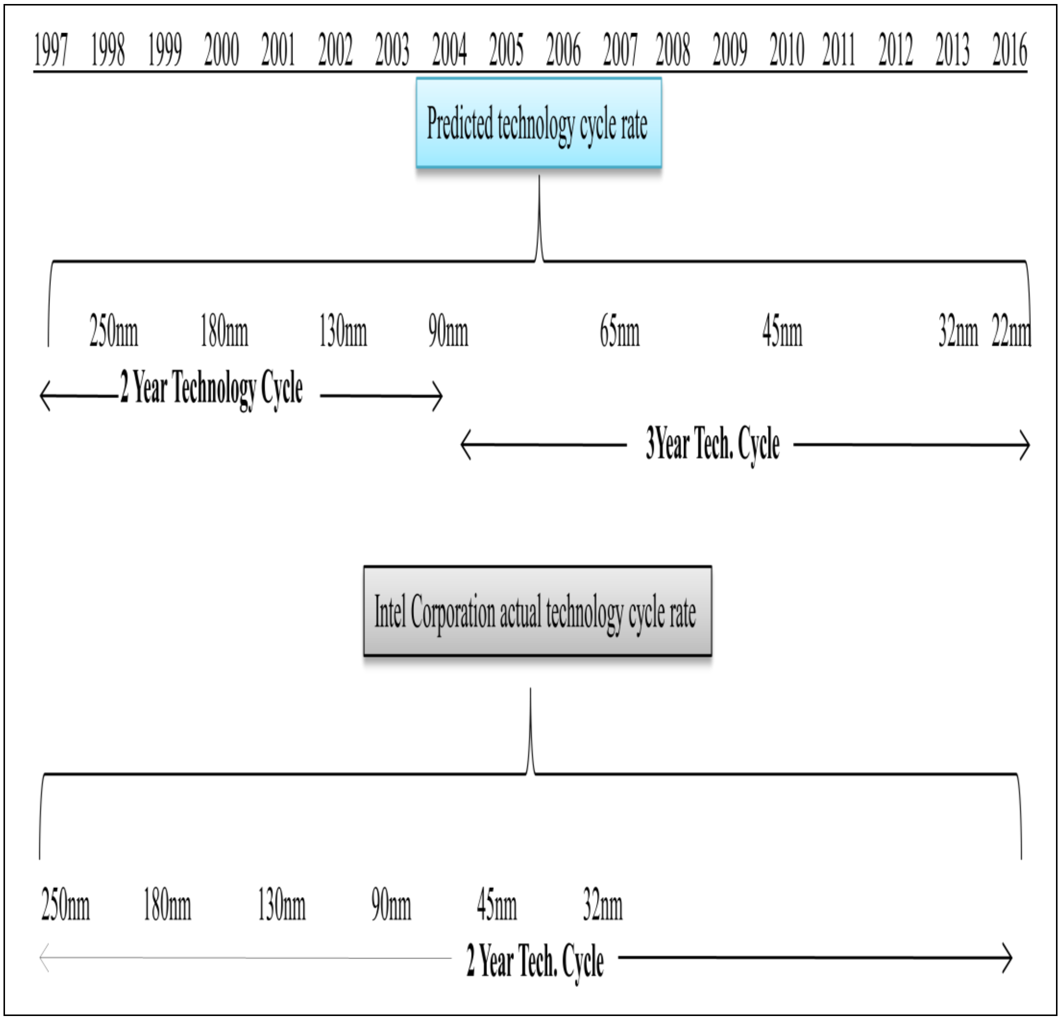
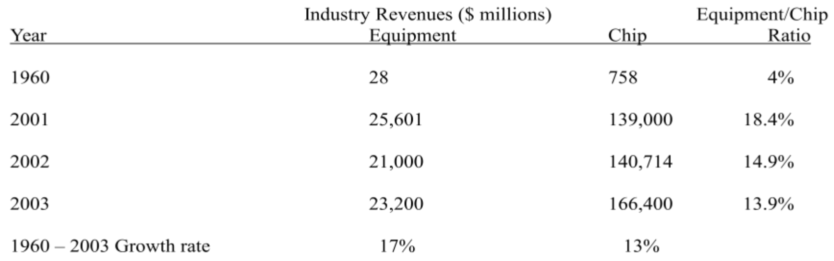


Figure 1.15. Timetable for new technologies (FitzGerald 2004)

Table 1.5 illustrates the relationship between equipment manufacturing revenue and product device revenue. The take away in this example is that sometimes new capital equipment is required to enable new technology manufacturing for the reasons stated in Moore’s law. However, there remains a direct relationship between equipment (new and old) and its necessary maintenance to ensure availability to manufacture high yield quality product.

Table 1.5. Chip and equipment industry revenues (FitzGerald 2004)



	Industry Revenues ($ millions)		Equipment/Chip
Year	Equipment	Chip	Ratio
1960	28	758	4%
2001	25,601	139,000	18.4%
2002	21,000	140,714	14.9%
2003	23,200	166,400	13.9%
1960 – 2003 Growth rate	17%	13%	

To better understand the opportunity and challenges associated with equipment availability management efforts, the definition of equipment operational status can be put into two categories:

- Up to production, the equipment is on-line, ready and capable of producing quality product.
- Down to production, the equipment is unavailable to produce quality product.

The “down to production” category has two subtle attributes that need to be understood:

- Unscheduled downtime, where the equipment is unable to produce quality product due to an expected or unforeseen issue. The Chartered Institute of Building classifies this category as emergency maintenance requiring immediate action to resolve failures (CIOB 1982).
- Scheduled downtime or planned maintenance is also known as preventative maintenance (PM) where the maintenance event is predictable or routine (CIOB 1982). During scheduled downtime

> situations, action can be taken at a time that is most beneficial to production needs in order to avoid unexpected failure modes before they occur (Seeley 1976).

The greatest opportunity to improve the production environment through equipment availability management is to strive to minimize unscheduled downtime, as these are the most disruptive and can potentially impact production schedules.

Variability Associated with Quality of Work

One commonality with every manufacturing organization, regardless of industry, is the need for a maintenance team; specifically, multiple technicians across multiple shifts supporting full time production with work needs to cover every day of the year.

Typically technicians follow a PM checklist or specification instruction sheet when performing maintenance work. To ensure PM tasks are performed in a repeatable and standardized fashion, it’s important to recognize that when more than one person is performing an action, there will be variations in how the instructions are interpreted and how the actions are performed.

Every maintenance manager should strive to reduce this work quality variation and explore areas for improvement, with the goal of achieving Preventative Maintenance (PM) tasks consistently no matter which technician is performing the work.

Consistent procedures and standardization of action is essential for predictive equipment performance. It is very important that all individuals recording data use the same category code, when evaluating both equipment and system operation, to log the same event (AMT 2002).

There are two categories of PM scheduling – time-based and usage-based:

- Time based PM tasks are scheduled in advance driven by intervals of time. The most common time based PM frequencies are daily, weekly, monthly, quarterly, semi-annually and annually.
- Usage-based PM tasks are driven by increments of usage on the equipment, like changing your vehicle's oil every 3,000 miles. For a semiconductor factory, usage-based PM scheduling is typically in terms of wafer throughput on a tool, e.g., performing a PM every 5,000 wafers processed through the tool. Most toolsets have wafer counters much like a vehicle has an odometer.

Objective

The objective of this dissertation is to make an iterative contribution to the Facilities Management (FM) industry by identifying an analytical method for sustained improvement of manufacturing equipment availability. Availability can be improved by decreasing the overall frequency and duration of equipment break-downs. The proactive equipment maintenance and organization change methodology discussed in this dissertation was tested in a pilot experiment, involving over 1,000 pieces of semiconductor facilities equipment, over the course of three years using an incumbent group of 27 facilities technicians, a new generation of 27 facilities technicians, and five incumbent mechanical engineers.

This research study and associated findings occurred at one of the world's largest semiconductor manufacturing sites from January 2009 through 2011. The criticality of extensive facilities to support semiconductor production processes cannot be understated when comprehending the requirements to maintain class one cleanroom environments. Heating and air-conditioning systems are continuously utilized to maintain the correct air flow volume, temperature control and humidity specifications, to reduce the potential environmental contamination containing product-killing airborne particles or water vapor. The production tools in the cleanroom also require a complex set of facilities support equipment that must perform within tight operational limits to ensure production is repeatable and in control. Downtime on any facilities system, especially unscheduled downtime, always results in cost to production. Whether it is parts or labor to repair the equipment, downtime always impedes manufacturing throughput due to limited equipment capacity; the result always means some loss in potential revenue.

This dissertation presents a process method to sustain improved efficiency with equipment availability through organizational change. This methodology strives for ownership among leaders versus management. The process is comprehensive and quantitative with participation focused at the lowest hierarchical level of the maintenance organization instead of the management level. This method should prove to be more effective for the organization over time as maintenance actions will continue to be required in the future, independent and regardless of who is in the organization.

The hypothesis stated in this chapter was found to be statistically valid. The unexpected collateral finding was the development and integration of a new equipment response flow that emerged as the organization transitioned consistently with theories developed by Douglas McGregor in the 1960s. McGregor’s theories, referred to as Theory X and Theory Y, suggest human motivation references often used in human resource management and organizational development. McGregor identified Theory X employees as employees who do not want to work; managers of this category of people must strive to motivate and energize them. Theory Y employees are self motivated; their managers can give more freedom without needs of constant oversight.

This dissertation discusses tool availability and employee survey metrics used to develop the status-quo environment of a reactive, controlling management mode of operation and a proactive, more autocratic leadership organization model. The final result was a mutual accommodation to increase understanding in the priorities that need to be worked in a maintenance environment to empower employees. This effort greatly benefited management as managers gained measured accountability and improved facilities equipment performance, which, if sustained, was immediately found to provide greater revenue potential for the overall business.

The basis for this study’s purpose was to address the criticality of improved availability of facilities equipment in the semiconductor industry and test a simple method to predict equipment failure before occurrence. As the technical testing model progressed, the methodology was found to have improved equipment performance indicators. A new organizational response flow emerged that ultimately transitioned the maintenance technicians from the status-quo of extensive management oversight and reactive equipment incident response to a proactive and more autocratic leadership environment. The maintenance organization demonstrated improved monthly equipment performance metrics, demonstrating fewer ITPs. There were four consistently positive, anonymous bi-annual employee satisfaction survey results (for approximately three years) before the method was found to be unsustainable in the absence of a change agent.

The author noted a lack of consistency with organizational behavior cited in McGregor’s Theory X and Y, and strived to research, understand and test whether or not an organization with strong tacit behaviors could evolve to sustain best in-class maintenance habits. Research of widely accepted organizational change experts was compared and tested to develop an iterative contribution to the FM industry. Further, this dissertation analyzed iterative progress for organizational change attributes required to develop sustained improvement performance modeling for equipment maintenance organizations.

While equipment performance was found to have improved, utilizing the author’s methodology, what was not expected but clearly demonstrated was organizational behavior regression to status-quo habits in the absence of the change agent. Even though the maintenance population had followed the predictive methodology for two years and benefited from obvious equipment performance indicator improvement, their desire to change was not maintained. When the program champion/author was removed from the organization over the course of 14 weeks, baseline conditions of substandard equipment performance returned.

Initially, this study’s purpose was to address the criticality of facilities equipment in the semiconductor industry and propose the ability to predict equipment failure causes before they happen. At the end of the hypothesis experiment testing, it was evident that organizational efficiency required a change agent that valued tacit and implicit job knowledge functions. The predictive failure method was successful in transforming the highly intensive and controlling status quo management cycle into an obvious leadership model consistent with a study by Dr. William Badger, in which decisions from management were being virtually eliminated (Hays 2000). When the change agent was removed, the organization regressed to the elements of disempowerment, requiring more oversight to continue improved change.

The International Facilities Management Association (IFMA) set the definition of facilities management as “the practice of co-coordinating the physical workplace with the people and work of the organization” (IFMA 2002). While this definition is accurate, it does not stress the ability for facilities maintenance leaders to contribute to the workplace as it relates to world class system availability and the need to encourage Theory Y (McGregor) organizational qualities. A well maintained facilities equipment set is an integral approach to operating, sustaining, and demonstrating continuous improvement required in a production environment in order to build the infrastructure that supports the primary objectives of an organization (Chen 2008).

Measuring Availability for Equipment Effectiveness

At a holistic level, the indicators will compare all downtime events, employee satisfaction and cost savings metrics at baseline facilities performance (pre 2009) versus predictive methodology performance that was implemented as the primary indicator in 2009 and utilized during the successive three years. Did the total number of downtime events decrease from one year to the next with only the hypothesis test model as the greatest source of change? How was the organization navigated to maintain performance improvements without the need for extensive management oversight?

Chapter 2

Literature Review

Literature references in Chapter 1 established the need for competitive business operations, like semiconductor manufacturing, to develop organizational structures that utilize their human resources to the fullest potential. In order to ensure maximum revenue and to meet the business cadence of emerging technology cycle time, employees must be empowered to make decisions that may have historically been reserved for management. The focus on continuous improvement must be alive and well on the factory floor to enable innovation. The challenge identified in research was for management to develop effective strategies for process change integration that meshed the technology of the industry with creative organizational structures to ensure program maintainability.

Research by Maslow and McGregor suggest that effective strategies for managing and maintaining change must start with a fundamental understanding of the conflict that exists between an organization’s need for change and an individual’s need for personal security. Competitive, capital intensive industries require intensive efficiency and utilization of resources (Chen 2008). The research objective in this study focused on a process method to sustain improved efficiency with equipment availability through organizational change versus increased capital spending.

In the author’s previously published literature, it was proven that facilities equipment availability can be improved through a data driven proactive effort of equipment monitoring versus the reactive “break fix” mentality. The author later witnessed an organizational behavior consistent with McGregor’s “Theory X” when the change agent was removed. This literature review will compare the established barriers of organization change with findings the author observed as constraining maintainable improvement within the facilities organization of the semiconductor industry.

The Organization’s Baseline Maintenance Performance

For a given demand and planning horizon, the general facility design problem is to decide how much capacity to build into the system (Kanagal 1990). During the past 20 years of semiconductor industry growth, the task of allocating maintenance resources and scheduling maintenance work has become more difficult (Moubray 1995). The level of capital intensity associated with modern high volume facilities in multiple industries drives a greater need for the maintenance organization to rapidly respond and repair equipment failures (Mosley 1998).

The prosperous economic environment prior to the 2001 “.com” bust enabled “break-fix” to be an acceptable means of capacity augmentation due to greater industry cash flows. At that time, more capital equipment on line resulted in increased production capacity. As previously discussed, “break-fix” methodology is reactive and does not foster the utilization of a data driven approach for accurate maintenance tracking. The predictive method suggested in this dissertation requires significant data logging to be maintained for every piece of equipment. The data logging is not difficult; it is a matter of capturing generic information about each piece of equipment on a regular schedule. Logging and tracking this information can provide useful metrics for understanding equipment performance such as (a) mean-time-between-failure (MTBF), (b) rolling availability percentage, (c) equipment performance symptoms, and (d) solutions. Having these critical attributes tracked gives greater insight to cost control. When tracking is correlated to a specific production load or timeframe, labor and parts usage are more predictable and therefore manageable. A proactive maintenance methodology falls directly in line with the “LEAN” principle known as “Muda,” the elimination of waste induced by unscheduled breakdowns (Linton 2006).

The opportunity statement that was explored in this study was: by analyzing initial conditions of facilities equipment maintenance performance, there is a significantly greater opportunity to clearly recognize and predict issues before they occur. By allowing a predictive maintenance model, the opportunity to reduce equipment downtime is increased, which results in greater potential for significant cost savings. The success indicators during testing of this model were based on equipment availability improvement as it related to the reduction of interruption to production (ITP) events. Increasing production equipment availability equals greater revenue potential and cost savings; greater cost savings provide greater efficiency and, potentially, better organization alignment of resources. Maintenance management has a direct influence on production performance (Yang 2007).

As mentioned in Chapter 1, to understand the wastes or inefficiencies existing in a maintenance organization, it is important to raise stakeholders' awareness of equipment operational status categories. At a high level there are only two categories that matter when it comes to production availability - production equipment status is either (a) "Up," on-line and ready to work or (b) "Down," off-line and not able to produce quality product. In order for any manufacturing business to maximize profit, the equipment needed to generate the product must be available or "up to production." In a perfect situation, the equipment should be available to manufacture quality product 100 percent of the time that it is expected to be on-line. Enabling 100 percent equipment availability requires a trained and informed maintenance organization to effectively service the equipment.

Because machines are not self-healing, they experience mechanical and electrical deterioration, thus requiring regular maintenance over time to avoid failure; a simple example is an automobile engine that needs an oil change on a specific frequency to avoid mechanical failure. There are two types of simple maintenance categories and two types of equipment "down" categories:

- Preventative maintenance (PM), scheduled down time.
- Corrective maintenance (CM), unscheduled down time.

According to Kagan, a "break-fix" mentality is the standard response most prevalent in a maintenance organization. With the risk of significant revenue potentially lost due to unscheduled production equipment downtime, "break-fix" is an unnecessary and provocative orientation for any maintenance group to rely on. In the year 2008, the author began recording the number of ITPs due to unscheduled down-time incidents occurring in a business quarter. The baseline of incidents by quarter over four years is illustrated in figure 2.1, ITPs by quarter.

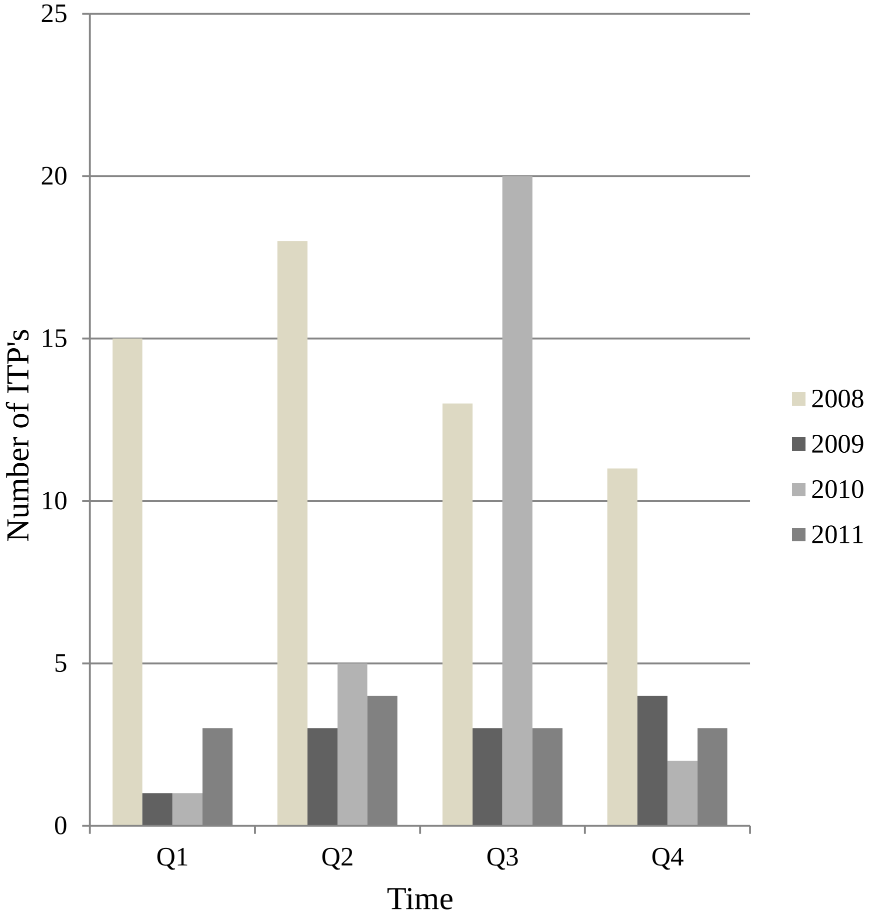


Figure 2.1. ITPs by quarter

Figure 2.1 demonstrates that ITPs in 2008 averaged 14.25 incidents per quarter; this was the baseline performance and the primary measurement for the facilities equipment availability improvement study.

The Cost of Poor Maintenance Performance

Given the significant capital costs in the semiconductor industry, experts pointed out that increasing the useful life of factory production equipment is required and expected in order to enable efficiency and opportunity for profitable operations. Figure 2.1 illustrates a real facilities scenario where every unscheduled equipment down-time event or ITP resulted in diminished time in production. Looking at specific impacts with ITP incidents to total equipment availability, the abatement profile in figure 2.2 demonstrates the full spectrum of equipment utilization time. Focusing specifically on the abatement equipment information in the chart, these tools were “up” and available for production 30 percent of the total time needed for production. During the year 2008, the abatement systems spent 70 percent of their available time “down” to production due to either CM or PM events. By viewing equipment availability this way, information regarding how the equipment is being utilized is captured at once, giving the viewer a quick perspective of the time available to support production.

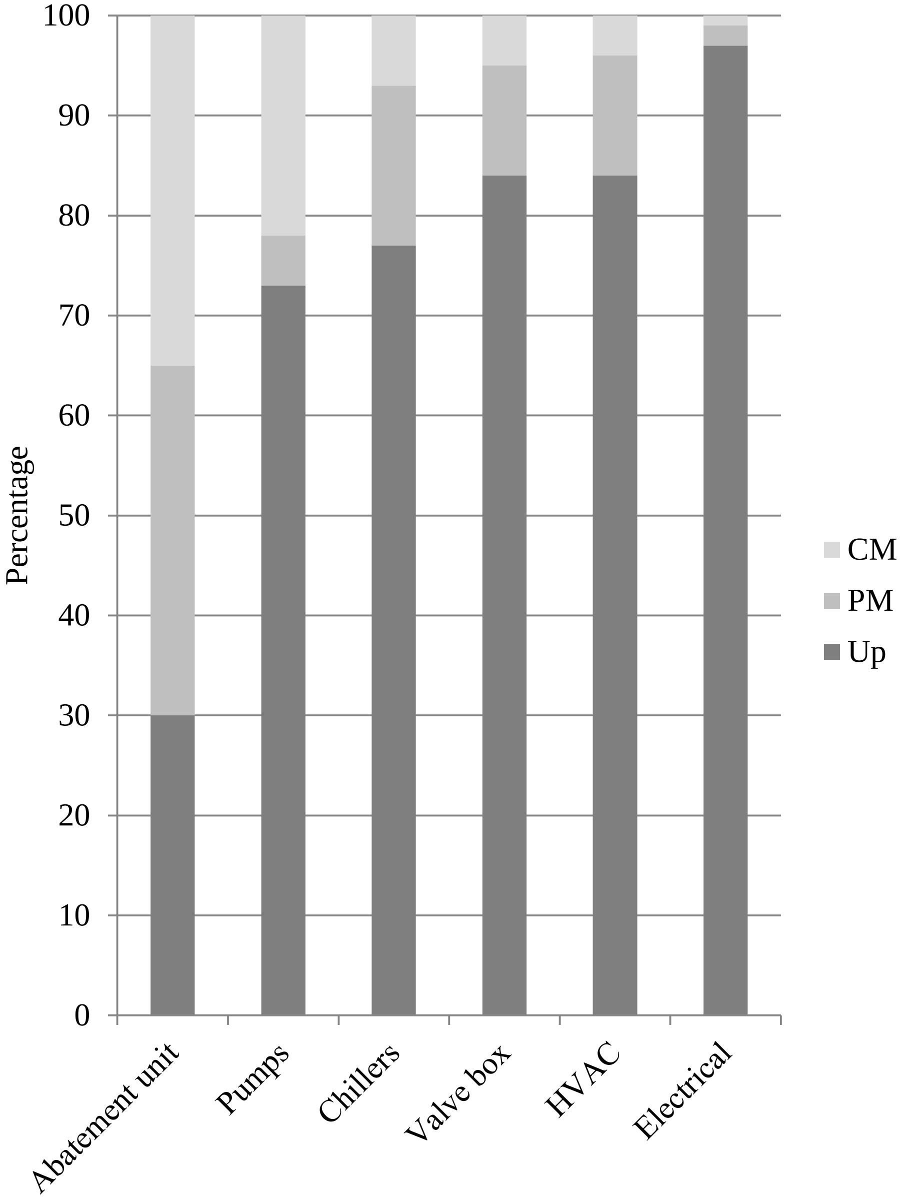


Figure 2.2. Percent equipment uptime availability by equipment category

We know that PM events will never cease to exist with electro-mechanical systems because all equipment requires maintenance. Embracing the fact that maintenance will always be needed, it is important to understand that PM events are far less disruptive to production schedules than CM events because PMs are scheduled; the equipment does not go off-line until a predetermined and expected interval of time. CM events are the most troublesome because they are a “surprise;” an unscheduled equipment off-line event that has many unknowns associated with the timing, cost and duration of the downtime. CMs always constrain production capacity, and typically result in product loss due to scrap, or reduced product quality. PMs are similar to taking your car in for regular maintenance; this service is scheduled on your timeframe, and there is usually a known cost and duration so efficiency is better managed. CMs are maintenance services required without warning, similar to a tire blow-out or an engine that just stops; in these examples the vehicle is stopped and must be repaired in order to return to service. You typically have a lower certainty of how much the repair will cost and how long the repair cycle will take.

Because CM events are unscheduled equipment failures that typically result in product loss, higher parts consumption and unexpected labor costs are two collateral impacts. Minimizing CM events to as close to zero incidents is the goal for every maintenance manager. The SEMI Guideline E-10 states the definition of these terms; CM failures are unscheduled interruptions to machine performance and are synonymous with a common repair category to correct failures (SEMI 1996).

By reducing all downtime events, equipment uptime is increased, which equates to greater equipment reliability and production capability. The semiconductor industry’s capital intensive environment drives a focus on equipment reliability and maintainability with the primary measurement for these attributes commonly referred to as Mean Time Between Failure (MTBF).

Understanding the difference between PM and CM categories is important. While no PM method can guarantee higher availability, the more data captured about the PM events can provide greater insight to understanding the symptoms of potential failures before unscheduled down-time occurs. In a manufacturing environment, PM events can be viewed negatively as an impact to production utilization capability and, therefore, are postponed to keep production running. In contrast, with human lives at stake, the airline industry's maintenance reliability performance is of significantly higher importance. Airplane maintenance is less likely to have PMs postponed. It is important for every maintenance stakeholder to understand the maintenance risk tolerance for their business and how CM events are affected as PM frequencies are rarely if ever at optimal intervals due to changing variables with production (SEMI 1996). In a production environment, a CM event equates to two possible results:

- Interruption to Production (ITP), where product was scrapped or put at risk for poor quality due to non-standard processing.
- Near Miss (NM), in these events product is not scrapped due to the equipment suddenly going off line – but it could have been.

Reducing production downtime events results in lower cost of ownership and increased production time available, thereby enabling revenue potential.

Capital intensive and competitive industries require intensive efficiency and utilization of resources (Chen 2008).

As stated before, the standard for equipment maintenance for most industries facilities maintenance groups is a “break-fix” mentality (Vavra 2007). In today’s constrained financial environment, facilities and production managers should align on the premise that it is typically less expensive to replace or repair a deteriorating mechanism before it breaks than to fix it after it fails. The cost of unscheduled ITPs also includes the increased production capacity constraints associated with not being able to predict which equipment sets will reliably produce. When an equipment set goes off-line in an unscheduled manner, work-in-progress inventory levels build in a queue, resulting in collateral manufacturing challenges. Unscheduled down-time events are more costly than the price of an effectively planned PM event. This orientation becomes a reality in today’s recessionary environment; businesses must balance the cost pressures of running a piece of manufacturing equipment to unscheduled failure, or to effectively plan maintenance events so performance is predictable. The financial climate will always bring about the condition of rethinking the importance of effective PM events (Blegen 1968).

For a given demand and planning horizon, the general facility design problem is to decide how much capacity to build into the system (Kanagal 1990). In the past two decades, changes in the production environment have made the task of allocating maintenance resources and scheduling maintenance work more difficult (Swanson 2002). The high level of capital intensity associated with modern automated equipment also places greater pressure on the maintenance function to rapidly repair equipment and prevent failures from occurring (Mosley 1998).

Unscheduled equipment down-time often results in damaged product since the manufacturing process became incomplete during the event. The status quo in typical maintenance organizations is that management is only really concerned with ITP events because scrapped product generates the most scrutiny from production management. This paradigm requires a change by all stakeholders if they are to break through to the best equipment availability possible. Tindle's research suggests that overall equipment effectiveness, as it relates to total productive maintenance, cannot be the responsibility of one organizational group like production or maintenance; it must be a company or organization wide objective (Gregory 2011). The strategy must have clear and measurable indicators that each person in the organization can turn to for better understanding and awareness to recognize progress and hurdles.

By utilizing all available information from each equipment maintenance event (from every technician that touched a piece of equipment), the ability to systematically capture and assess performance information associated with availability can be summarized in a chart. Without this information, the maintenance staff is blind to how the equipment is performing. By not reviewing all performance information, management sets the tone for quality in the organization and subversively priorities resources based on a small sample of data, without considering all of the facts.

Osborn states that the environment of an organization has a direct impact on its processes and outcomes. Every organization's environment is comprised of three distinct variables: risk, dependency, and inter-organizational relationships (Osborn 1974). To start an effective maintenance program with this perspective, sustainable maintenance practices were divided into three vectors of organizational alignment:

- Inter-organizational relationships – actively participating teams, made up of maintenance, production and engineering personnel, who are charged with analyzing and improving performance in their respective areas.
- Dependency to foster teamwork – enhanced by having both maintenance and production groups routinely inspect equipment in order to identify problems early and provide basic documentation on their findings. For example; is the equipment leaking, squeaking or vibrating? Abnormal findings need to be identified as soon as possible for early correction.
- Understanding risk – this can be shared in a similar fashion by shifting the focus from measuring downtime to more holistic and preventative measures like overall equipment effectiveness (OEE), which includes the number of NM events.

Developing a successful maintenance project requires a well-planned maintenance effort to control the process and to reduce the risks associated with performing the required maintenance tasks. Prioritization of the required maintenance tasks is a key factor for having a well-planned maintenance process (Abdelmoez 2007).

The first step out of “break-fix” is the move to PM, which should at least include developing work orders by proactive NM events that drive investigation of irregular performance before the system fails. When a NM is identified, a PM work order is initiated in a Computer based Maintenance Management System (CMMS). NM findings are important and should be tied to an effective spare parts inventory. Completion of these work orders should be tracked to better understanding the most effective PM frequency for the system, and enable improved visibility to move into PdM.

The method studied and explored for this dissertation demonstrated that management was not listening to, or taking into consideration, all of the available information surrounding equipment maintenance events. Specifically, NM downtime events were being logged by maintenance technicians, but management did not incorporate the findings. The status quo in the studied facilities organization was that NM events were considered insignificant to management because they did not interrupt factory operations with scrap. However, NM events should have been captured in the control chart as dominant information because a NM event is still a down time event to which technicians must respond with labor and parts expenses on an unscheduled basis. Capturing all downtime events by category provides, over time, a much greater understanding of system performance. Having the ability to raise awareness and trend repeat failure occurrences needs to be embraced by both equipment and production management. This gives management an opportunity to view past performance trends, which has the strong potential to promote future performance predictions.

Figure 2.3 illustrates the status quo where management only views ITPs or equipment downtime events that result in scrap. The chart illustrates the average number of events being reviewed at about 14 per quarter.

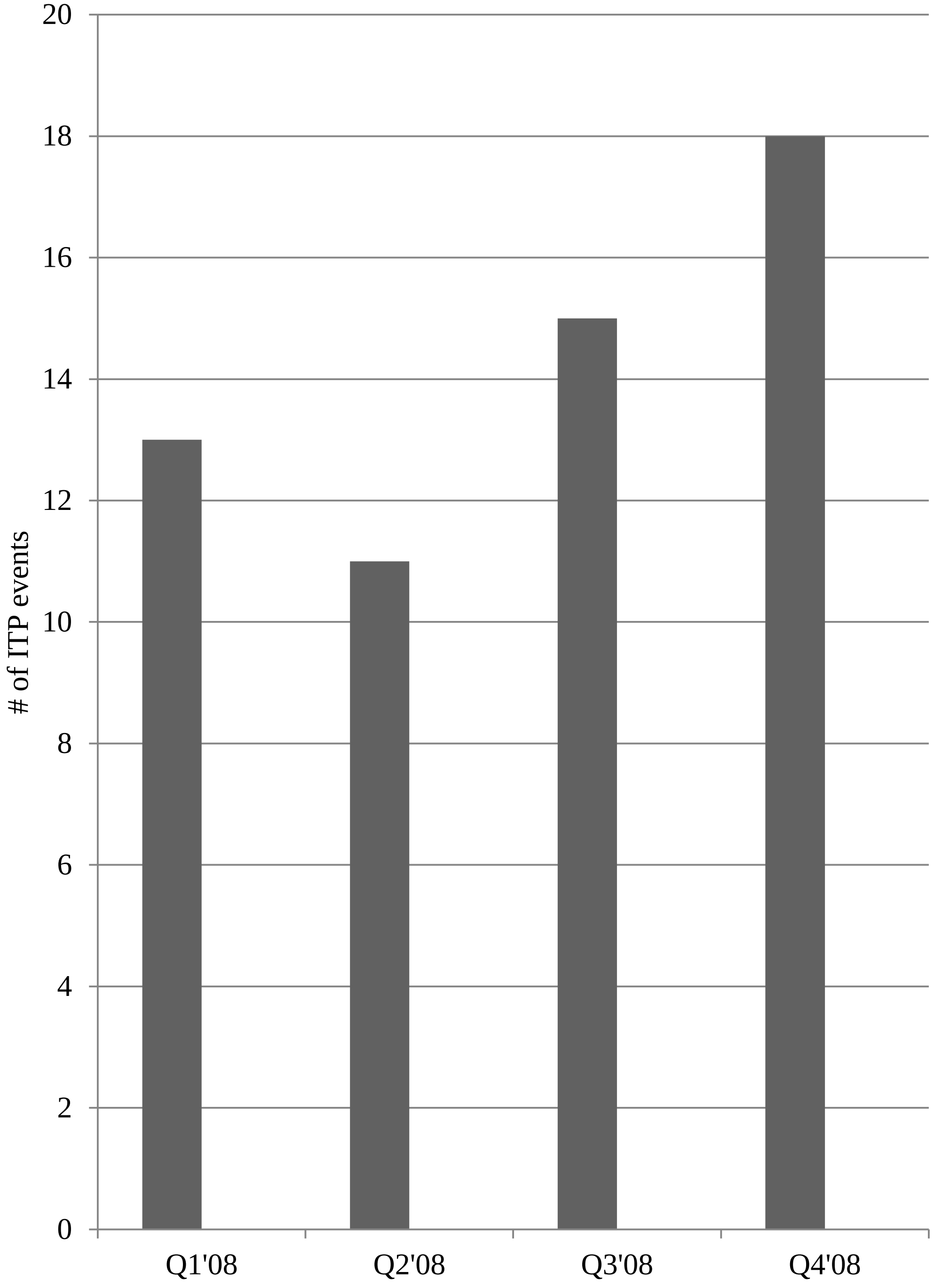


Figure 2.3. 2008 average ITPs by quarter

Figure 2.4 illustrates a Pareto chart where highlighting the volume of ITP events by category, one through six in this case, helps the organization clearly see which items are the most frequent and or problematic.

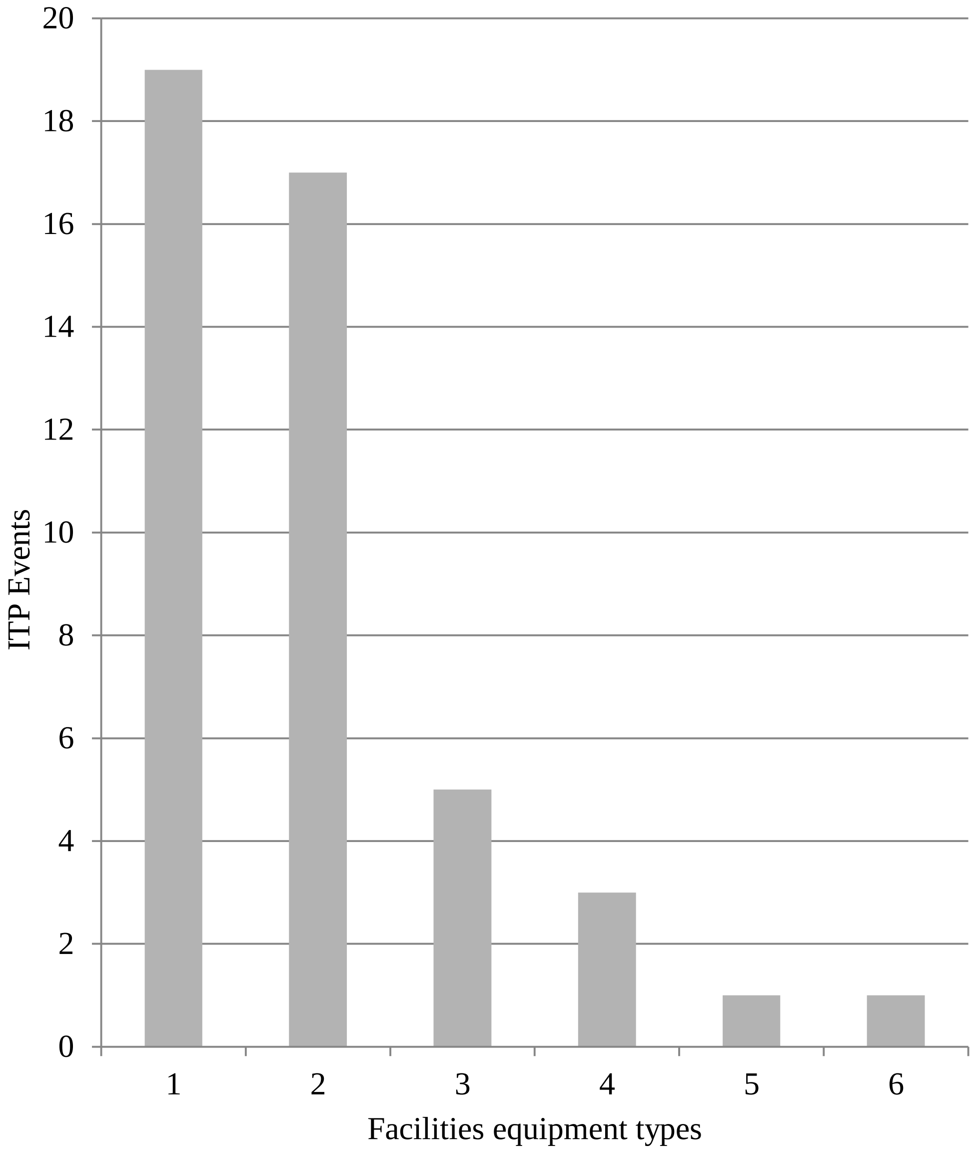


Figure 2.4. Pareto of ITP events by facilities equipment type

Figure 2.5 shows the status quo communication and response process flow chart. Figure 2.6 shows the change in paradigm requested from management during the pilot testing versus the status quo in figure 2.5. The change in perspective and response flow was found to allow the maintenance organization to more effectively collaborate in the new process flow. All dominant equipment performance information was collected and reviewed by all stakeholders in the facilities and production organization.

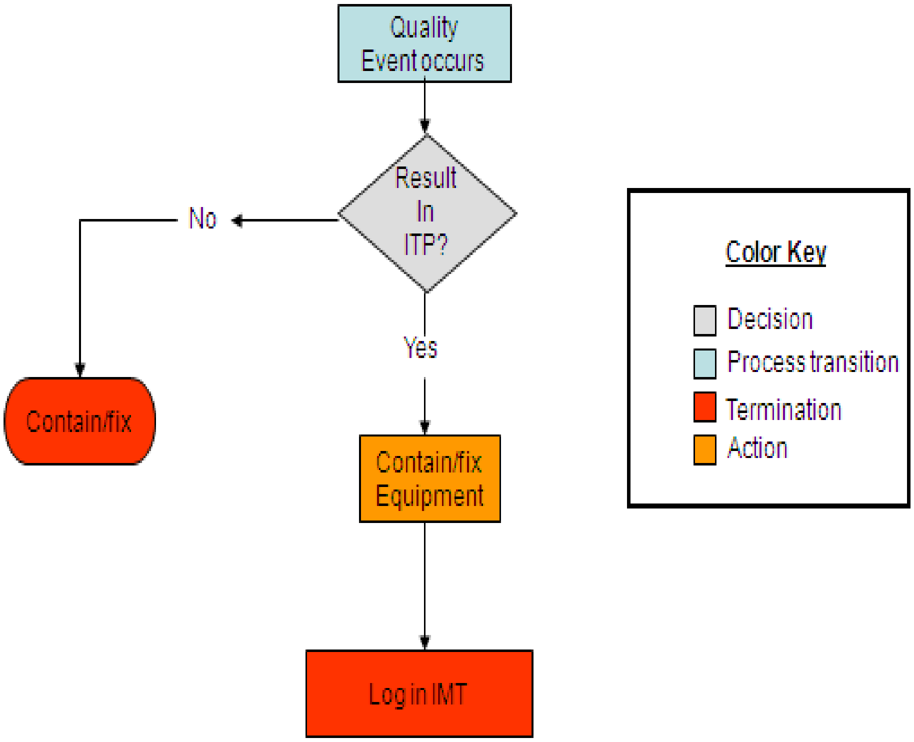


Figure 2.5. Status quo communication and response process flow chart

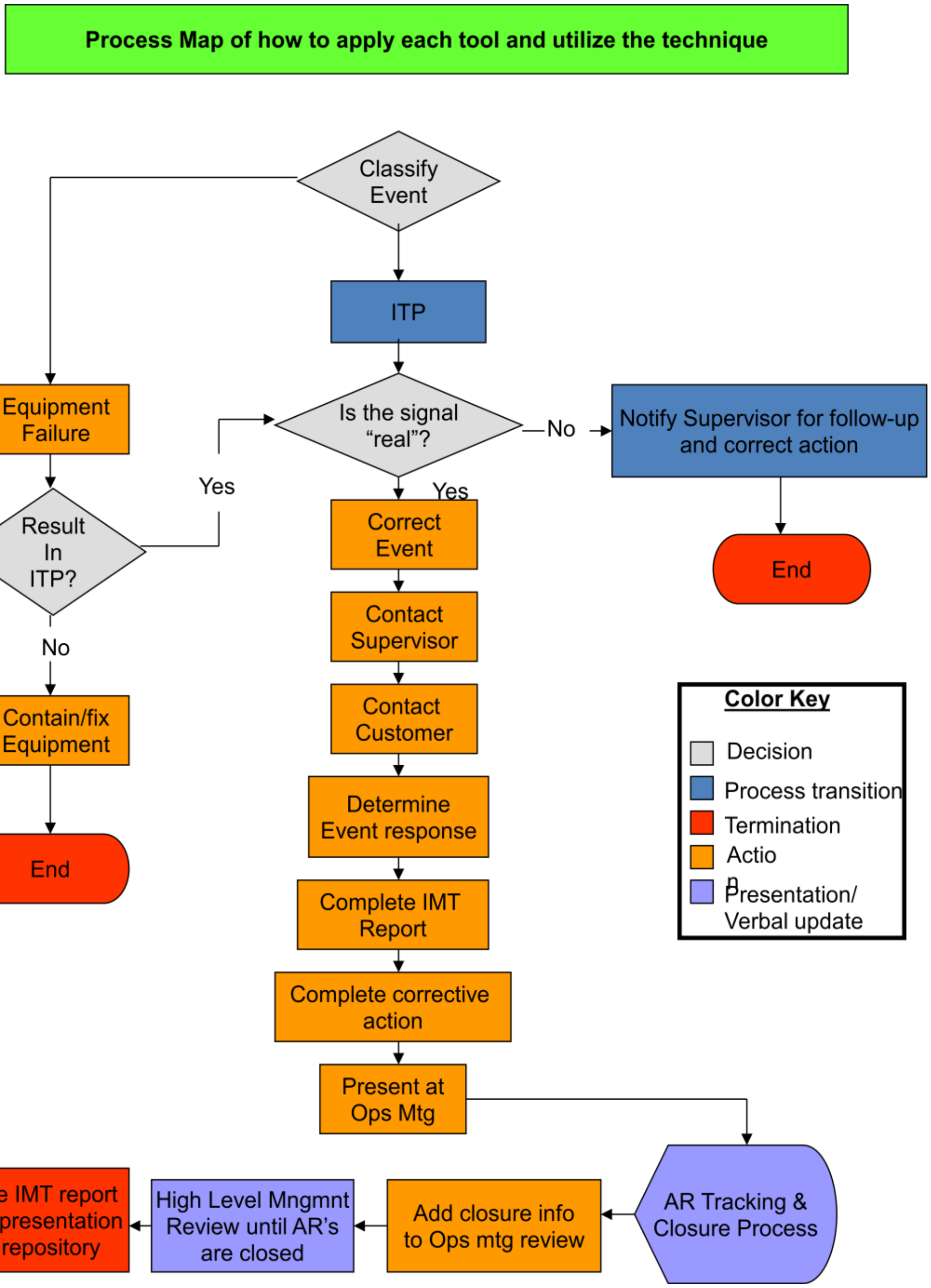


Figure 2.6. New communication and response process flow chart

Utilizing the Predictive Failure Method to Improve Maintenance Performance

Referring back to figure 2.1, which shows the reduced ITP incident rate for every quarter after 2008 (except for third-quarter 2010), it was found that something within the program changed in 2010. The author established his predictive failure program at the beginning of 2009 and continued it through successive years. The program change agent and stakeholders were awarded extrinsic rewards on multiple occasions for improved performance. So why would anything change?

It was only during the author/change agent’s absence in July of 2010 that the predictive failure program failed to sustain equipment availability improvement. The only change to the environment for the facilities organization was the change in leadership. The author/change agent was absent from the organization for eight weeks during the third quarter of 2010. All other aspects and variables remained constant.

The predictive failure program that had been in place for two years, and had successfully mitigated equipment corrective failure incidences, required all facilities technicians to participate in the data-driven method based on observation trending. Equipment content experts (trained and certified system technicians and engineers) participated by logging all unusual equipment observations during the scheduled rounds and readings program. Findings from the rounds and readings program were referred to as NM events. By establishing and understanding the initial conditions with the equipment versus NM observations, participants would trend the NM data to enable decisions on labor models, spare parts inventory quantities and capital and expense forecasts. By sharing equipment health trends transparently throughout the organization hierarchy, everyone had the opportunity to participate in problem solving and risk mitigation. For example, if a person buys a new vehicle and establishes a baseline understanding that the car does not leak fluids or operate outside of the manufactures recommended specifications, the owner can more effectively understand a problem if there is a quantified change in vehicle baseline performance. In the proactive failure model, the vehicle owner should take note if the vehicle begins to operate outside of the baseline conditions. If the vehicle were to suddenly operate at a different temperature or leak fluids, there is potential for the owner to have a proactive notice for scheduling a service event rather than waiting for an ITP incident - unscheduled break-down.

As illustrated in figure 2.1. this predictive method of rounds and readings for NM documentation and trending was found to be effective for two years. All facilities stakeholders were aware of the decreased ITPs, and it was thought that the organization had embraced the predicative method because of improved participation in performance results. However, when the change agent was removed, ITP incident frequency reverted to pre-change levels. This continued until the change-agent returned.

Upon return, the change-agent noticed that NM logging and trending participation had substantially decreased (figure 2.7).

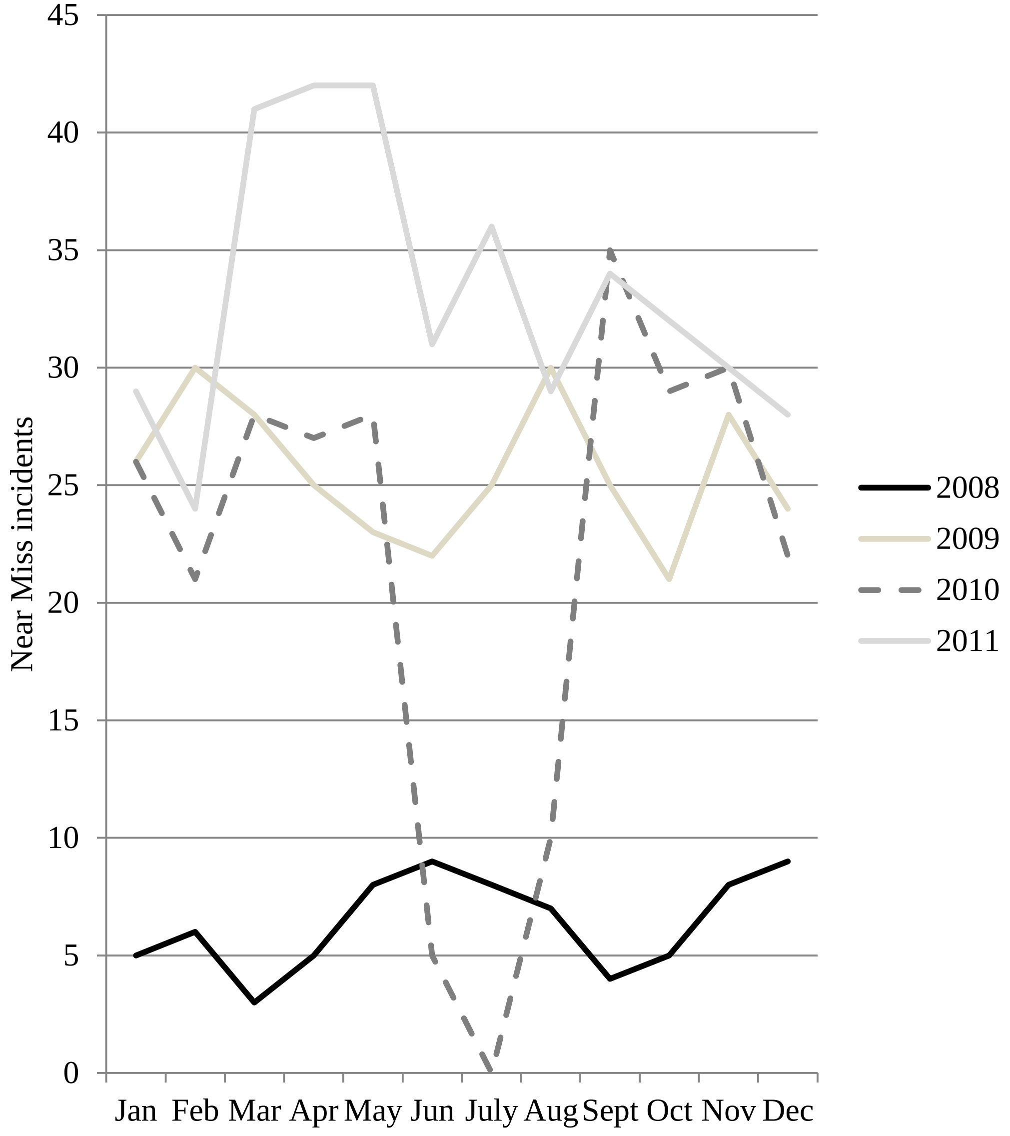


Figure 2.7. Near Miss (NM) incidents by year

With the correlation (dashed line in figure 2.7) of the lack of NM findings at the same time as the increased ITP volume in figure 2.1, the change-agent spoke to the organization about the need for the effective equipment performance trending review to identify equipment performance risks.

Within the successive four weeks, NM logging participation had returned to the levels of low ITP occurrences in 2009 and 2011. When the organization had stopped recording NM findings associated with equipment health, ITP incidents reverted to the highest increase in two years. It was not until the change agent returned that NM logging resumed and ITP incidents decreased to established improvement model levels.

Boundaries to Organizational Change

Ben Franklin was quoted as saying that there are only two things certain in life, “death and taxes.” It is understandable that Mr. Franklin may have forgotten to add the concept of “change” to his list. Change is a part of everyone’s life. Today’s rate of business change is gaining momentum as information technology continues to increase; creating a situation of heightened anxiety for organizations and stress on individuals.

Barriers to organizational change implementation are often referred to as sources of resistance to change. Stress caused by demands that are placed on individuals charged with enacting new behaviors might also serve as a barrier to change. In explaining why people experience stress, Schabracq and Cooper (1998) contend that individuals develop general automatic responses to work and life events. These responses enable them to meet recurring needs in set ways that permit them to evolve necessary skills, which provide a sense of control and a source of positive reinforcement. This way of functioning is described as being inherent in specific situations and as comprising a set of situated roles that reduce uncertainty in everyday interactions. When an organizational change is initiated, an individual's situated skills may become invalid. The more dramatic a change, the less effective people feel with established skills. As changes begin to aggregate, coping and adapting are likely to become more difficult resulting in anxiety. Different individuals have varying abilities to learn new roles. Stress is expected in the face of change as new skills and behaviors are required (Callan 1993).

Opposition to Change

Organizational change is generally considered to be a difficult and timely process due to the high level of energy required to achieve the essential planning, communication, and execution necessary for transition. Resistance to organizational change is inevitable since organization members are asked to reexamine and modify their behaviors. Resistance maintains the status quo until the reasons for change are both conscious and compelling. Instead of accepting people's feelings and seeking to understand the potential reasons for resistance, organization leadership often views resistance reasons as excuses. Management may persistently push for what needs to happen even in the face of today's harsh realities (Agocs 1997; Pamela 1997). One possible solution explored by the author in this study was to furnish fluency in the vision; allow all stakeholders to participate in planning, offer persistent support though indicator reviews, and provide an opportunity for multi-communication channels.

Why are people resistant to change?

A recent U.S. Census Bureau survey indicated that there has been phenomenal growth in information technology usage over the last few years. About 95 million Americans are currently using the information technology relevance activities, with most happening inside organizations (Robbins 2001). The result of forcing people to reevaluate their behavior and modify their daily work patterns to integrate technology clearly cultivated initial resistance (Robbins and Coulter 2002).

Self and Schraeder (2009) declared resistance to change to be “the most significant threat to the successful implementation of change initiatives.” Dent and Goldberg (1999), Gordon(1998), Baran (1986) and Coch and French (1948) pointed out **e**mployees resist change for several logical and very understandable reasons. Consistent with McGregor (1969), people resist change because of the implications to their jobs, careers, pay and self-esteem. Some resistance will remain underground while it is gathering strength. People talk - then a wall of resistance suddenly appears. It is far easier to move forward if the wall is not built at the beginning. A proactive effort to reduce change resistance can occur more readily if a communication strategy is carefully planned to account for the initial resistance (O’Connor 1993).

Planning the implementation strategy to account for resistance is an essential component of the change management process. Tichy and Ulrich (1984) stated that getting the change “written down and communicated is the easy part;

getting [it] implemented is the challenge." When significant levels of resistance are encountered, these forces often contribute directly to the demise of the change effort. The stakes are high in implementing change, as failed change efforts do not simply result in an organization's in-ability to improve, the organization usually returns to the previous status quo with little to no impact on the company's results. Failed change efforts are extremely costly because they not only absorb much time, resources, and money, but failure can also result in decreased employee loyalty, a weakened ability to achieve company goals, and other unexpected residual effects (Kinicki and Kreitner 2006).

Organizational Change Resistance Stems

Dent and Goldberg (1999), Gordon (1998), Baran (1986), Coch and French (1948), and Mealiea (1978) presented the following factors regarding uncertainty and threat:

- All change upsets the status quo and produces uncertainty.
- Consistent with McGregor's "Theory X" worker (2001), the most common finding with change resistance is that few things are potentially more unsettling and threatening than changing how employees are evaluated and rewarded. These feelings are strong and there are natural reactions to not knowing how one will be treated in a new program.
- Change is seen as a threat most often when it is imposed from the hierarchy above.

- A common problem with many change programs is that designers move too quickly without getting the appropriate understanding and support from program users.
- Many employees will be skeptical of new programs because prior programs promised more than they delivered or turned into bad experiences.
- Most people do not like surprises in their work environment. For the same reason, employees like programs and policies that are familiar. They like it when they know how they will be evaluated and what to expect in their pay.

Social researchers reviewed Dent and Goldberg (1999), Gordon (1998), Baran (1986), Coch and French (1948), Mealiea (1978), and McGregor (1969) and agreed that even if the existing program is far from perfect in delivering pay for performance to individuals or teams, many employees will prefer that system to risking the unknown.

Psychologist Lewin and Stephens (1994) developed a model for understanding the change process and the resistance that occurs. They argued that successful change in organizations should follow three steps:

- unfreezing the status quo
- change, movement to a new state
- refreezing the new change to make it permanent

The status quo can be considered to be an equilibrium state of balance. To move from this equilibrium, to overcome the pressures of both individual resistance and group conformity, unfreezing is necessary (Lewin and Stephens 1994; Lewis, Long, and Cummings 1981). The driving forces, which direct behavior away from the status quo, may need to be increased. The restraining forces, which hinder movement from the existing equilibrium, may need to be decreased. Clampitt and Downs (1993) noted that communications activities should coincide with the general stages of a planned change and the relevant information requirements. In the unfreezing stage, Clampitt and Downs (1993) argued that the primary communication objective of the unfreezing stage should be to prepare organizational participants for the change. This has been called "readying" the organization, and the research results are clear concerning the wisdom of such preparation. If the change is more than marginally incremental, it is likely that resistance will surface because old values and methods are implicitly challenged. Stone (1995) and Judson (1991) believed some resistance will remain underground while it is gathering strength.

In the change stage, normally there is a lot of organizational activity as plans are being implemented. Because most of the workforce is not directly involved with each change, and may not know exactly what is happening, there is a lot of uncertainty. As a consequence, rumors and resistance tend to emerge. The communications strategy during the changing stage should have three primary objectives (Baran 1986):

- The first is to provide those who initially are not directly involved with the change, with detailed and accurate information of what is happening.
- Second, those not currently involved should be aware of how they will become engaged in the future, how the change will affect them, their new roles and responsibilities.
- The third is to challenge whatever misinformation is circulating about the change.

The final stage, refreezing - the primary organizational objectives during this stage include building structures and processes that support the new ways. Do efficiencies result? These issues are especially important at this stage because people are getting firsthand experience with the personal impact of the change. This impact may not be consistent with management’s expectations or it may be perceived as negative. Puccinelli (1998) and Coch and French (1948) noted the information flow should be multidirectional, continuous and concrete so that people can become comfortable in the fact that they have a reasonable understanding of the personal implications of the change regardless of their attitudes toward the change itself.

The Hawthorne Effect

The term “Hawthorne Effect” is used to describe the effects of the physical working conditions on employee productivity (Oxford, 2001). The author’s findings on organization change resistance revealed the importance of the social dimension in a workplace. Given the same tools and pay, a different mental attitude could mean an increase in output of 20 or 30 percent (Roethlisberger 1939). The Hawthorne studies established that specifics like rest periods, length of work hours, supervisory and management training programs, counseling, vocational guidance, and personnel administration all affect the social dimension and potential productivity of an organization.

Understanding why the facilities organizational in this study chose not to participate with NM logging is a matter of worker performance. The improved ITP performance results were from feedback and reinforcement through learning. Prior to his absence the author/change agent believed workers had adopted the goal of bettering their past levels of ITP performance through their work with transparent performance information and shared decision making. The Hawthorne Effect established that when obstacles to improved performance are removed, performance can be expected to improve. The author/change agent witnessed validity with the Hawthorne Effect in that changing the media in which NM logging occurred was more impactful to productivity than any other aspect of the program change. The author was surprised to learn that it may not be necessary to provide extrinsic rewards for performance because it had no long term effect on the maintainability of the change. Extrinsic rewards were provided in the Hawthorne study and in the author’s predictive failure program. The author/change agent felt extrinsic rewards may actually be an organizational obstacle to improved performance.

Organizational Obstacles with NM Logging

The change agent utilized stakeholder surveys given consistently every six months throughout the course of the predictive failure program. The intent of the surveys was to seek understanding of the organizational acceptance for the predictive failure program. Averaged survey results are shown in table 2.1. The survey was administered anonymously every six months to all 40 facilities technicians. The results demonstrate high confidence that the facilities technicians accepted the program as an effective program with only slight score degradation in the area of how the NM incidents were logged. Most notably, not all 100 percent of the participants agreed that the use of personal computing devices to record NM events was more effective than recording by hand with pen and paper. The only change obstacle identified consistently was utilization of the PC, all other aspects of the predictive failure program remained constant.

Table 2.1: NM logging effectiveness survey results

NM Logging Effectiveness	1H 2009	2H 2009	1H 2010	2H 2010
Is NM logging an effective use of time to prevent ITP?	99%	100%	100%	100%
Is NM logging good use of time?	99%	100%	100%	100%
Are rounds and readings more effective with a tablet PC versus paper/pen?	95%	95%	100%	100%

With agreement feedback remaining at 100 percent during and after the 2H 2010 decrease in NM logging participation and increased ITP rate, the change agent/author began another survey with the same facilities technicians with the intent of better understanding whether the organizational obstacle was the method of logging NMs. The results in table 2.2 show 62 percent of the participants were generally dissatisfied with the predicative failure model and 38 percent were not comfortable with the new way of recording NM incidents; the organizational obstacle was established as the tablet PC usage.

Table 2.2: Survey of system effectiveness

Why does our quality slip when the manager is out?	2H 2010
Not comfortable with new data logging	31%
Don’t like the new system	27%
Don’t trust that the system works	4%
I’m following the system and have no issues	38%

Socio-Cultural Obstacles with Technology

The rise in computer use has facilitated a shift from cultures of passivity to cultures of participation; everyone is being offered the means to participate (Fischer 2011). The opportunity for increased participation through a new medium represents unique and fundamental challenges as people move away from a world in which a small number of people define rules and make decisions to one or more collaborations. Technology is driving a cultural shift in the world, one in which everyone has more opportunities to share findings and options through active participation. Organizational culture is described by McGuire and Rhodes (2009) as “emerging social beliefs that expand behaviors and learning, extending choices by creating new tools and meaning.”

Implied in the definition is the suggestion that organizational culture is a social element with ongoing interaction. This becomes significant in a technological context because it is people who frequently apply technology within an organization. Dawson (2010) concluded that organizations have distinctive social environments in their culture, generated from a collection of traits that creates a unique “personality.” The author/change agent noted that core concepts in psychology and sociology were applied to the organizational change model, and organization participation was grounded by assumptions regarding innovative technological developments, like the use of a PC versus pen and paper for capturing information. Consistent with Dawson’s (2010) noted behaviors for organizational cultures, participation is not dictated by technology, but rather by the result of changes in human behavior and the social organization. The use of technology as the primary mechanism to drive change is not sufficient by itself. A socio-technical environment requires a culture of active contributors engaged in the innovative design, adoption, and adaptation of the desired technology. McGregor (1969) and Dawson (2010) are aligned on the premise that a fundamental challenge for participation is to create an environment that not only technically enables the users’ participation, but also appeals to the individual’s assessment of value.

Dawson (2010) noted four cultures of participation to enable change:

1. Making changes must be seen as possible. Participants should not feel intimidated and should not have the impression that they are incapable of making changes.

2. Benefits must be perceived. The benefits perceived may vary, but there must be social benefit (community status) and personal benefit.
3. The environment must support the work people are engaged in. Change environments will not succeed if they are focused on activities that people do not value.
4. Low barriers must exist to allow for changes to be easily shared. Change growth will be accelerated when participants can share and collaborate.

Consistent with Dawson's (2010) and Fischer's (2002) notes, to be successful against the challenges of initiating change, a "loose fit" model should be projected. To gain better participation and attract other organization members, a few organization stakeholders should be utilized to generate the change content. Cultures of participation offer important and interesting opportunities to address the major problems in our societies and business organizations. Fischer (2002) points out that a culture of participation does not require every participant to contribute, but all participants must have opportunities to contribute when they want to. The key concept here is meeting the psychological need of the participant in order to satisfy the function of a social relationship between the leader and the needs of the follower consistent with McGregor's motivational theory (1966).

The author/change agent's predictive failure study strived to introduce the program through technical awareness of the program change conditions. This was done by making operating manuals and training sessions available and focusing on the physical aspects of the program change for rounds and readings. Management actively discussed the program change expectation of utilizing PCs for routine NM logging; the expectation was communicated as required by all. Unfortunately, demanding participation was not in-line with Fischer's (2002) findings to address the participant's psychological need. While participant training was prioritized, not enough attention was given to the psychological and social impacts of the organizational change.

Psychological considerations are those that cause people to alter the way they relate to, and feel about, what they are doing. Any change process will create doubts and questions in a person's mind. The severity of these doubts depends in part on the individual's personality and experience; however, it is likely that many of these questions can be predicted. Social considerations refer more to alterations in the individual's established relationships with others in the work group and with the organization as a whole; they should not be minimized or discounted.

Measuring the Resistance to Change

The common ground for psychologists and researchers (with regard to the organizational change previously discussed) is that individual attitudes toward change are a function of various factors such as predisposed feelings about change. The extent that change affects perceived personal security or insecurity, invokes emotion with effected cultural beliefs and norms consistent with McGregor (1966). Attitude is also impacted by the individual's degree of trust in management and work groups. Additionally, historical events relevant to the change significantly contribute to potential apprehensions. Finally, the manner in which change is introduced and implemented is the determining factor in the degree of resistance to such change.

The author accepted the evidence provided in the survey results (table 2.2) and realize that 62 percent of the organization's personnel did not value the new method despite the positive facilities performance improvement. Dr. Barbara Rogoff (2003), a behavioral psychologist, offered a developmental theory that participation is required for developmental learning. There is a correlation between the research and Rogoff's theory. Specifically, Rogoff's findings note that when people are engaged in a new learning experience for routine and tacit situations, the social relationship provides important insights that can foster collaboration for future participation. This is useful when considering effective and maintainable change approaches in an organization.

An essential element of the change agent's role in helping the organization learn new ways of performing routine tasks is to help people adapt through focused support on social relationships. Kinicki and Kreitner (2006) suggest that change managers should, at minimum, employ the following techniques to prepare employees for change (and thereby build commitment):

1. Provide as much information as possible to employees about the change.
2. Inform employees about reasons and rationale for the change.

3. Conduct meetings to address employees' questions regarding the change.
4. Provide feedback mechanisms so that employees have the opportunity to discuss how the proposed change might affect them.

Given all the forces involved in minimizing organizational resistance, change agents may only have significant impact on two components of the conditions: (a) the extent to which people may be apprehensive about the change and (b) the manner in which the change is introduced and implemented (Judson, 1992).

In order for a change agent to predict and potentially overcome negative reactions to change, Luecke (2003) provided some guidelines. Luecke and Galpin (1996) agree that the common way to reduce change resistance is through effective management of the psychology of change. Suggestions for handling four stages of negative reactions are:

- Handling the initial shock of the change. The change agent is advised to assist stakeholders in managing the stress of change and provide outlets so people can raise issues and provide feedback.
- Promoting "small group cohesion." An effective method used by the military to connect individuals with others undergoing the similar transitions. Employing this strategy can help to alleviate defensive feelings that generate resistance.

- For acknowledgement, acceptance, and adaptation, change agents need to focus on group dynamics within the stakeholder population, since people are “generally less concerned with the tasks they are given than on how they fit in with the group” (Luecke 2003).
- Having a priority of focusing on constructive and effective listening will go a long way in helping the change agent be supportive of all stakeholders involved in the change.

While simple in theory, these actions are typically neglected as the change agent may only be focused on the change results.

Energizers

Supporting energizing and motivational behavior from the stakeholder population is closely related to employee engagement since it represents the “psychological processes that cause the arousal, direction, and persistence of voluntary actions that are goal directed” (Kinicki and Kreitner 2006). The foundation of motivational theory is that people generally change what they care about (Hamel and Breen 2007). The change agent must consider the method and action to address how change programs impact others socially and psychologically. They need to do this in order to better understand what motivation exists for stakeholders to accept and implement the change with minimized resistance. The psychological process supporting motivation is critical for managers who aim to guide employees towards accomplishing organizational goals (Kinicki and Kreitner 2006).

Motivational theory is developed from social psychologists' researching management and leadership techniques, which effectively improve the workplace environment through positive stakeholder experiences. Early research in motivational theory focused on the need theories of motivation. Employees operate most effectively when their needs are satisfied (Williams 2005). Need theories address the "physiological or psychological deficiencies that arouse behavior" among individuals (Kinicki and Kreitner, 2006). Human needs vary depending upon the environment, time and place.

Social psychological pioneer Abraham Maslow built the framework for depicting the levels of human needs with his interpretation, *The Hierarchy of Needs*, published in 1943. Maslow suggested five basic human needs that govern motivational behavior: physiological, safety, love, self-esteem, and self-actualization (arranged according to increasing hierarchy in a pyramid style diagram). Maslow's hierarchy demonstrates a primary concept in graduated fulfillment. As a person's lower (more fundamental) needs are satisfied, an incremental set of needs are activated (Kinicki and Kreitner 2006). Maslow's theory provides valuable insight in change management strategy; it helps the change agent to understand how to motivate employees so that they may satisfy and predict their needs. Success at accomplishing human motivation means that managers should address “targeted benefits” that satisfy an employee’s specific needs (Kinicki and Kreitner 2006).

De-Energizers

A definition of the term “de-energizer” refers to the loss of an employee’s motivation to work (Dictionary of Human Resource Management 2001). De-Energizers may be enabled with behaviors like: poor timekeeping; failing performance; or a lack of due diligence and declining engagement with work tasks. De-Energizers may arise in an organization for any number of reasons; however, management action is often the source.

De-Energizers are people that consistently make motivational withdrawals from the energy of the organization’s progress toward change. As McGregor (1966) noted, some people, as a means of self-motivation, are just excited to work with their peers; people they engage with daily that have a positive set of beliefs. It can be assumed that most managers with motivated groups do have commonality in that they all avoid demotivating their teams. The findings from published organization consultant Paul Glen (2005) state that a team’s motivation grows organically; often out of the control of managers. Demotivation and dejection usually start at the top. Glen (2005) states that organizational motivation trends are relatively “fragile.” The underlying message is that a manager may not be able to create a motivated team, but he often has the power to kill whatever motivation manifests. Therefore, one of the best things a manager or change agent can do to support energizers is to make sure that they, themselves, are not de-energizing leaders.

The author/leader took one month to roll out the empirical information as a means of energizing the organization with positive communication on results. The intent was to highlight the perceived success with interpersonal relationships that enabled program change. This was accomplished through daily, one-hour meetings with the affected work group. The manager/change agent assumed that short-term results with the process change meant that everyone understood the obvious need and benefit for the modifications to status-quo routine, and organization buy-in had been achieved. It should be noted that the process was considered by managers at Company ABC to be a success as ITP events were reduced significantly. However, feedback from the affected stakeholder population showed that they felt the change in expectations over time was considered abnormal, in that it was “too much additional work, implemented too fast.” The social comfort to integrate the new system could have benefitted from the considerable research in the process of organizational change as suggested in the work of Lewin and his “unfreezing–moving–refreezing” model (Lewin and Gold 1948).

Lewin’s model focused on changing the behaviors of groups with actions initiated in phases over a substantial amount of time. Similarly, Kotter’s (1995, 1996) model has been synthesized into an eight-step process for leading organizational change:

- establishing a sense of urgency
- forming a guiding coalition
- creating a vision
- communicating that vision
- empowering individuals to act and removing obstacles
- creating short-term wins
- consolidating improvements and creating more change
- institutionalizing new approaches

Lewin (Lewin and Gold 1948), Schein (2004), and Kotter (1995, 1996) emphasized that the change process proceeds through phases, and requires significant time in order to transition the context and foster development. The clear message of a need for a consistent collaborative process to implement change over a significant period of time also reaffirms Rogoff's orientation that "intent participation" versus "assembly-line instruction" can be more effective at developmental learning (Rogoff 2003). For a change agent to elicit a sense of ownership and minimize de-energizing an organization, a quality relationship is required. Practicing psychologist and management consultant Eileen Berman (2003) states, "It takes time, it takes effort, it takes caring, it takes social sense, it takes interest." Change tends to create anxiety. The important thing to remember when making a change is to persist with it even though desired results may not emerge immediately. In order to minimize de-energizing the organization, change agents must begin by establishing sincerity within the organization.

People in the organization need to know (be shown) that the change agent is real in his/her conviction. Significant change of tacit knowledge takes time, persistence and consistency on the part of the change agent to bring about the desired behavior from the organization.

Phases in Implementing Change

Research on implementing change as a process has its roots in the early work of Lewin (1947). Lewin conceptualized change as progressing through successive phases called unfreezing, moving, and freezing. Building on this early work, Judson (1991), Kotter (1995), Galpin (1996), and Armenakis, Harris, and Feild (1999) described multi-phase models for change agents to follow in implementing changes.

The Judson (1991) model of implementing a change is comprised of five phases:

- analyzing and planning the change
- communicating the change
- gaining acceptance of new behaviors
- changing from the status quo to a desired state
- consolidating and institutionalizing the new state

Within each phase, Judson (1991) discusses predictable reactions to change and methods for minimizing resistance to change agent efforts. Among the different methods Judson (1991) discusses for overcoming resistance are alternative media, reward programs, and bargaining and persuasion.

In contrast to Judson’s (1991) five phases, Kotter (1995) recommended eight steps for change agents to follow in implementing fundamental changes in how an organization operates:

- establishing a sense of urgency by relating external environmental realities to real and potential crises and opportunities facing an organization
- forming a powerful coalition of individuals who embrace the need for change and who can rally others to support the effort
- creating a vision to accomplish the desired end-result
- communicating the vision through numerous communication channels
- empowering others to act on the vision by changing structures, systems, policies, and procedures in ways that will facilitate implementation
- planning for and creating short-term wins by publicizing success, thereby building momentum for continued change
- consolidating improvements and changing other structures, systems, procedures, and policies that aren’t consistent with the vision
- institutionalizing the new approaches by publicizing the connection between the change effort and organizational success

In a third attempt to offer guidance for successfully implementing change, Galpin (1996) proposed a model comprised of nine wedges that form a wheel. As a foundation for each wedge in the model, Galpin (1996) stressed the importance of understanding an organization’s culture as reflected in its rules and policies, customs and norms, ceremonies and events, and rewards and recognition. The Galpin wheel consists of the following wedges:

- establishing the need to change
- developing and disseminating a vision of a planned change
- diagnosing and analyzing the current situation
- generating recommendations
- detailing the recommendations
- pilot testing the recommendations
- preparing the recommendations for rollout
- rolling out the recommendations
- measuring, reinforcing, and refining the change

Chapter 3

Research methodology

Beginning in early 2009, the author initiated an effort to perform trend analysis on all ITP and NM downtime events. The IMT database was used to identify and track all these events. A quantitative research methodology was used with statistical regression and trend analysis on data from the IMT database to review ITP incident performance in the 2008 and 2009 timeframe, with experimental performance results applied in 2009.

This dissertation utilizes all NM incident data. The data was collected from equipment performance stakeholders, and captured in a database for the review of event frequency intervals and responses over the course of five years; 2007, 2008, 2009, 2010 and 2011. The tested performance results were implemented beginning January, 2009 and compared to the expected 98 percent goal for the world class standard for equipment availability (Singh 1991). The proposed predictive methodology suggested in this dissertation relies on the historic trend of data by category to identify equipment performance behavior that may indicate premature failure and unscheduled downtime in the future.

How the Tools and Methods were Implemented

This study documents the research experiment and testing performed to validate a significant equipment maintenance process improvement within the facilities organization at one of the semiconductor’s manufacturing sites. The suggested maintenance program data analysis provides greater potential for identifying equipment performance trends that could result in greater safety awareness, equipment cost of ownership savings, labor efficiency improvements, and bureaucracy reduction prospects to be utilized across multiple industries. The standard tools used to repeat this process included:

- Database logging tool needs to be identified – locally it was called “Incident Management Tracking” (IMT) for this study. Each user needed to understand and have access to the database. Users needed to be trained and shown how to perform a NM logging event.
- Defined role expectations on what incidents to log – each equipment performance stakeholder was required to provide NM input for equipment behavior findings whenever an incident occurred. All maintenance event findings were expected to be logged into the database in order to attain enough incident volume. This data was the foundation used to trend and assess historic equipment performance and enable expected performance prediction for hypothesis testing.
- User expectations documentation – the end result of the findings should be an obvious, at a glance assessment of the performance initial conditions. The users input for quantitative input, such as whether the equipment was leaking, squeaking or acting unusual from a measurable perspective, needed to be captured in a standard fashion to make analysis simple, repeatable, easy to validate and quick to illustrate.

The study and associated testing established a guideline method for stakeholder notification and general communication of equipment performance incidents. A verbal communication path was initiated to encourage awareness through discussion. There were two methods of verbal opportunity:

- Employee Dialogue Sessions (EDS)
- anonymous Management Feedback Tracking (MFT) surveys

Testing the hypothesis utilized a technique that followed these documented and well communicated guidelines through e-mail, morning operations meetings, field walk discussions, and employee manager one-on-one meetings. The data and tracking procedure utilized for the hypothesis testing during the experiment documented the roles of users and provided training and access to the data base, which gave a daily review of the previous 20-hour incident input and provided recognition for quality findings.

In summary, database information was collected real-time every day during the four-year period. The users were well practiced and compliance was re-enforced as an employee expectation during daily operations maintenance review meetings. The hypothesis testing objective focused on clearly communicating that the program was to provide more proactive failure rates through equipment behavior initial condition tracking of NM events - facilities equipment system downtime that manifests an interruption to production but incurs no product loss.

In the event an equipment downtime incident occurred, the expectation was that all incidents were captured in the database and reviewed, normalized (verified for accuracy with first person dialog) and summarized for management review at the operations meeting within 24 hours. After management review, all incident investigations and clarifications were tracked to ensure closure to any questions with the intent of sharing a clear, factual "lessons learned" example with similar business groups to mitigate future occurrences. Table 3.1 illustrates how each user group participated in the program.

Table 3.1. Employee participation roles

Review Forum Title	Owner	Media	Stored Location	Retention Period
Facility Incident Reports	Technician author	IMT database	Server location, IMT Tool	1 Year shared access; 3 years electronic media storage
Management Morning Operations Minutes / Closure Tracking	Morning Ops Chairperson	Electronic copies on meeting shared drive	Operations Documents shared section	1 Year
Incident Tracking Logs or Operations Indicator Rollup Logs	Facilities Management	Operations Webpage	IMT Tool Storage files in Admin. Office	1 Year shared access; 3 years electronic media storage.

The gap in the status quo data analysis process is that it only reviews and measures IMTs that have wafer scrap impacts. It is not expected, nor is it a regular practice, to review the non-scrap events. As noted earlier, there were 366

IMTs logged in 2008, and only 57 events involved scrap. Any trend in the remaining 309 IMTs was potentially lost because the information was not reviewed for predictive opportunity and learning. Because the business unit measures performance on the ability to reduce ITPs, the focus of an IMT trend review is not leveraged to reduce ITPs or improve efficiency, cost savings, et cetera. The intent of this research was to use all the pertinent information available to build a predictive preventative maintenance model.

Expected Participation by User Group

Whenever a downtime event occurred, the loss of equipment capacity resulted in a classification of one of four possible unscheduled downtime categories:

- ITP – known product scrap occurred as a result of the incident
- NM – no product scrap occurred as a result of the incident
- Out Of Specification (OOS) – unscheduled equipment taken off line due to operation outside of process specification limits
- Out Of Control (OOC) - unscheduled equipment taken off line due to operation outside of process control limits

The program study expected participating users to take action, based on their assessment of initial conditions, by documenting the event findings in one of the four categories. Once an incident of unscheduled downtime was identified, contained and documented, the user notified the on-shift maintenance group leader in order to begin the initial incident tracking. The group leader on shift at the time of notification documents the incident occurrence for review at the operations meeting the following day. This is done in order to understand the efforts to rectify the downtime event and to ensure the incident was documented in the database. The group leader does not change the information captured by the first responder; the group leader's role is to ensure the reporting process has been initiated and to note whether the incident is categorized consistently in the standardized format identified in the program guidelines. If the downtime incident does not fit the existing category assigned by the first responder, the group leader notifies factory production (representing the equipment downtime) and seeks to align containment strategies with production management awareness.

Containment of the incident is the first order of business. After getting the situation in control by mitigating all safety and quality risks, the first responder takes time to document the incident's initial conditions in a wireless enabled tablet computer connected to the IMT database. IMT incidents are reviewed each weekday morning at the group maintenance operations meeting with all on-shift users in attendance. During this meeting all clarifications and edits are captured to accurize or bolster information regarding the initial conditions in terms of context and technical details. After the morning meeting review, the IMT event is considered complete and no further edits are condoned with the intent of minimizing change.

If a more formal post mortem investigation is required for extensive clarification or understanding of complex findings, the group leader on shift contacts the first responder for the event in question and coordinates a meeting within 72 hours to ensure that as much detail as possible is identified. Equipment downtime incidents have visibility in every morning maintenance operations meeting. All incidents are tracked to ensure closure of questions regarding clarification.

Incident Tracking for Each Unscheduled Downtime Event

As soon as a piece of equipment experienced an unscheduled downtime event and the equipment was contained for all potential safety and quality risks, the initial conditions of the event were recorded in the IMT database. This recorded data was used as the primary information building block for development and tracking this research study. The data was used for comparison of pre and post program base lining of equipment reliability performance indicators.

For the purpose of this dissertation, the data was used to create success indicators and Pareto charts to raise visibility obvious to all stakeholders. Utilizing CMMS data to increase organizational inclusion for strategic decisions was found to bolster leadership principles like transparency and clear communication, which in turn assisted proper resource orientation and labor alignment. Developing and sharing CMMS data was clearly found to have significantly improved job performance indicators. In the study, the increased performance information flow expectation setting clarified working relationships.

Clarifying the IMT Investigation for Organizational Alignment

Every unscheduled downtime incident was expected to be closed within seven days, unless there were exceptions requiring additional investigation. In the four-year study, the maintenance group consistently executed this responsibility. The group leader was responsible for closing the incidents by insuring the documented clarifications were complete in the database and the information was accurate and ready for archiving. Incidents that could not be completed within seven days were expected to be closed in the IMT database tool within one-month. During the study, the longest duration for the few exceptional incident investigations was two weeks. Typically, additional time was due to the need for lagging data associated with the event, like product yield data. During the event investigation period, an “IMT AR (Action Required)” notification was tracked in the morning operations meeting for progress and expected closure updates.

Equipment incidents requiring IMT reports were only closed by the group leader on shift after all assigned ARs were completed. Responsibilities for each user were communicated in morning meetings as follows:

- Technician (first responder) documents and classifies all NM or ITP incident conditions based on the definitions previously described.
- First responder communicates incident to the on-shift group leader with as close to real-time response as safely possible.
- First responder documents the IMT report on the same shift the incident occurred.

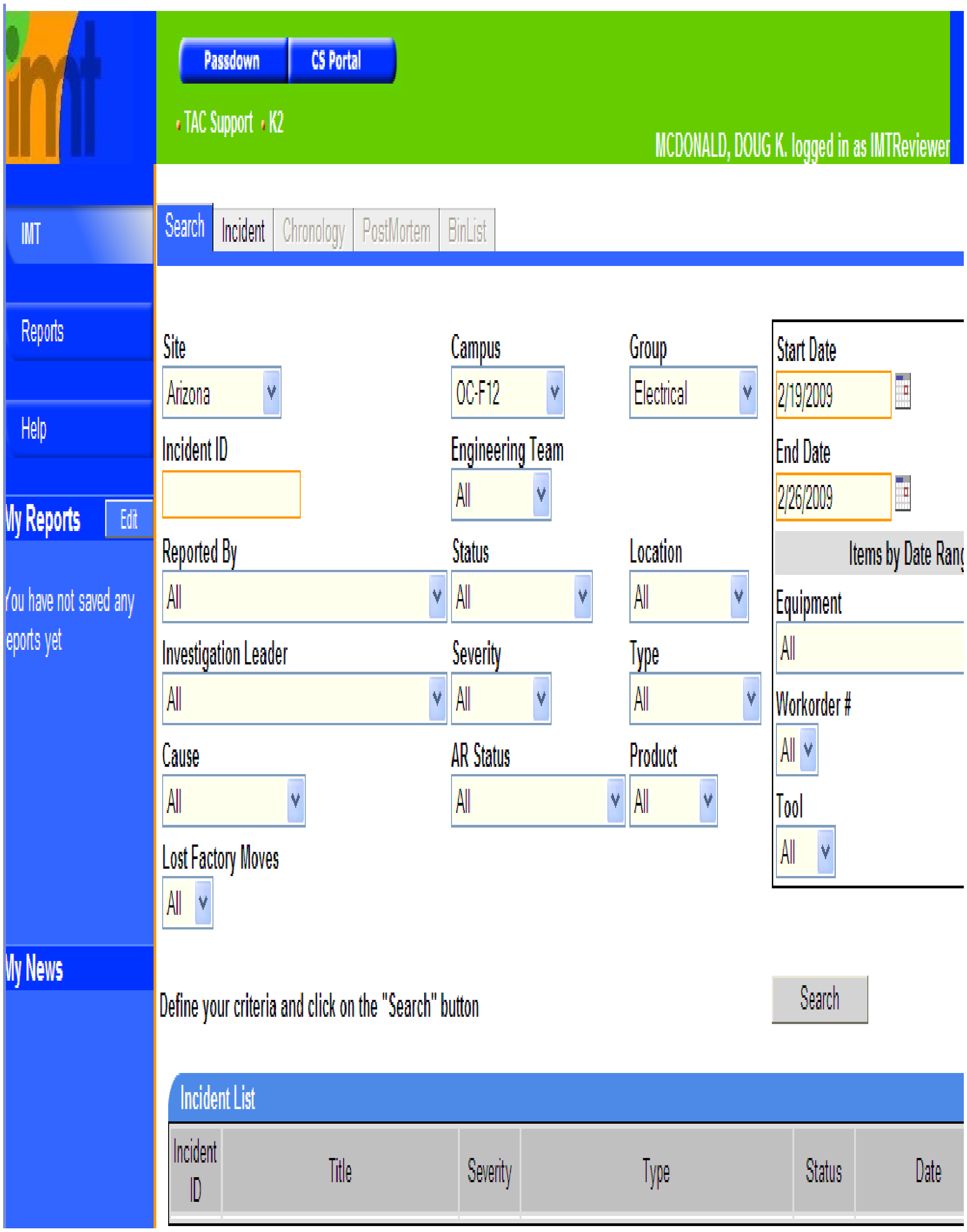
- First responder supports all investigation assignments for clarification with the report he/she originated.
- Group leader on shift notifies production management of ITP condition and all known associated impacts, risks to production and suggested next steps.
- Group leader presents new and updated incident reports at the morning operations meeting for effective cross shift organization communication.
- Group leader ensures investigation documents are managed so ARs are completed by the incident owner and archived in the database.
- Group leader completes management review of equipment behavior for trending signals based on IMT incident reports and ensures completeness of reports.
- Group leader ensures IMTs are closed within seven days of event occurrence.
- Group leader reviews historic IMT incident data for correlation and corrective action that may assist with predictive issues on upcoming associated maintenance work orders.
- Group leader actively promotes stakeholder participation with investigation closure and “lessons learned” that will be shared with similar business groups - with the intent to mitigate issues for these groups.

Equipment Engineering Responsibilities were summarized as follows:

- Engineering supports and reviews all new IMT incident reports for content accuracy and corrective actions as requested within 20 hours of inception.
- Engineering leads and actively participates in all incident investigations.
- Engineering presents equipment performance trending at various meetings (morning operations meeting, fab ops meeting if required) on frequency equal to at least monthly occurrence.
- Engineering reviews system and specific equipment incident data trends with statistical models that may identify probability for repetitive and predictable equipment behavior.

Expectations for Event Reporting

Figure 3.1 illustrates the database interface used by the first responder to capture all downtime incidents' initial conditions. The intent of documenting all of this information is to provide the foundational data supporting evaluation of equipment performance over time: the SEVERITY (NM or ITP), the OCCURRENCE (frequency), and the DETECTION CAPABILITY (group leader post mortem corrective actions). All facilities equipment maintenance stakeholders have access to this interface and are expected to actively participate in documenting each downtime incident's initial condition. Understanding that technicians are the primary users for responding and documenting equipment events into the IMT tool every time an incident occurred is a core premise. Figure 3.1 illustrates a screen shot of the actual IMT event form used by maintenance personnel during this study.



MCDONALD, DOUG K. logged in as IMTReviewer

You have not saved any
eports yet

Site: Arizona
Campus: OC-F12
Group: Electrical
Start Date: 2/19/2009
End Date: 2/26/2009
Incident ID:
Engineering Team: All
Items by Date Rang
Reported By: All
Status: All
Location: All
Equipment: All
Investigation Leader: All
Severity: All
Type: All
Workorder #: All
Cause: All
AR Status: All
Product: All
Tool: All
Lost Factory Moves: All

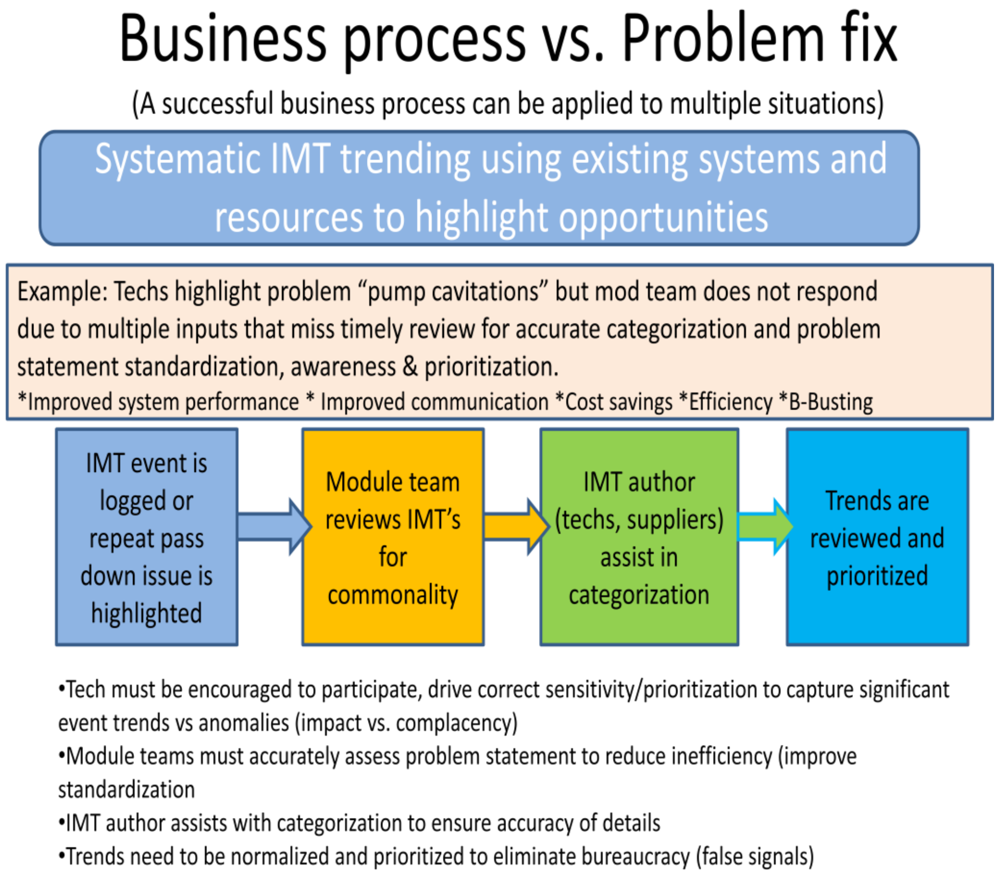
Define your criteria and click on the "Search" button

Incident List

Incident ID	Title	Severity	Type	Status	Date

Figure 3.1. Event database input interface

Figure 3.2 illustrates the process flow of how the event response works from an overview perspective.



Business process vs. Problem fix

(A successful business process can be applied to multiple situations)

Systematic IMT trending using existing systems and resources to highlight opportunities

Example: Techs highlight problem "pump cavitations" but mod team does not respond due to multiple inputs that miss timely review for accurate categorization and problem statement standardization, awareness & prioritization.
*Improved system performance * Improved communication *Cost savings *Efficiency *B-Busting

•Tech must be encouraged to participate, drive correct sensitivity/prioritization to capture significant event trends vs anomalies (impact vs. complacency)
•Module teams must accurately assess problem statement to reduce inefficiency (improve standardization
•IMT author assists with categorization to ensure accuracy of details
•Trends need to be normalized and prioritized to eliminate bureaucracy (false signals)

Figure 3.2. Tested predictive methodology documentation flow

Utilization of Computer-based Maintenance Management Systems (CMMS)

Understanding reference and comparison for "management" and "leadership" during the study is important. The organization used in this study had an adverse relationship with previous management regimes. Organization personnel referred to those individuals as "micromanagers" that consistently attempted to control all practices of the maintenance organization. Understanding this negative orientation, the author sought to pursue a “leadership” style strategy for aligning people and resources in a manner that would more positively maximize the ability of the existing content experts to use their skills and create more collaborative workplace solutions.

When managers take the time to develop simple CMMS data indicators, organizational leadership begins to increase - awareness and communication of common tasks are better understood. Analyzing and sharing simple information such as (a) the number of maintenance tasks performed, (b) the average time spent on scheduled and unscheduled maintenance, and (c) the maintenance activities that were most prevalent provides critical insight on business and organizational health.

The status quo organizational philosophy in the studied organization at Company ABC was referred to as “managing by objective.” This term seeks to align a specific goal or commitment to a much larger business division; expecting the individual to strive for a strategic goal or mission. For a better understanding of the maintenance business operations, it is paramount for managers, who are intent on leadership, to include the organization in timely and current information. Future leaders need the organization’s constructive expertise and feedback. By aligning the correct resources to actively review trends and equipment performance information, decisions are reduced and solutions become more obvious to every stakeholder. Minimum communication is required because the charts and data are presented in an obvious format.

Helping all levels of the organization understand the strategic direction through transparency of shared information results in less emotion (especially negative emotion), which could adversely impact working relationships and business performance. In this effort, managers spend an appropriate amount of time developing performance data and seeking input from maintenance content experts. Managers need enhanced interpretation of available data. This hypothesis was examined through a case study in the semiconductor industry, wherein the maintenance department of the facilities management group of Company ABC adopted leadership principles and implemented a CMMS data review with all levels of the organization. This case study showed increased efficiency and buy-in versus when management previously made organizational decisions with incomplete data.

Figure 3.3 illustrates a polynomial of year over year normalized IMT event comparisons from the CMMS data for an “at a glance” reference to the decreasing number of events over time.

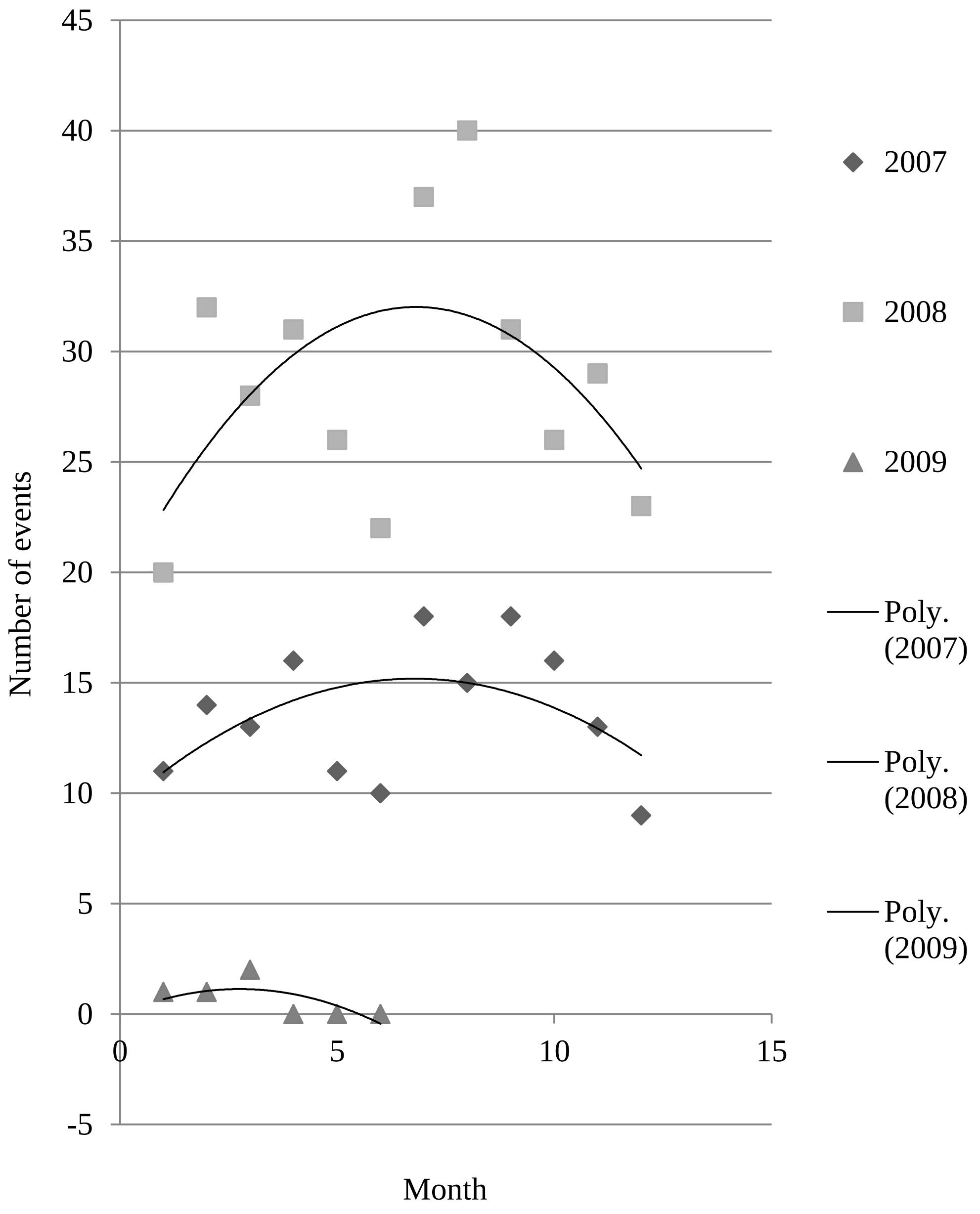


Figure 3.3. CMMS ITP incident comparison year over year

Figure 3.4 shows the trend in availability improvement year over year by the same organization during the four year testing program, supporting data driven incident tracking and review that enabled leadership predictive failure analysis. The diamonds indicate the actual average availability percentage for each year; the line represents the polynomial of all points during the test.

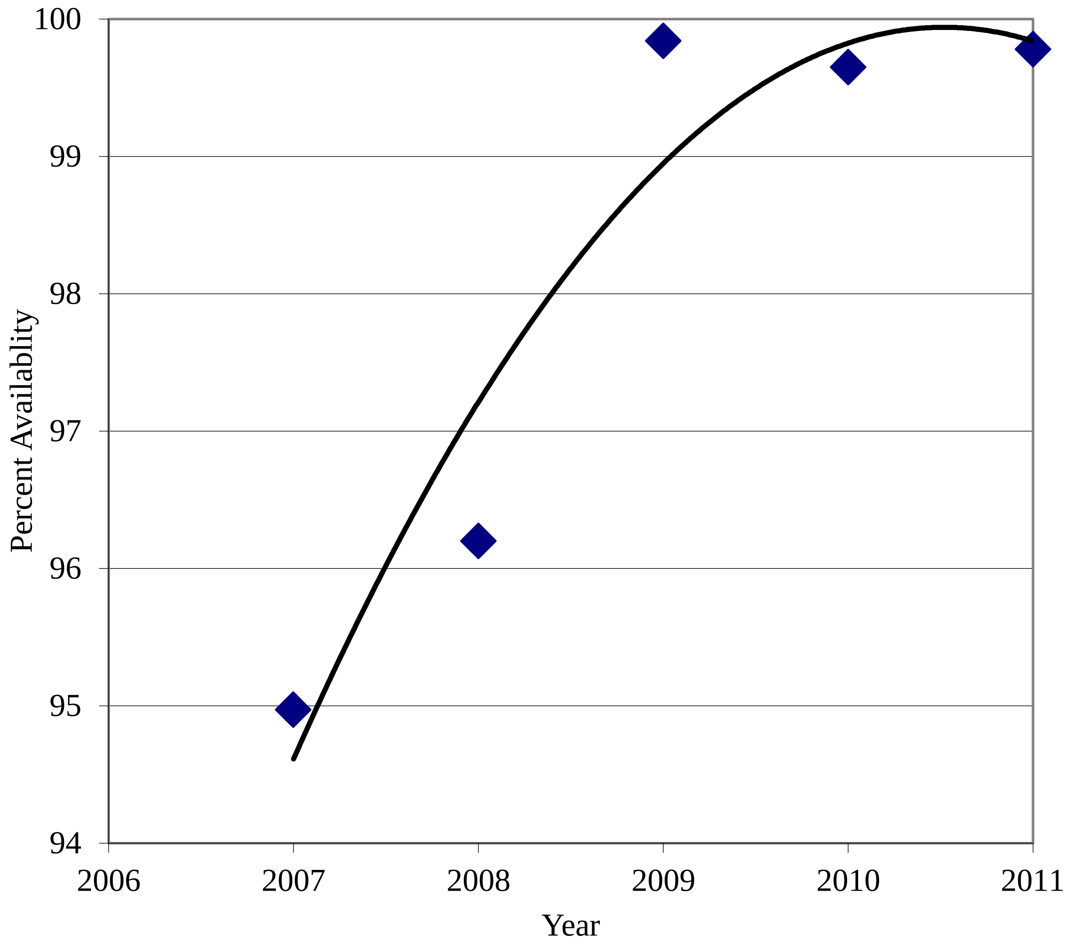


Figure 3.4. Equipment availability trend by year

The CMMS contribution was integral to the testing program as the IMT database was filled with more than 300 technician incident reports per year, from 2009 through 2011. All event incidents were categorized and incorporated to generate equipment availability performance trends. There is a high degree of certainty that all incidents were captured. Data integrity was met based on job expectations as defined in the program’s roles and responsibilities, as well as in the consistent organization collaborative review with the engineers and group leaders every 24 hours. User job expectations during this timeframe required maintenance technicians, group leaders, and engineers to actively input clearly defined and standardized equipment incident reports into the IMT database. Figure 3.5 illustrates the characteristics of reporting incident activity over the four years of program implementation testing and study.

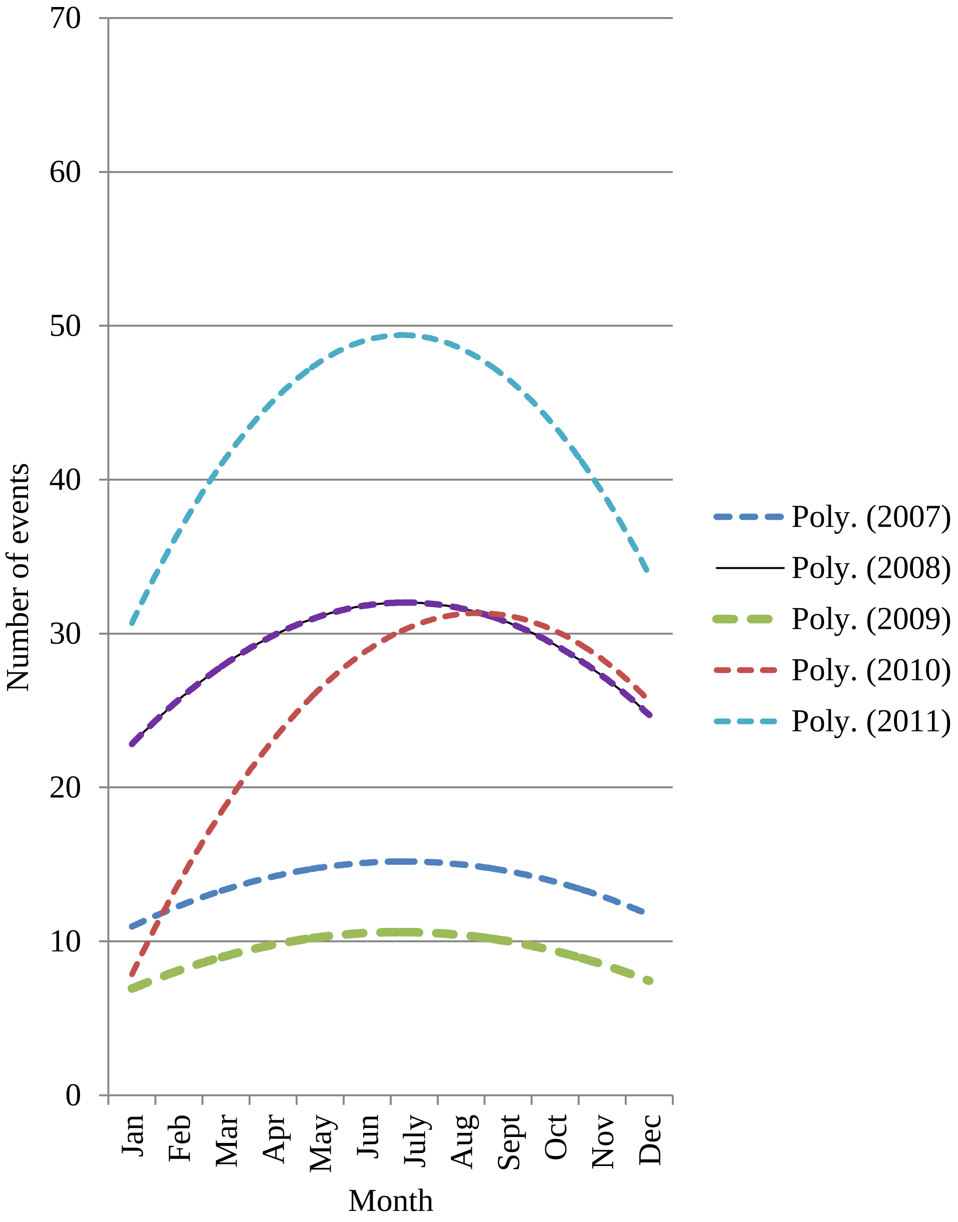
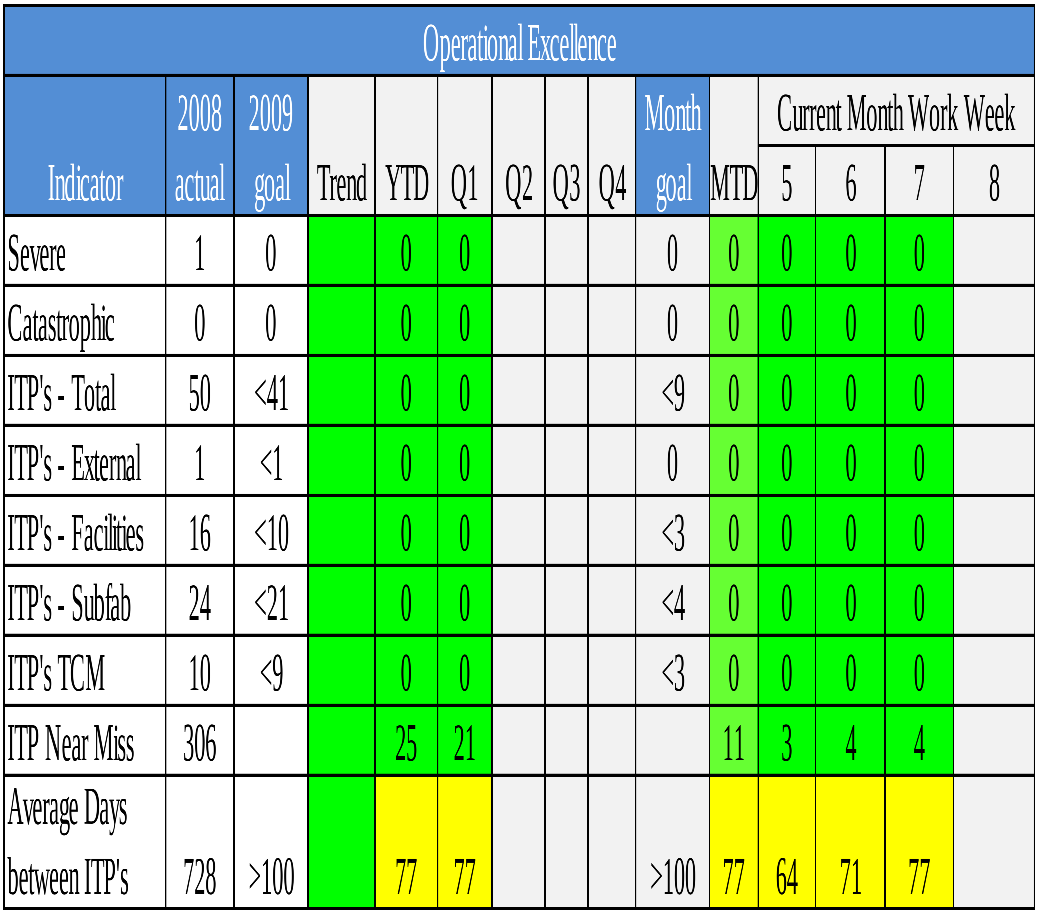


Figure 3.5. IMT incident volume year over year

As illustrated in figure 3.5, the data collection interface was instrumental in establishing core raw data input, which shows usage volume by year. The CMMS access made analysis and hypothesis testing possible. The data collection method in the proposed program required equipment technician personnel to complete an IMT report any time an unscheduled incident occurred. The template for the report was simple to use with a check box to signify major incident facts, like whether or not product was scrapped as a result of the unscheduled downtime.

Keeping in perspective that the status quo equipment health assessment program used by Company ABC only reviewed and measured unscheduled events that had wafer scrap impact, it was not expected, nor was it a regular practice to review, the non-scrap events. In 2008 there were 366 IMTs logged; only 57 involved scrap. Any trend or equipment performance information in the remaining 309 IMTs was not effectively utilized for equipment health learning. The entire information set was not reviewed for predictive opportunity and learning. Because the business unit measured performance on the ability to reduce ITPs, the focus of an unscheduled incident trend review was not leveraged to its full potential for reducing all unscheduled events and improving efficiency, cost savings and labor resourcing.

The status quo process of only reviewing equipment scrap events provided a reduced level of performance for predictive analysis since all available dominant information for unscheduled, non scrap incidents was selectively filtered. As seen in figure 3.6, an indicator tracker was utilized in the status quo review process of scrap events. By only reviewing scrap event data in the IMT database on a quarterly basis, stakeholders were blind to the reality of the full context of equipment behavior.



Operational Excellence

Indicator	2008 actual	2009 goal	Trend	YTD	Q1	Q2	Q3	Q4	Month goal	MTD	Current Month Work Week			
											5	6	7	8
Severe	1	0	🟩	0	0				0	0	0	0	0	
Catastrophic	0	0	🟩	0	0				0	0	0	0	0	
ITP's - Total	50	<41	🟩	0	0				<9	0	0	0	0	
ITP's - External	1	<1	🟩	0	0				0	0	0	0	0	
ITP's - Facilities	16	<10	🟩	0	0				<3	0	0	0	0	
ITP's - Subfab	24	<21	🟩	0	0				<4	0	0	0	0	
ITP's TCM	10	<9	🟩	0	0				<3	0	0	0	0	
ITP Near Miss	306		🟩	25	21					11	3	4	4	
Average Days between ITP's	728	>100	🟩	77	77				>100	77	64	71	77	

Figure 3.6. Status quo operations dashboard

Opportunity for Measurable Improvement

The intent of this research study was to perform trend analysis on all unscheduled equipment downtime events, both ITP and NM incidents combined. Analyzing all available performance data exposed significant equipment behavior trends and provided greater insight for an improved business process opportunity that was not visible by viewing only ITP events. The improved data analysis process provided greater ability to identify trends that drove proactive failure analysis resulting in cost savings, efficiency improvements and bureaucracy reduction prospects.

Measurement of NM volume was incorporated with the existing operational dashboard indicator package (figure 3.6). With consistent IMT logging compliance for all unscheduled downtime incidents, the data just needed to be analyzed and presented as the true reality of factual equipment health. With significant increase in available data, the measurement process was improved for “at-a-glance” trend analysis. There was a greater resolution by category of incident and magnitude of occurrence. Figure 3.7 utilizes all unscheduled downtime data by tool type category.

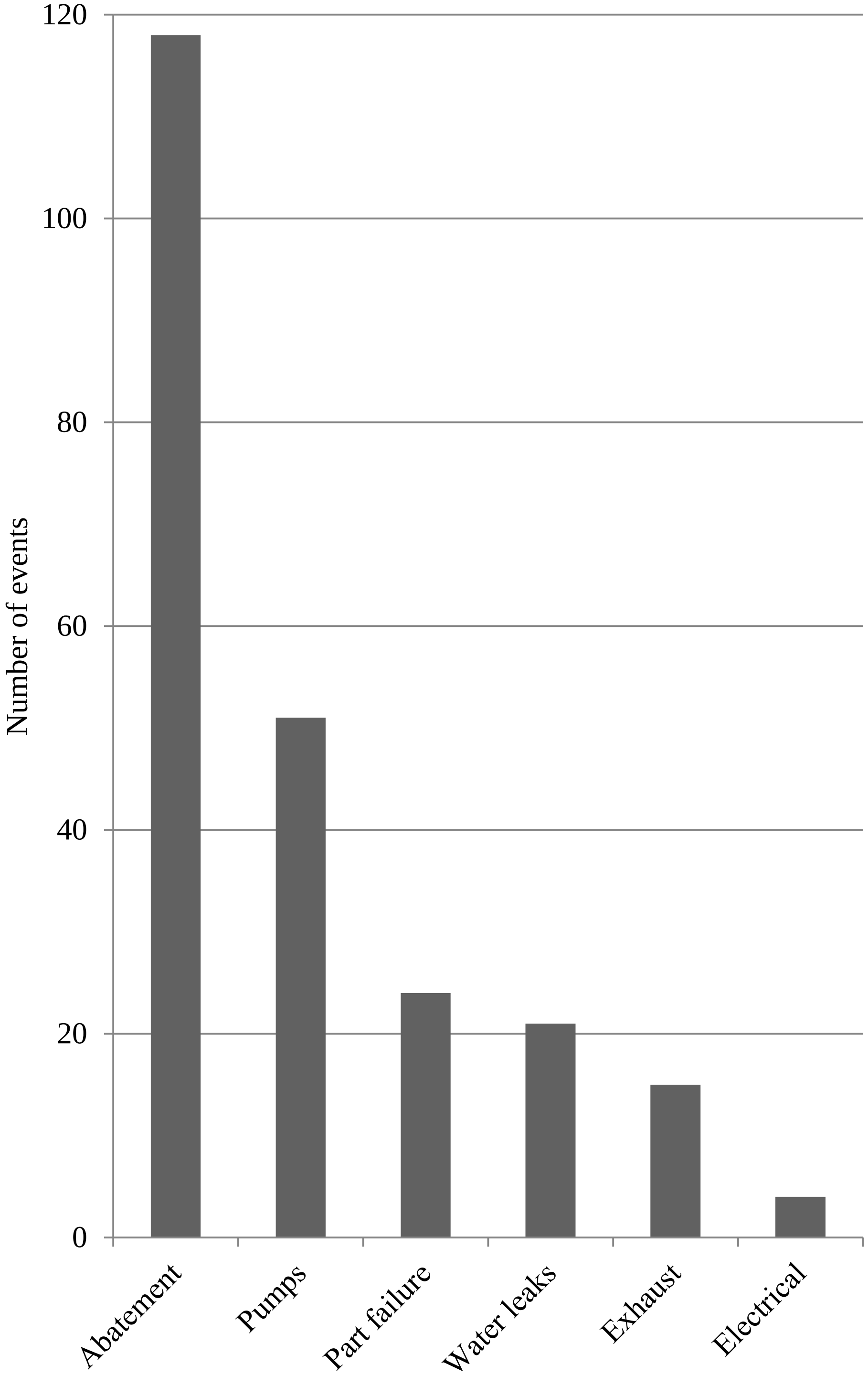


Figure 3.7. All unscheduled downtime incident data by tool type over time

Upon generating the initial information of downtime by tool type, the data was analyzed once more to determine if a possible signal in the particular time or equipment subsets would demonstrate a different performance orientation or insight on the situation. The technician first responder population encountered a break-through during one of the monthly feedback meetings that was held to gain input on possible improvements. At this meeting, a technician commented on second level downtime by tool data; he suggested that premature pump failures were part of the unscheduled production equipment downtime. Having the IMT database information readily available, stakeholders were able to examine this observation and investigate the cause effect of pump downtime.

With further analysis, the technician's hypothesis on premature pump failure was validated by the volume of IMTs for premature pump failures compared to all other attributes for downtime. Pursuing the technician's observation allowed other engineering stakeholders at the meeting to see that the number of pump rebuilds associated with the premature failure causal was approximately 50 pumps per year. Understanding that 50 pump rebuilds equated to $289,000 of unnecessary spending, the toolset engineers were able to work with the pump supplier to investigate root causes and solution implementation. Additionally, there were labor, downtime, and chemistry expenses not quantified in the $289,000 savings that made the finding even more valuable.

In this example alone, the new program for identifying equipment health - utilizing all available and dominant downtime information - greatly improved the reduction of downtime events for premature pump failures. By resolving the premature pump failure issue, the associated cost savings due to reduced incidents yielded a conservative value of wafer scrap revenue savings that was applied to the before and after ITP reduction results. Figure 3.8 illustrates the production revenue savings of at least $3.3 million.

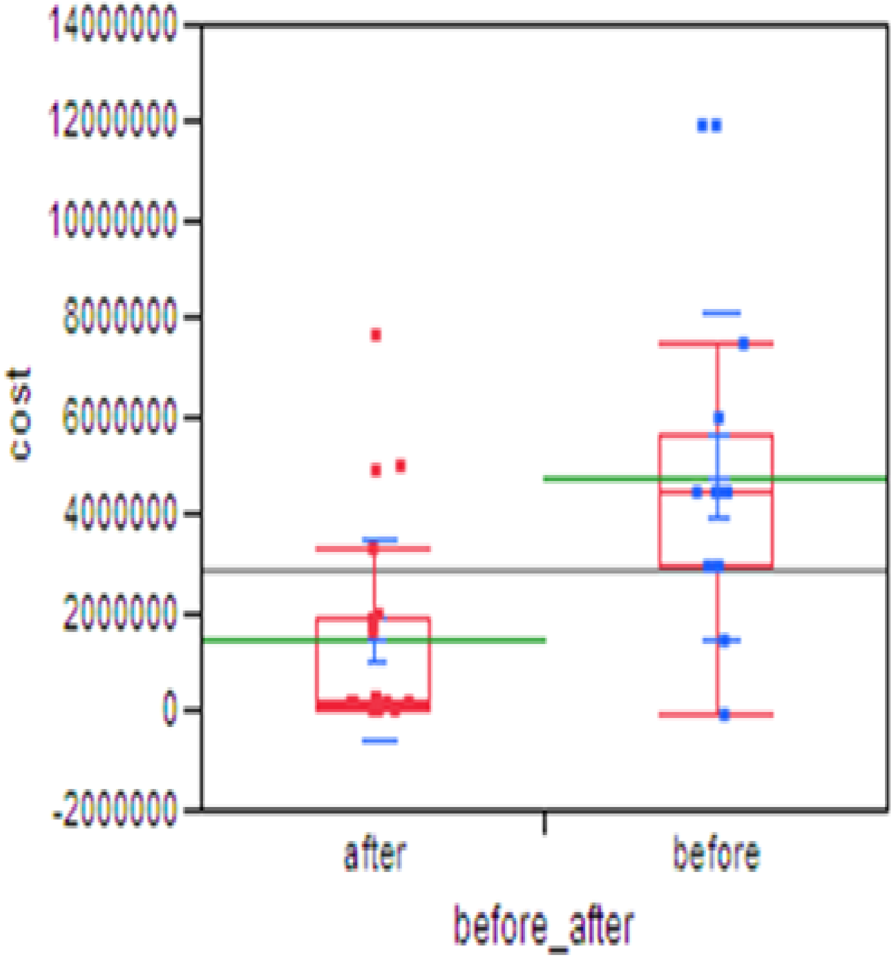


Figure 3.8. Premature pump failure mitigation cost savings results

By analytically reviewing all dominant information captured as pump IMT events over the successive year, the solution for premature pump failures was validated; the signal did not occur as a failure causal (figure 3.8). It is reasonable to suggest that reviewing all incident data offers a high probability of predictability and insight for proactive failure awareness.

As illustrated in figure 3.9, the new level of performance in 2011 compared to the status quo in 2008 suggests the hypothesis is validated based on the significant reduction in unscheduled downtime events through forecasted event management.

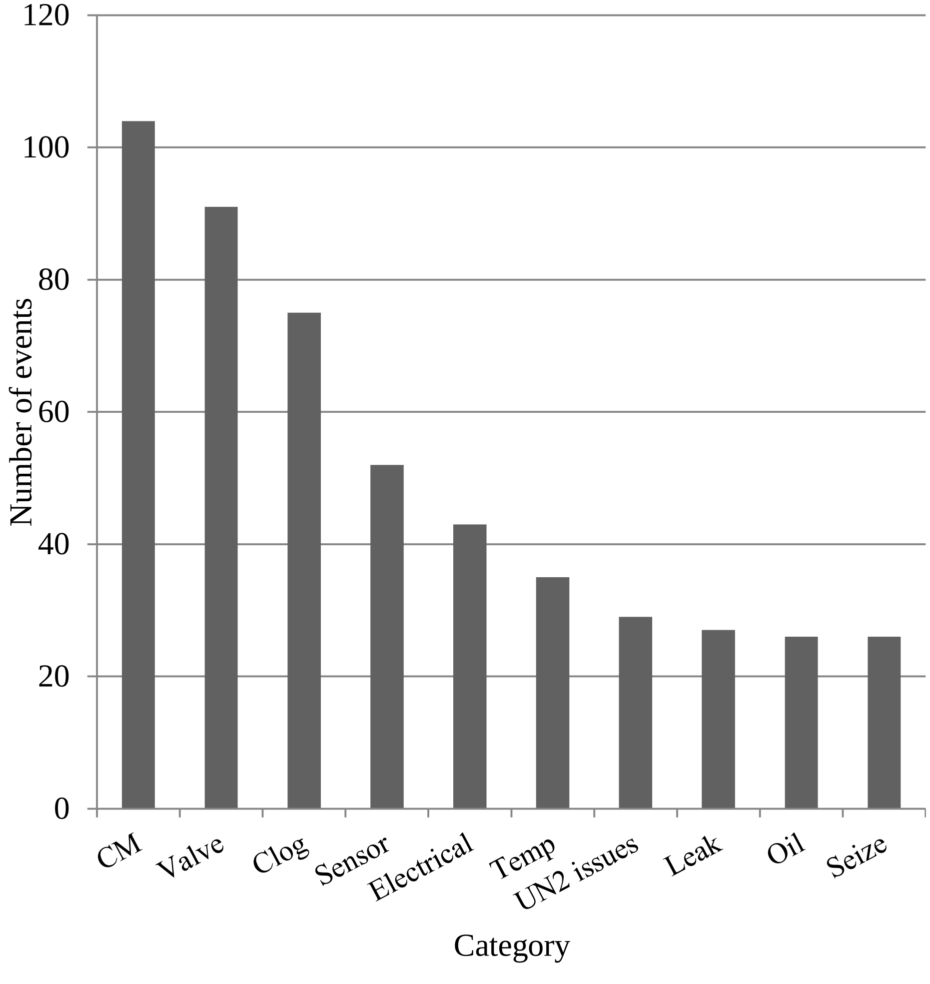


Figure 3.9. Pareto of IMT incident modes for pump faults

Figure 3.10 clearly demonstrates the campaign for unscheduled downtime reduction through predicative NM logging. By raising stakeholder visibility on obvious equipment health information, a key performance improvement was developed. Year over year volume of ITP events is captured in table 3.2. Keeping in perspective that during 2007 and 2008, ITP incident volume was in the 25 range, notice the improvement post second half of 2008 (post hypothesis testing). During this timeframe, the author began an organizational campaign to utilize all dominant unscheduled downtime data as a predictive instrument for future equipment performance issues.

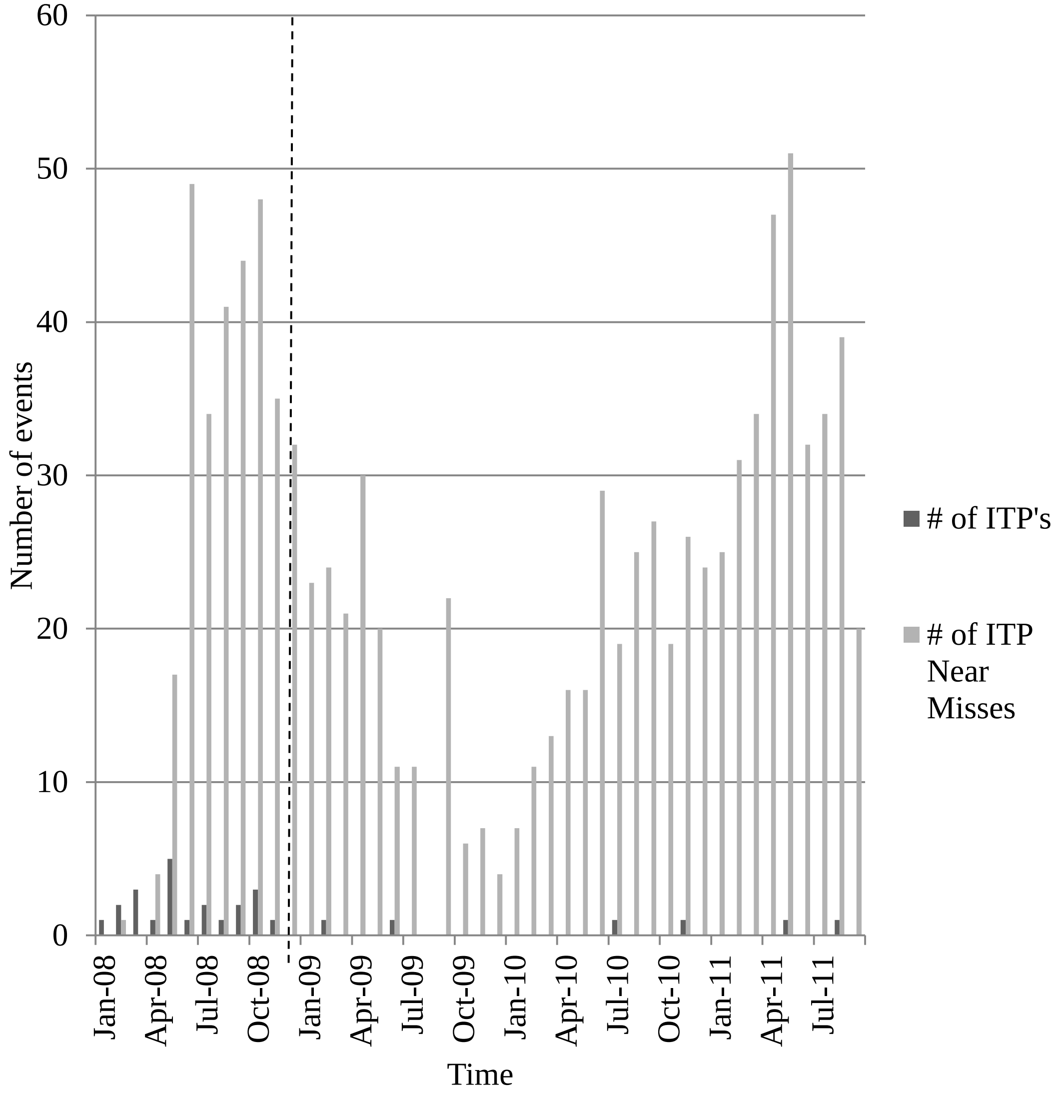


Figure 3.10. 2008 through 2011 NM and ITP comparison pre and post hypothesis testing

Table 3.2. Volume of ITP events year over year

Year	2007	2008	2009	2010	2011
ITP’s	23	25	2	2	2

The dashed vertical line through figure 3.10 reveals the time when enough specific NM data was available to begin a high volume analysis (by category) of equipment behavior findings. Figure 3.10 clearly shows that the ITP frequency of occurrence and magnitude or volume of occurrence was reduced almost immediately after the January 2009 timeframe when equipment performance data became available.

Figure 3.10 provides another interesting observation - the significant decrease in NM logging during the second half of 2009. It was during this time that the author, the program leader and facilities manager for the affected organization, took a sabbatical. The 14 week sabbatical from August 2009 through most of November 2009 was the only program change to the expectation that NM logging and event analysis occurred within the organization. Given that the volume of NM logging resumed shortly after the program leader returned from sabbatical, and has not dropped off to that magnitude or duration again, the leading hypothesis is that NM logging is not sustainable in the absence of leadership accountability.

Organizational Change in the Absence of the Leader

The purpose of this section of the research methodology is to explain the processes utilized to identify findings (associated with NM logging) that provided organizational change agents and managers guidance when they addressed individual resistance to organizational change. The methodology approach focused on exploring individual stakeholder resistance to organizational change within the confines of 60 facilities people at company ABC. With the intent of maintaining effective business results, due to the NM logging process change, the findings provided guidance for organizational change agents and managers to understand and deal with stakeholders’ resistance to change.

Research cited in this dissertation’s literature review examined the cognitive, affective, and behavioral aspects of individual resistance, and how that resistance is influenced by:

- individual predispositions towards openness and resistance to change
- individuals’ considerations of threats and benefits of change
- communication, understanding, participation, trust in management, and management styles
- the nature of relationships with the change agents.

According to Drucker (1995), organizations are now encountering a different environment. This era is shaped by fast change, high technology and adaptability of entities. The fast change process may include many opportunities for organizations to maximize their profits, while at the same time the process generates risks that may drive the organization out of business.

In order to survive, 21st century organizations realize they need to innovate, and this process should be continuous (Drucker 1995). Today’s organizations also need to understand that information has the power to drive businesses; that “information has strategic value” (Drucker 1995) as a resource, in addition to the classical resources of money, material and people. Organizational change is a difficult but inevitable process (Davenport 1993, Drucker 1995, Hammer 1993).

The challenge with change implementation in Company ABC was that the lifecycle of its manufactured products continued to shorten. The organizations at Company ABC were under constant pressure to introduce new product offerings; therefore, for this research, knowledge and technology were the main drivers for implementing change.

The Research Methodology Selected

The “Action Research Model” (figure 3.11) was selected as the method testing program for this dissertation. The model was one of the first theoretical frameworks used to understand relationships between diagnosis, feedback and organizational change. This model was initially developed by researchers interested in studying and solving problems in groups and organizations at the close of World War II (Smither, Houston, McIntire 1997).

This research methodology sought to determine solutions to real problems in the facilities industry by collaborating with stakeholders to collect data, feed the data back, and develop action plans for change. The change agent fed outcome information to organizational members and promoted participation on a daily basis. The experimental changes and iterations made within the organization were measurable and repeatable.

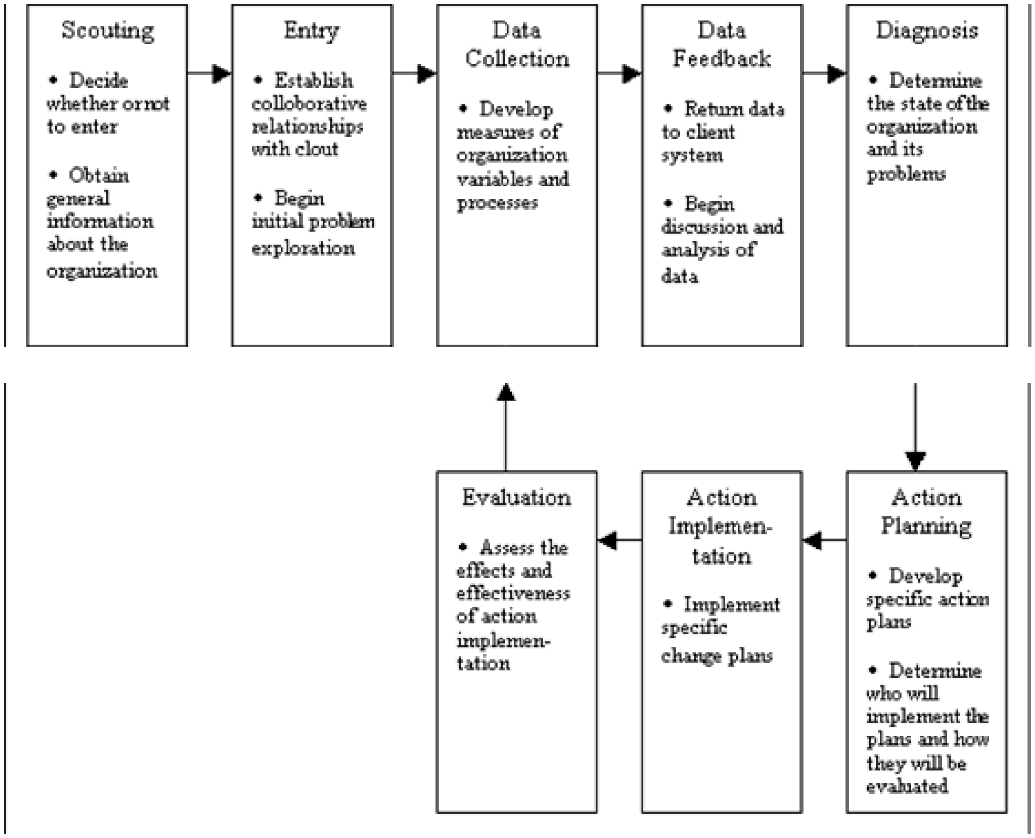


Figure 3.11: Action research change model (Smither, Houston, Mcintire, 1997)

Research Methodology Design Steps

The planned change model developed by Frohman, Saskin and Kavangh has eight action research phases that apply to the organizational change process (figure 3.11).

- Scouting Phase: Initial description of the organization is developed. In this case general information about the organization was collected and the organizational change agent made a decision whether or not to enter the proposed change initiative. The change agent openly discussed the theoretical orientations of ITP reduction so the affected organization stakeholders had an opportunity to understand the intended values, assumptions and biases.

- Entry Phase: The change agent clearly identified problems found with the maintenance organization’s behavioral response to change, and clearly documented the relationship of the facility technician group.
- Data Collection Phase: With the support of organizational members, the change agent illustrated detailed information - direct and recent successes from the previous two years. This detailed information included specific successful ITP reduction processes directly resulting from NM process changes that practitioners had worked to document and collect.
- Data Feedback Phase: After data collection, outcomes were shared with practitioners, via daily meetings and e-mails, in order to begin collaborative problem solving. Practitioners began to understand the organizational need for change. In addition, they received highlights of the positive impact of previous attempts.
- Diagnosis Phase: Both the change agent and NM logging practitioners worked together to interpret the meaning of the data and identify problems and opportunities for improvement.
- Action Planning Phase: The change agent led practitioners in iterative meeting discussions to develop specific strategies for change with the expressed intent to improve ITP reduction.

- Action Implementation Phase: The change agent worked collaboratively with the facility technician practitioners to ensure the change strategy was properly implemented. Problem solving and monitoring processes were instituted with dialog and feedback occurring every 24 hours in operations meetings.
- Evaluation Phase: The change agent and practitioners evaluated data outcomes of change processes daily to determine the success of the various program change attempts. This data was used as a guide for the next process change implementation.

Process Change Improvement and Innovation

Davenport (1993) defines the difference between process reengineering and process innovation as, “Reengineering is only part of what is necessary in a radical change of process; it refers specifically to the design of the new process. The term process innovation encompasses the activity and the implementation of the change in all its complex technological, human and organizational dimensions.”

The change agent and technician practitioners classified the methodology processes tested by their value chain target and process structure as follows:

- Core processes – Company ABC manufactures a variety of products with a varying complexity of support needs, examples include: (a) proficiency of technical ability across a range of equipment sets, (b) awareness of production technology idiosyncrasies; and (c) the need for increased automation and around the clock support every day of the year. These variables were considered as primary activities in the value chain of performance improvement.

- Support processes - frequency of interaction with internal customers for effective communication of system ownership associated with facilities downtime was critical. Effectively supporting activities to demonstrate model based problem solving and mitigation of repeat equipment failures was considered a core attribute in the change process.
- Business network processes – participation and learning encouragement to extend practitioner education beyond the boundaries of the tactic knowledge with organizational status quo was identified as a core function for maintaining collection of the required NM data that proved to be effective for predicting and mitigating ITPs.

Principles of Practice

To encourage participation, the principles of practice for ITP reduction were communicated (internally at all levels) to production line customers, suppliers and facilities system shareholders. As methodologies for ITP reduction were tested and measured, one of the critical success factors, communicated from the outset and throughout all the stages of methodology testing to ensure transition awareness, was principles of practice.

The first process method to enable sustained change performance was transitioning from the status quo of technician practitioners' logging a NM manually with pen and paper to automation - inputting the information in personal computers. The idea was developed as the change agent actively listened to feedback in daily operations meetings. Technicians would cite that NM loggings had been misplaced, and logging was creating ergonomic risk due to the volume of incidents being recorded. Tablet personal computers (PCs) were purchased and distributed to every practitioner for NM logging. Figure 3.12 illustrates the NM logging change process sequence thus far.

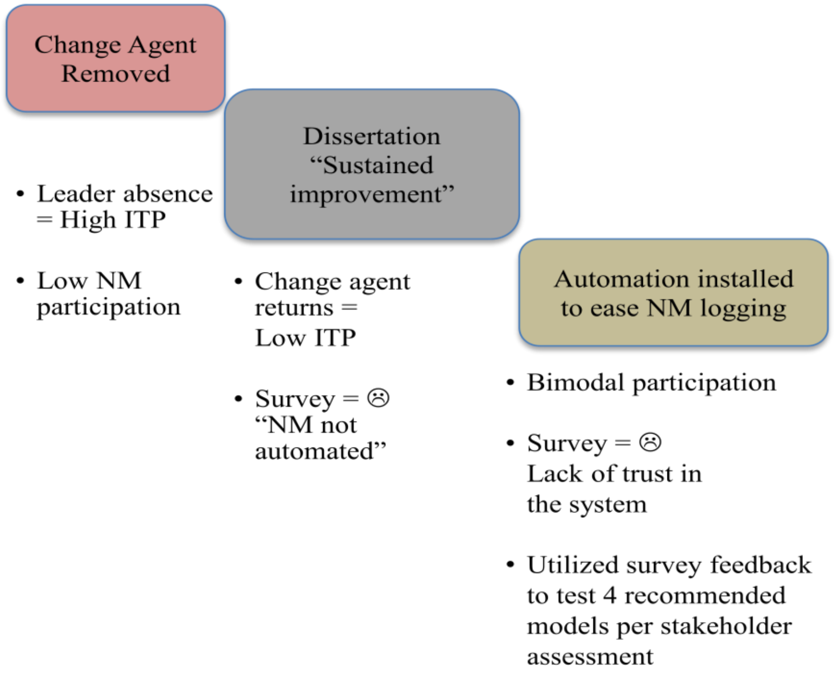


Figure 3.12: Method change for iteration number one

While automating NM logging was identified as a potential breakthrough for practitioners during daily review meetings, the results had only iterative improvement. Participation in NM logging improved, but the results indicated a bi-modal participation rate. With the intent to generate greater participation from the entire practitioner population, as well as encourage more effective methods, the change agent continued to follow the action research change model (figure 3.11) and to evaluate the data during daily meetings.

A second process change method to be tested was developed through participant dialogue that addressed the need of removing ambiguity, which would improve efficiency for the users. The recommended solution was to break away from the status quo of every user logging NM for every type of facilities equipment as illustrated in figure 3.13.

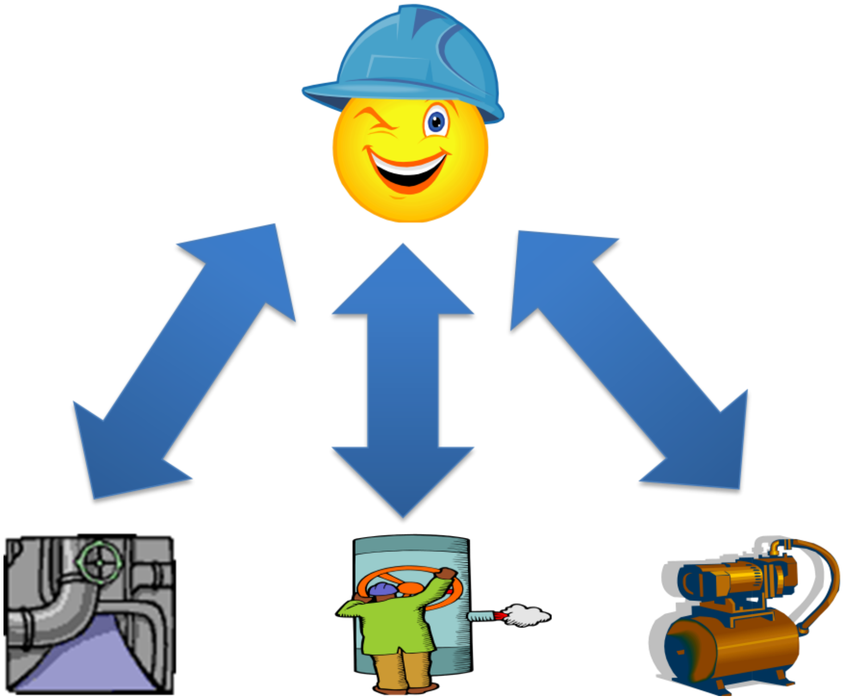


Figure 3.13. Status quo NM logging – every practitioner documents all equipment

Through daily communication meetings within the technician population, it was found that certain practitioners had a preference for developing their technical expertise on specific equipment types. The change agent agreed to adopt this method as the second process ownership adjustment to be measured for participation improvement; this method was referred to as “equipment dedication,” since technicians were dedicated to log NM incidents based on equipment type (shown in figure 3.14).

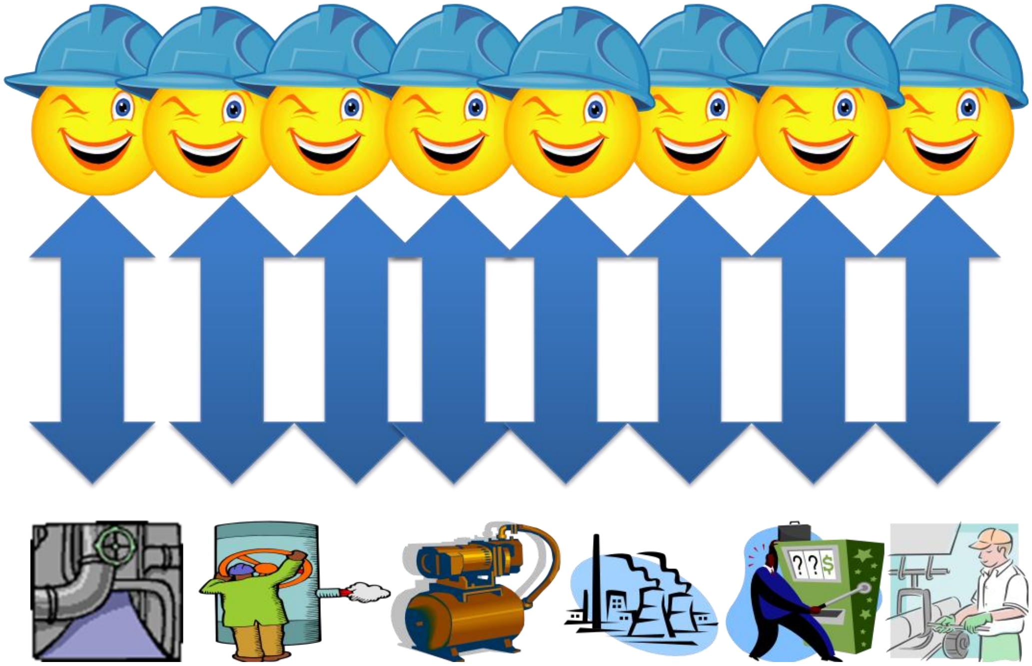


Figure 3.14. Change method process two – dedicated NM logging by equipment type

Practitioner dedication was found to have limitations associated with technician availability. Since there were ten different equipment types to monitor on every shift, if a technician was not at work (sick, vacation, etc.), NM logging would not occur for every equipment type. With the intent to generate greater participation from the entire practitioner population, the change agent continued to follow the action research change model (figure 3.11). Data was evaluated during daily meetings to encourage discovery of more effective methods.

Through the daily meetings, certain practitioners revealed that they had a preference for developing their technical expertise on specific product manufacturing equipment types. The change agent agreed to adopt this method as the third process ownership adjustment to be measured for participation improvement (figure 3.15). This method was referred to as “process dedication.” Since there were only three process types, technicians were dedicated with a greater sense of being without a job compared to equipment dedication.

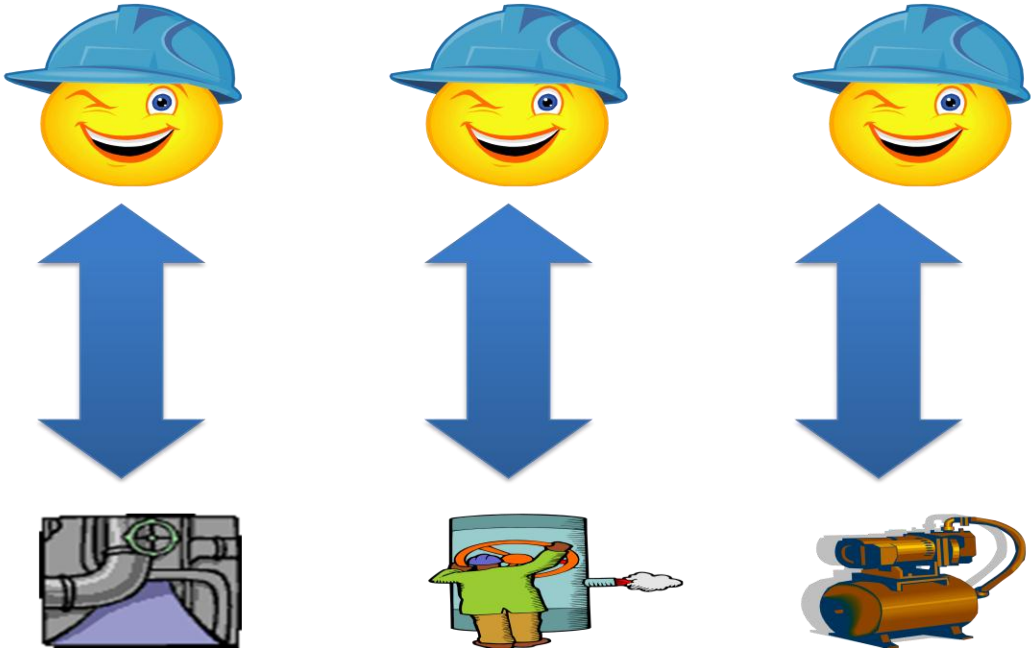


Figure 3.15. Change method process three – dedicated NM logging by process type

Practitioner dedication by process type was found to have limitations associated with scope alignment. Work allocation associated with each process was to found to be non-linear, resulting in a waste of technician utilization. Because consistent participation in NM logging had not improved to a sustainable level, and with the intent to generate greater participation from the entire practitioner population, the change agent continued to follow the action research change model (figure 3.11) and evaluate data during daily meetings.

It was also found, through daily meetings, that practitioners were open to NM logging by geography across the various shifts worked. The change agent agreed to adopt this method as the fourth process ownership adjustment to be measured for participation improvement. This method, illustrated in figure 3.16, was referred to as “shift dedication.”

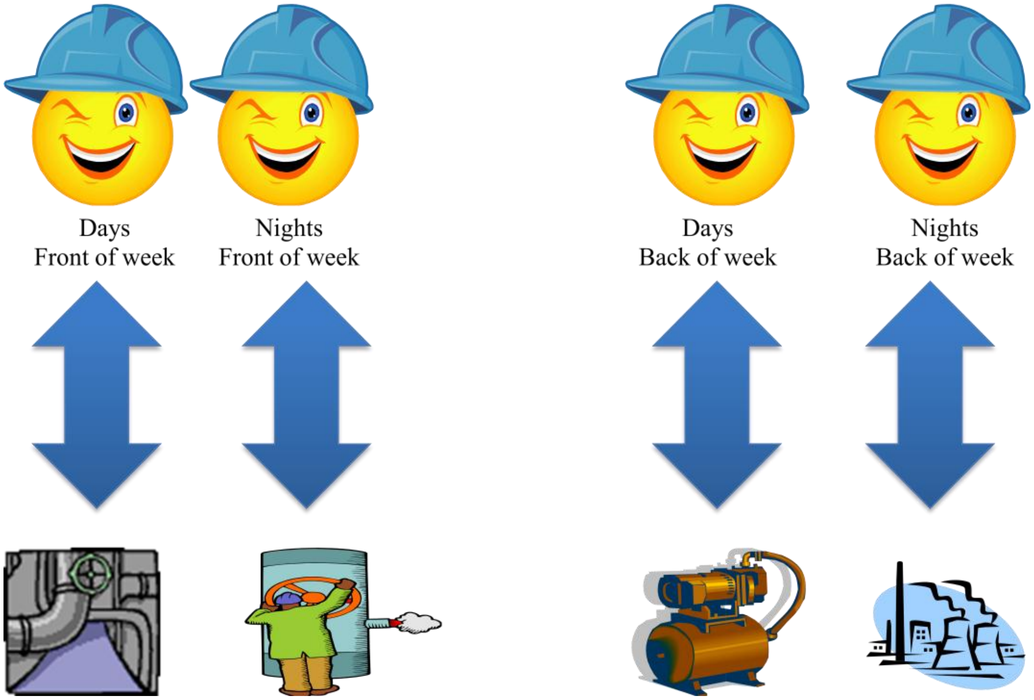


Figure 3.16. Change method process four – dedicated NM logging by shift

Practitioner dedication by shift type was found to have limitations associated with continued participant dissatisfaction. With the intent to generate greater participation from the entire practitioner population, and because consistent participation in NM logging had not improved to a sustainable level, the change agent continued to follow the action research change model (figure

3.11) and evaluated data during daily meetings. Practitioners also were encouraged to discover more effective methods.

It was also found, through the daily meetings, that practitioners were establishing a “resignation” attitude with no initiative for new ideas that might promote participation needed to maintain NM logging at an effective level. The change agent appealed to practitioners through conversations, classes and associated research. As a result, practitioners began to examine and implement a fifth methodology, based on findings associated with change enablers. Research on organization change in a typical population suggests that only 16 percent embrace innovation and the early adoption of change. In his 1962 book, the *Diffusion of Innovations*, Everett Rogers stated that adopters of any new innovation or idea could be categorized on a classic bell-shaped curve with the following descriptions:

- Innovators (2.5 percent) - educated, multiple information sources, greater propensity to take risk
- Early Adopters (13.5 percent) - social leaders, popular, educated
- Early Majority (34 percent) - deliberate, many informal social contacts
- Late Majority (34 percent) - skeptical, traditional, lower socio-economic status
- Laggards (16 percent) - neighbors and friends are main information sources, fear of debt

Figure 3.17 illustrates Rogers' research findings associated with a typical population's categorization of change readiness.

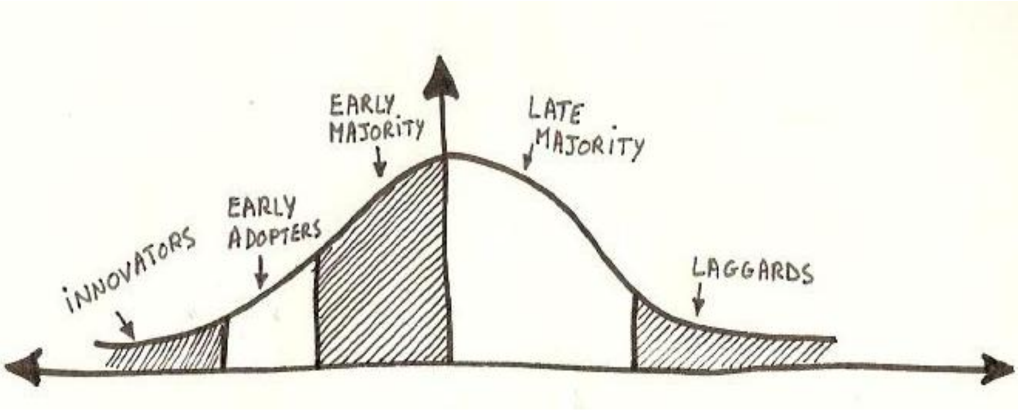


Figure 3.17. Organization change bell-curve (Rogers 1962)

The fifth methodology attempt utilized existing technician "early adopter" practitioners with high participation (generation one) to train newer employees within the organization, working less than one year (generation two). The focus of this model would be to show employees with low tactic knowledge how NM logging should be performed, without the bias of "the way we've always done it" practices. Execution of the training and implementation program is illustrated in figure 3.18.

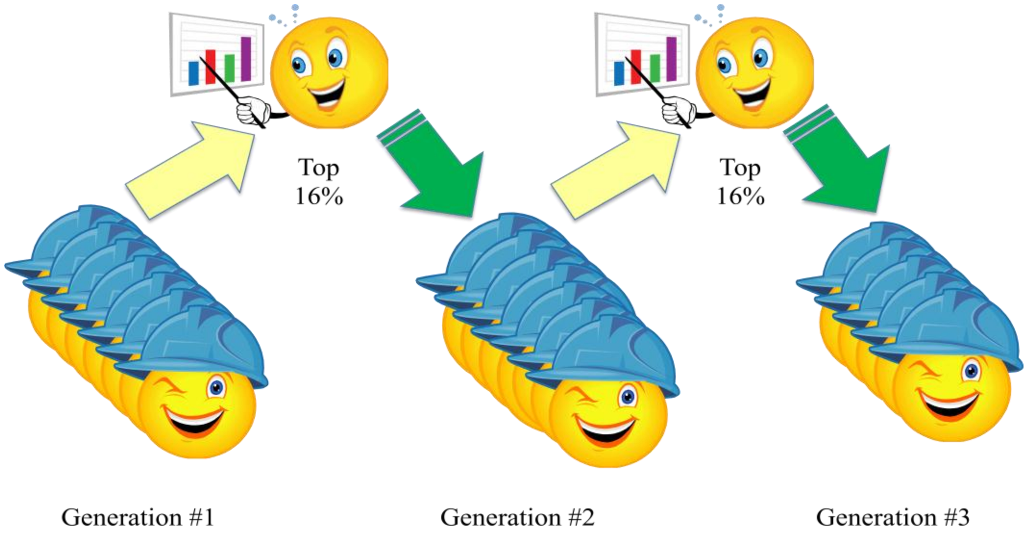


Figure 3.18. Diffusion of innovations

Sampling Methods

Evaluating each of the methods used to research and test the viability of maintaining NM logging involved three primary sample methods:

- NM logging volume over time – collected every 24 hours from technician input via table PCs during their "rounds and readings."
- ITP incident rate over time – tracked by the internal production management staff based on the amount of facilities incidents negatively impacting production capability.
- Facilities Technician Participant Satisfaction Survey results – consistent surveys completed by all participating facilities technicians.

Method of Data Presentation

Over the course of three years, the data collected in this study yielded 2,400 NM logging entries, 19 ITP incident reviews and 760 survey responses from greater than 40 facilities technician participants. The summary of information was collected in five illustrations (figure 3.19; figure 3.20; figure 3.21; figure 3.22; and figure 3.23):

- Figure 3.19 – contingency analysis of study survey over time mosaic plot
- Figure 3.20 - one-way analysis of research method practitioner response over time mosaic plot
- Figure 3.21 – contingency analysis of study survey by year mosaic plot
- Figure 3.22 - NM and ITP performance over time
- Figure 3.23 - participation of NM logging over time by practitioner tenure

Table 3.3. Research method practitioner survey response over time

Study Survey	1H 2009	2H 2009	1H 2010	2H 2010	1H 2011	2H 2011	1H 2012
Not comfortable with new data logging	5%	7%	5%	31%	10%	5%	5%
Don’t like the new system	7%	7%	6%	27%	20%	3%	3%
Don’t trust that the system works	8%	9%	11%	4%	20%	5%	5%
I’m following the system and have no issues	80%	77%	78%	38%	50%	87%	87%

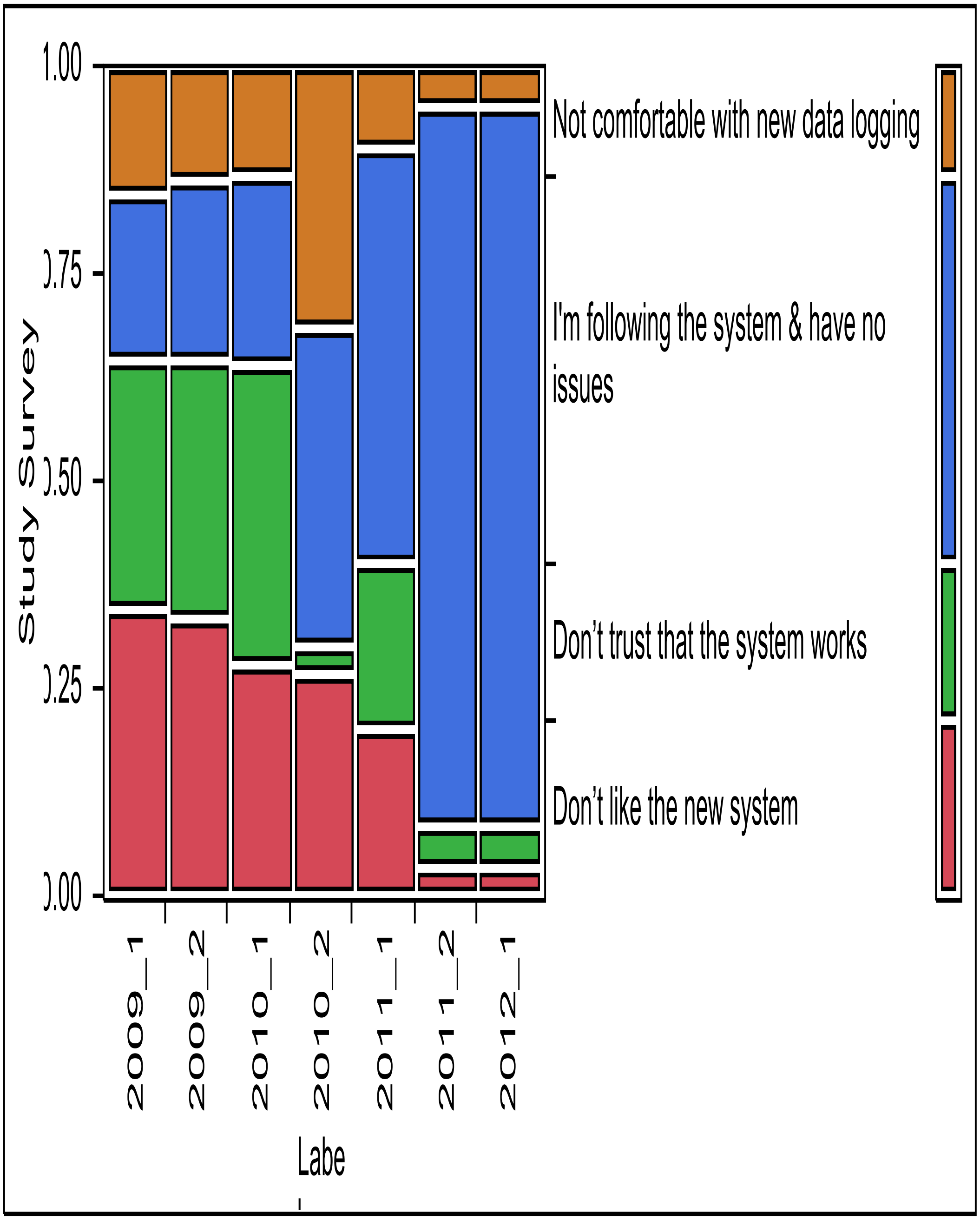


Figure 3.19. Contingency analysis of study survey over time mosaic plot

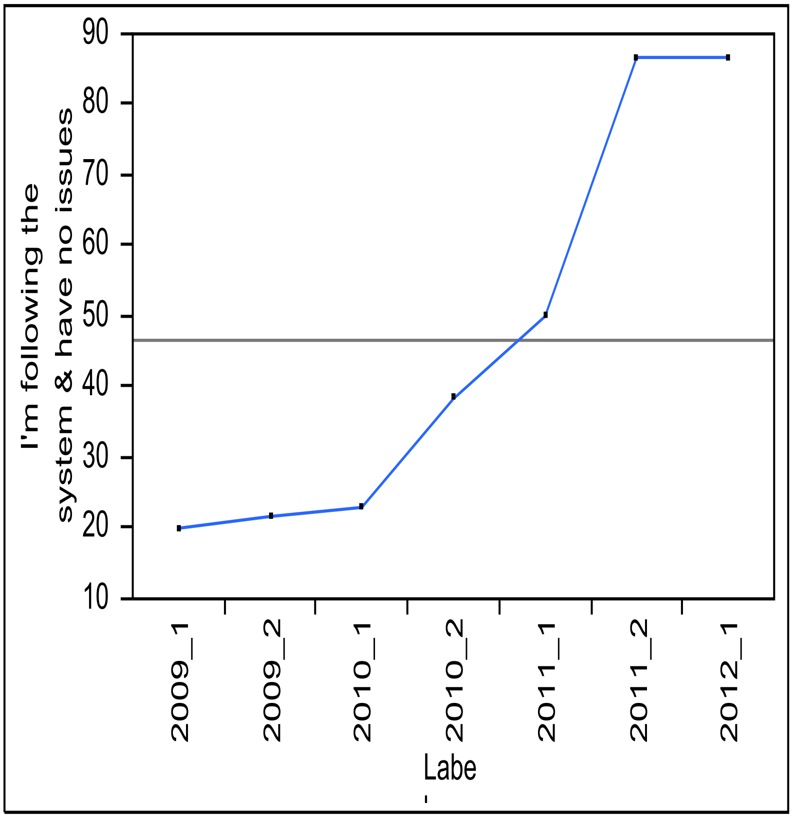


Figure 3.20. One-way analysis of research method practitioner response over time mosaic plot

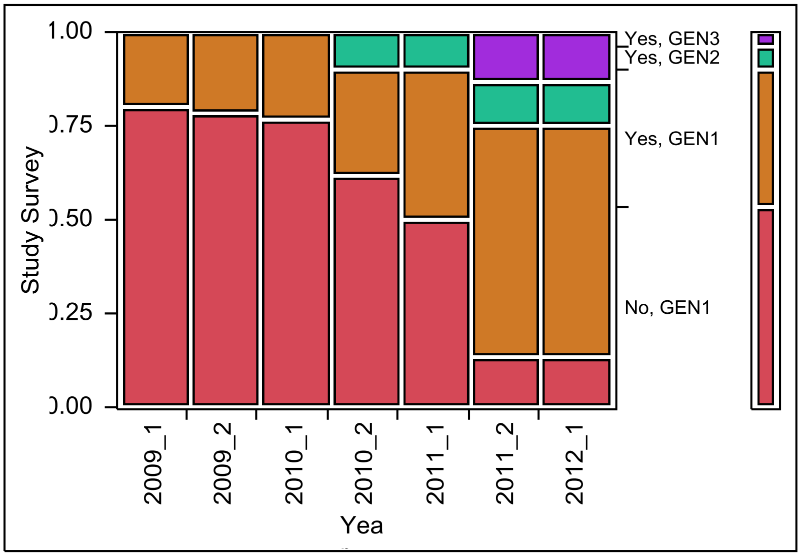


Figure 3.21. Contingency analysis of study survey by year mosaic plot

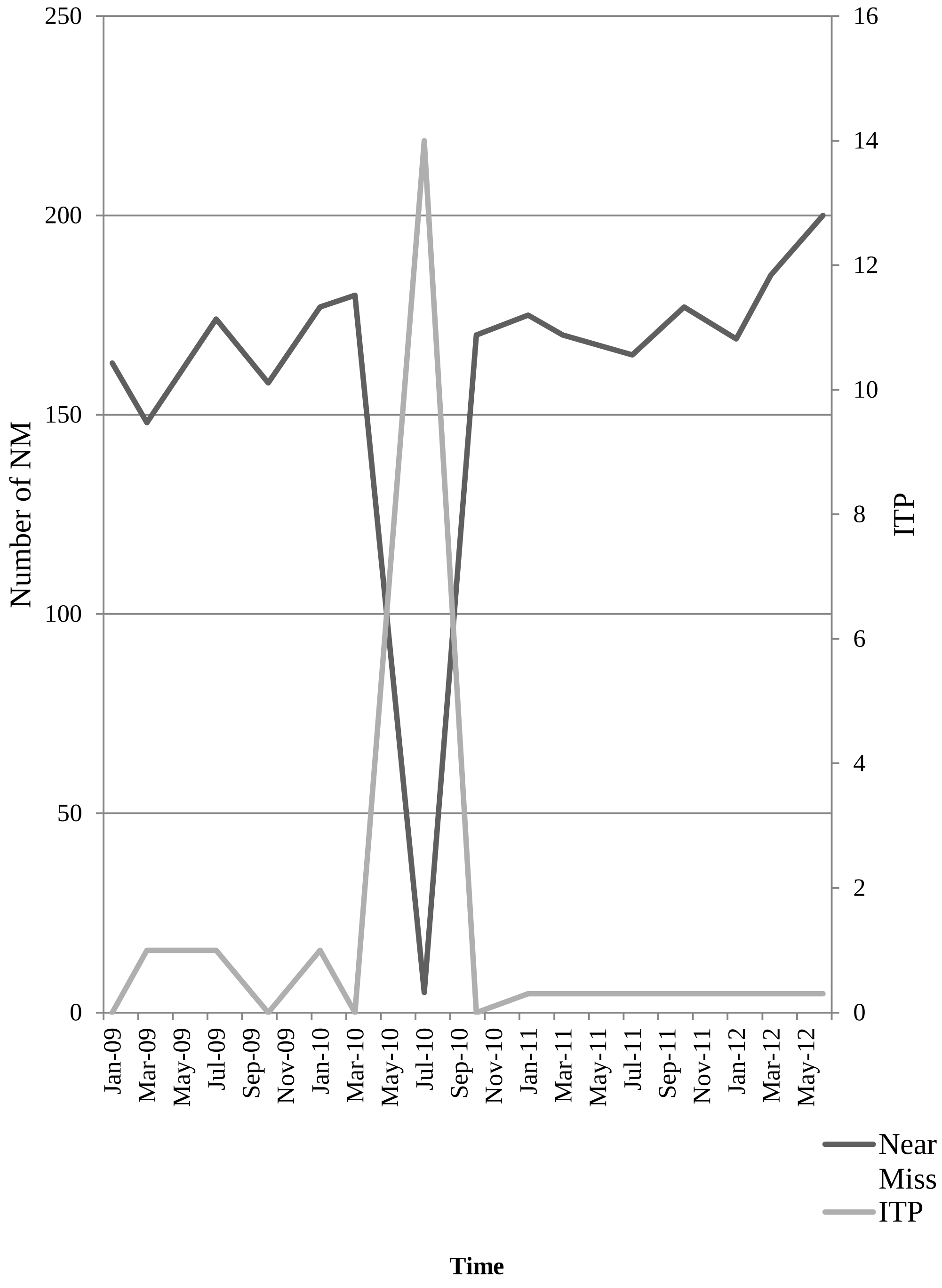


Figure 3.22. NM and ITP performance over time

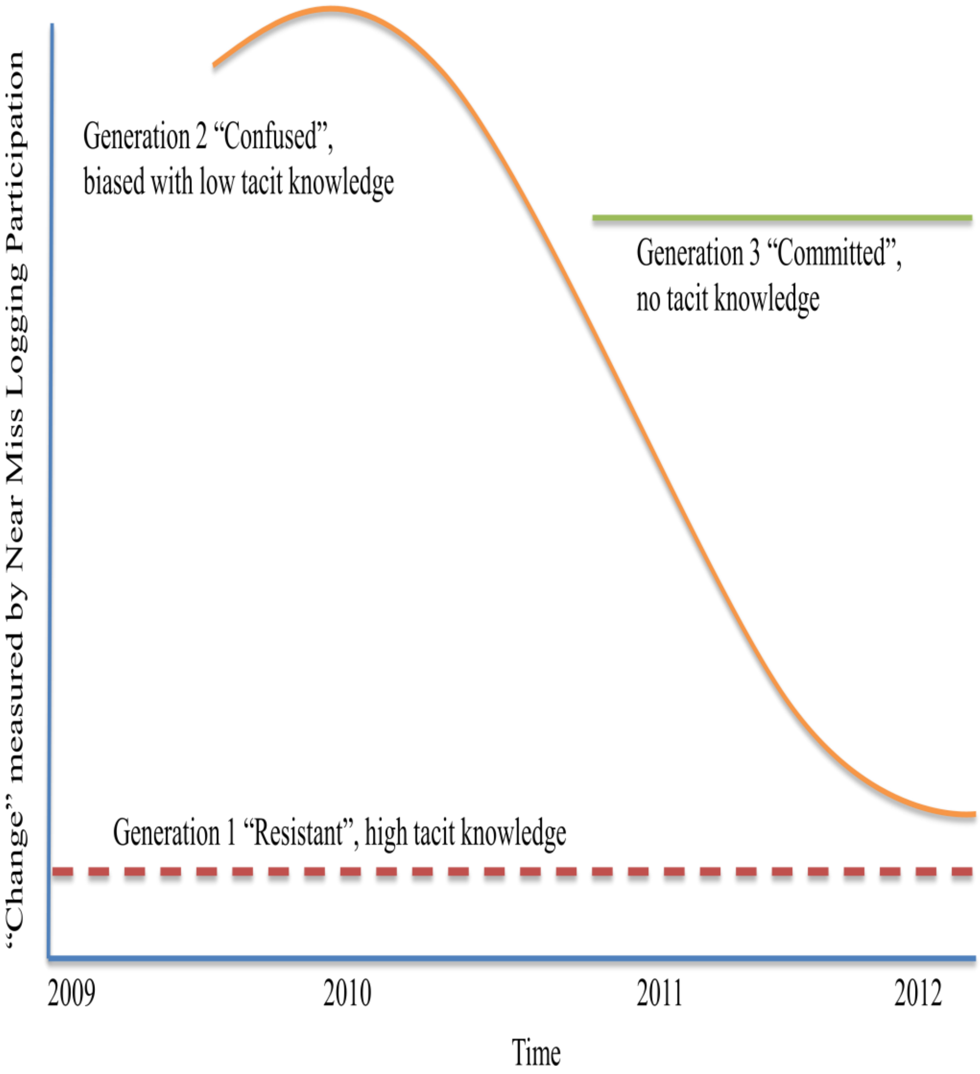
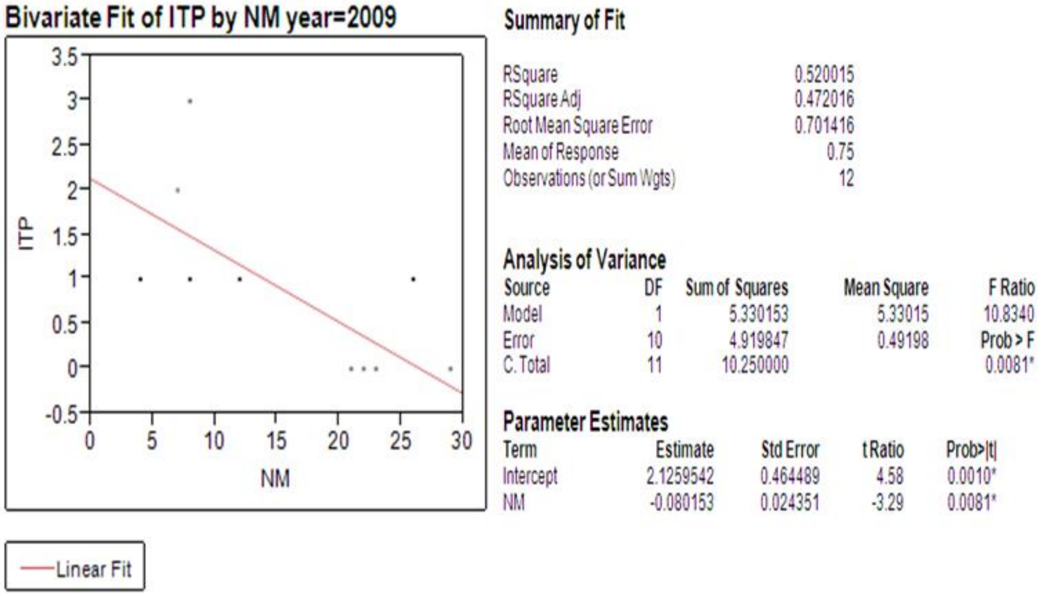


Figure 3.23. Participation of NM logging over time

Data Analysis Interpretation

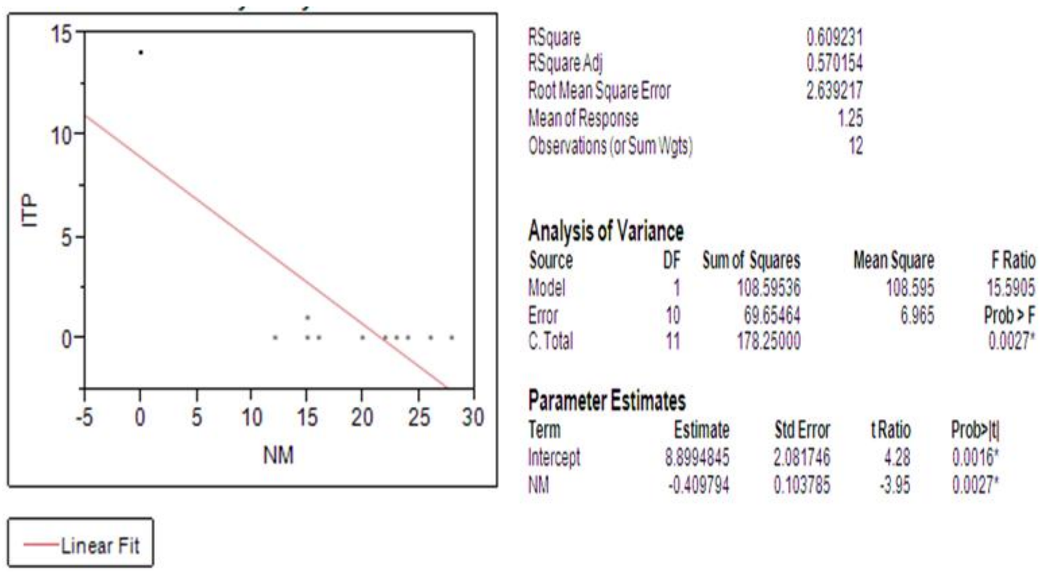
After reviewing this study's collection of exploratory research data, a statistical correlation was found between mitigation of ITP incidents through review of NM logging. Analyzing the 2,400 NM incidents exposed significant equipment performance trends and provided insight supporting process improvements. Figures 3.24 through 3.27 demonstrate a typical linear regression model used to check goodness of fit for NM incidents as a predictive element of ITPs. The number of NM incidents by month is compared to the number of ITP incidents by month over the course of 2009 through 2012 year to date.



```
Summary of Fit

RSquare                          0.520015
RSquare Adj                      0.472016
Root Mean Square Error           0.701416
Mean of Response                     0.75
Observations (or Sum Wgts)             12

Analysis of Variance
Source        DF   Sum of Squares    Mean Square    F Ratio
Model          1         5.330153        5.33015    10.8340
Error         10         4.919847        0.49198   Prob > F
C. Total      11        10.250000                   0.0081*

Parameter Estimates
Term          Estimate   Std Error   t Ratio   Prob>|t|
Intercept    2.1259542    0.464489      4.58    0.0010*
NM           -0.080153    0.024351     -3.29    0.0081*
```

Figure 3.24. 2009 linear regression of all unscheduled NM and ITP incidents

The regression model illustrated in figure 3.24 projected statistically significant positive correlation with 52 percent of the ITP event variability attributed to NM findings. As a result, it can be said with some confidence that as NM incidents increase, there is a probability that ITPs will increase.



RSquare	0.609231
RSquare Adj	0.570154
Root Mean Square Error	2.639217
Mean of Response	1.25
Observations (or Sum Wgts)	12

Analysis of Variance

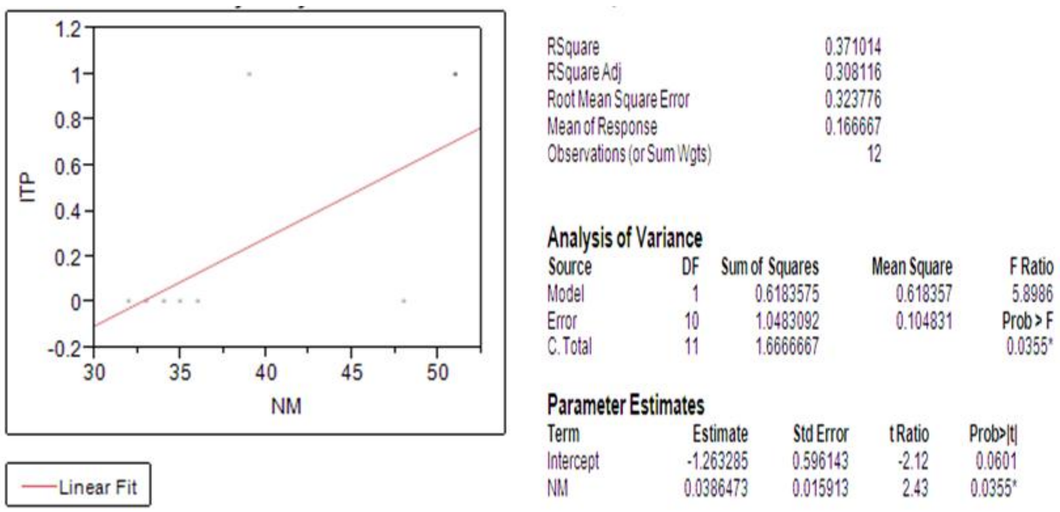
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	108.59536	108.595	15.5905
Error	10	69.65464	6.965	Prob > F
C. Total	11	178.25000		0.0027*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.8994845	2.081746	4.28	0.0016*
NM	-0.409794	0.103785	-3.95	0.0027*

Figure 3.25. 2010 linear regression of all unscheduled NM and ITP incidents

The regression model illustrated in figure 3.25 projected statistically significant positive correlation with 60 percent of the ITP event variability attributed to NM findings. As a result, it can be said with some confidence that as NM incidents increase, there is a probability that ITPs will increase.



RSquare	0.371014
RSquare Adj	0.308116
Root Mean Square Error	0.323776
Mean of Response	0.166667
Observations (or Sum Wgts)	12

Analysis of Variance

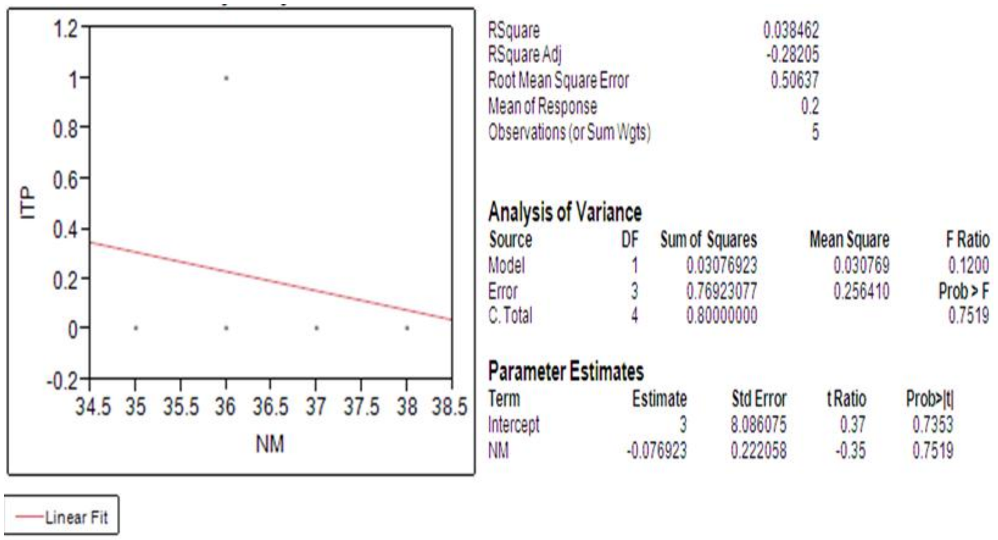
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.6183575	0.618357	5.8986
Error	10	1.0483092	0.104831	Prob > F
C. Total	11	1.6666667		0.0355*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.263285	0.596143	-2.12	0.0601
NM	0.0386473	0.015913	2.43	0.0355*

Figure 3.26. 2011 linear regression of all unscheduled NM and ITP incidents

The regression model illustrated in figure 3.26 projected statistically significant positive correlation with 37 percent of the ITP event variability attributed to NM findings. As a result, it can be said with some confidence that as NM incidents increase, there is a probability that ITPs will increase.



```
RSquare                         0.038462
RSquare Adj                     -0.28205
Root Mean Square Error           0.50637
Mean of Response                     0.2
Observations (or Sum Wgts)             5

Analysis of Variance
Source        DF   Sum of Squares    Mean Square     F Ratio
Model          1       0.03076923       0.030769      0.1200
Error          3       0.76923077       0.256410    Prob > F
C. Total       4       0.80000000                     0.7519

Parameter Estimates
Term           Estimate    Std Error   t Ratio   Prob>|t|
Intercept             3     8.086075      0.37     0.7353
NM            -0.076923     0.222058     -0.35     0.7519
```

Figure 3.27. 2012 year-to-date linear regression of all unscheduled NM and ITP incidents

The regression model illustrated in figure 3.27 projected statistically significant positive correlation with 38 percent of the ITP event variability attributed to NM findings. As a result, it can be said with some confidence that as NM incidents increase, there is a probability that ITPs will increase.

Research results also support findings from Psychologists Maslow and McGregor, suggesting that effective strategies for managing and maintaining change must start with a fundamental understanding of the conflict that exists between an organization’s need for change and an individual’s need for change. Given that Company ABC must change to meet business needs, and people innately resist change, this research methodology analyzed findings associated with iterative single variable process change testing to determine an optimal and repeatable scenario for establishing maintainable process change integration in a facilities organization.

Chapter 4

Data Collection

This dissertation suggests an iterative, data driven asset management technique for technical leadership to improve (a) working relationships, (b) resource alignment, (c) more effective communication and (d) performance results through clear presentations of existing information within the CMMS program effort. The opportunity statement explored and tested during this study successfully allowed content experts at the lowest level of an organization to actively participate in analyzing business performance indicators that resulted in a minimized need for management decision making. The specific example in this research study was tried with regard to performance information measurement for increasing facilities equipment availability.

For the past 20 years, the author has worked in a very technical semiconductor manufacturing environment where most business situations were driven by upper management decisions. Managers consistently gave direction on (or managed) technical programs even though they admittedly did not have any firsthand knowledge of the systems. For the better part of 20 years, the author watched and acquired this behavior, eventually being promoted into the madness of this complexity. As a part of this blind and emotional management, the author led a disgruntled group of content experts who were either too intimidated or too resigned to speak up.

Four years ago the author made a career change to the facilities management group. The author’s first thought with this new scope was “there is a vast breadth of responsibility.” Facilities systems affect everything - building maintenance, site electricity, site security, chemistry, waste management, water purity, and mechanical systems associated with heating, air-conditioning and humidity control, to name a few. The scope of responsibilities is immense. Although the author managed a capable staff of engineers that had earned degrees from some of the world’s finest institutions, he felt the need to attend Arizona State University to learn more about Facilities Management, in order to better direct his employees’ activities. What he didn’t expect to learn was that leadership means he needed to minimize the micro-management habits he had been taught by industry and focus on the positive alignment of employees to their passions. He needed to empower these brilliant minds in order to unleash their true capability.

During a recent re-organization exercise at Company ABC, the author was given the opportunity to lead a mature team of electricians and electrical engineers (13 technicians); the team was responsible for site electrical distribution system maintenance and sustaining activities. During initial conversations with the team, feedback was clear that everyone was stretched to the limit with Preventative Maintenance (PM), Corrective Maintenance (CM) and Predictive Maintenance (PD) activities. PM, CM, and PD activities are described as follows:

- Unscheduled downtime is identified as Corrective Maintenance (CM), which is a reactive process caused by unforeseen damage or failure. CM is a result of a major failure or shut down and is not conducive to efficient production (Payant 2007).
- Scheduled downtime or Preventative Maintenance (PM) is defined as, "pre breakdown work performed on a facility's equipment and systems to eliminate failures and/or breakdowns, or to keep such failures and/or breakdowns within predetermined economic limits" (Payant 2007).
- Predictive maintenance (PD) is recognized as, "maintenance identified and performed when empirical data that are collected and reviewed indicate that maintenance is required" (Payant 2007). In the case of electrical scopes, PD is Infrared Scanning of electrical components to monitor and detect overheating of circuitry.

With the intent of being a good leader, the author wanted to trust what his new organizational members were reporting, but, at the same time, verify the extent of their input with dominant information. The author's first step was to reference the CMMS database. Knowing that 13 full-time technicians are capable of working 27,040 hours per with an effective 65 percent availability after vacations, sick time, et al., Company ABC's standard calculation equals a total available man hours of 17,576. Figure 4.1 demonstrates the initial findings of the 2009 and 2011 CMMS work logged by category.

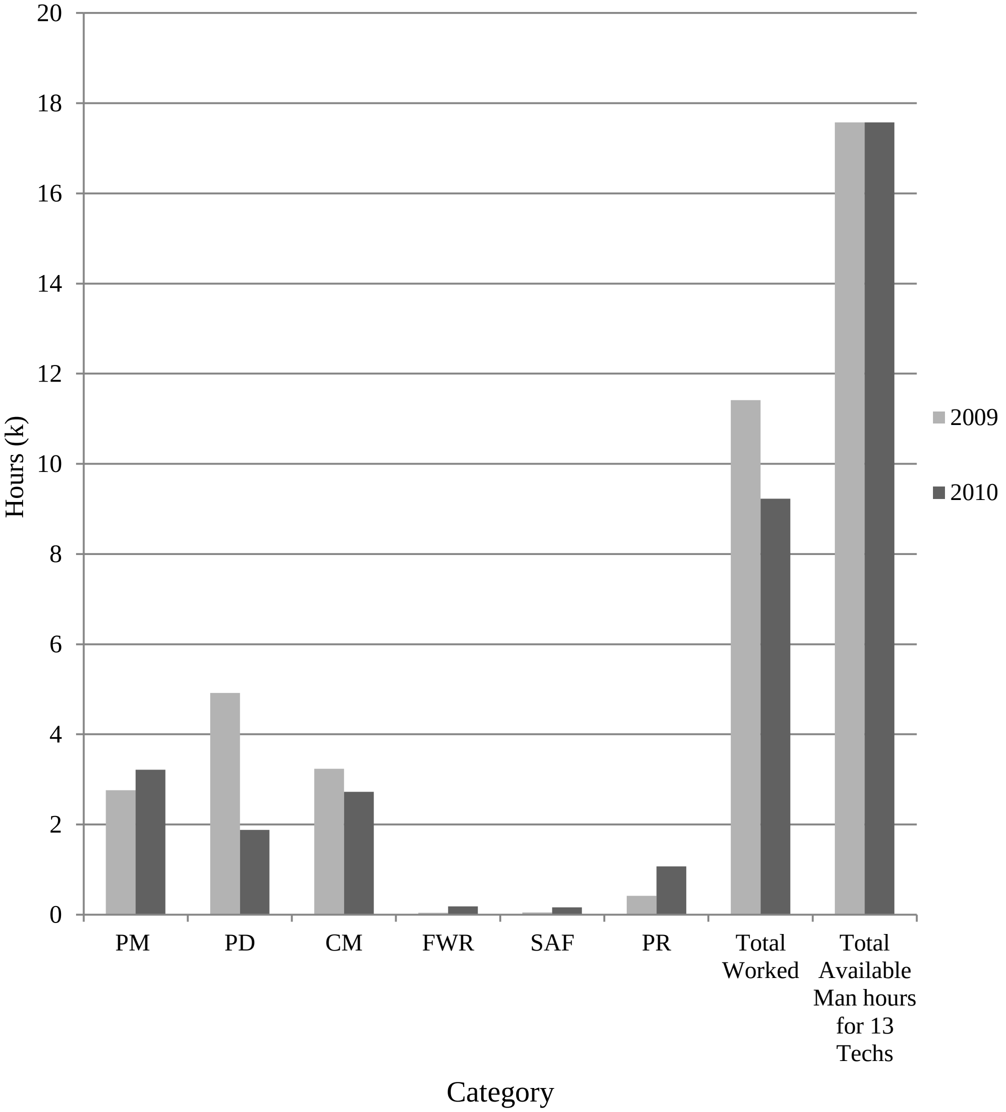


Figure 4.1. Technician labor hours per year by CMMS category

With the dominant information of actual hours worked now available for review, a few key facts came to light:

- It was obvious that total hours worked were grossly under total hours available to work.
- There are differences or non-standard variation in PM and CM time.
- PD labor hours were significantly reduced from 2009 to 2011. The author’s intent at this point was to understand why labor had decreased from 2009 to 2011 as a function of the equal reduction in PD. A paramount advantage of CMMS information can be the ability to “drill down” in the details of certain categories of maintenance or work orders to better understand the conditions of these areas. Figure 4.2 illustrates an example of being able to drill down with more resolution in the CMMS data to understand the frequency of task occurrence compared to the duration of the tasks.

The author was able to effectively present the obvious data to the employees and gain their agreement that plenty of labor resource capability was available, they just weren’t being effective. By illustrating the dominant information, the choice to not hire more workers was obvious and the emotion was minimized by all stakeholders because the answer was highly visible and factual.

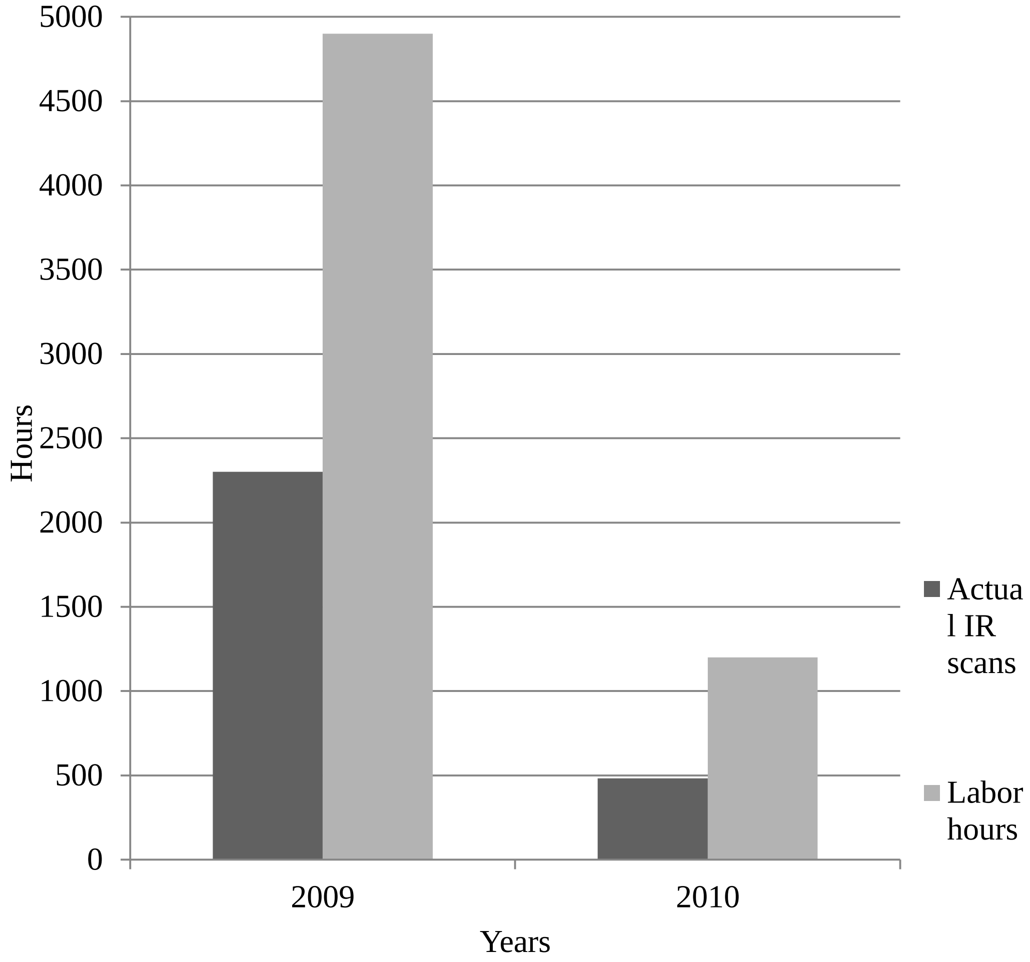


Figure 4.2. Total IR scan labor and number of events for facilities

Status Quo Process

The maintenance and facility management methodologies at Company ABC's electrical facilities department utilized the CMMS data collection as a means to expect technicians to schedule and document maintenance events; however, management never role modeled data review. The status quo level of performance was a shameful and reactive leadership position as no one really knew how effective the labor model was for this area. Ultimately perceptions were formed that technicians were overworked and more headcount was needed, when in fact the opposite was true.

Due to the gap in oversight, valuable data within the existing and well used CMMS database was being utilized only at a fraction of its capacity. The technicians were doing exactly as asked by utilizing the CMMS to respond to the maintenance schedule tracked in the CMMS, to log work order reports, and to track all downtime incidents in the CMMS. Opportunity was lost in the valuable ability to generate equipment availability, labor utilization, and business performance metrics from the collection of this raw data.

In this situation, Company ABC’s facilities management team was blind to the facts of the situation; the management team intended to increase headcount to the electrical team when the next hiring opportunity was available. Prior to this effort, no one had used, or even considered to use, the CMMS to review actual historic labor worked versus total labor available. While the notion of missing such a simple practice may appear inconceivable, this was a very real and common miss across multiple disciplines. While some peer managers and ancillary stakeholders would later downplay the accuracy of CMMS data, citing the potential for large tolerances in the ability to capture all work events and time spent by category, it was agreed that CMMS data at least provided a baseline to better understand business performance metrics over time and the ability to trend, which promotes prediction.

Proposed Alteration Methodology for Improved Utilization of CMMS for Leadership

This research tested the potentially significant business process improvement to utilize existing data within the facilities management organization at one of the world’s largest semiconductor manufacturing sites. Effectively analyzing CMMS tools would provide greater opportunities to identify facilities equipment performance trends that would result in cost savings, efficiency improvements, and bureaucracy reduction prospects across multiple business groups. Furthermore, the proposed change in management approach would aim to transfer the responsibility of assessing equipment failure solutions from management to expert field technicians.

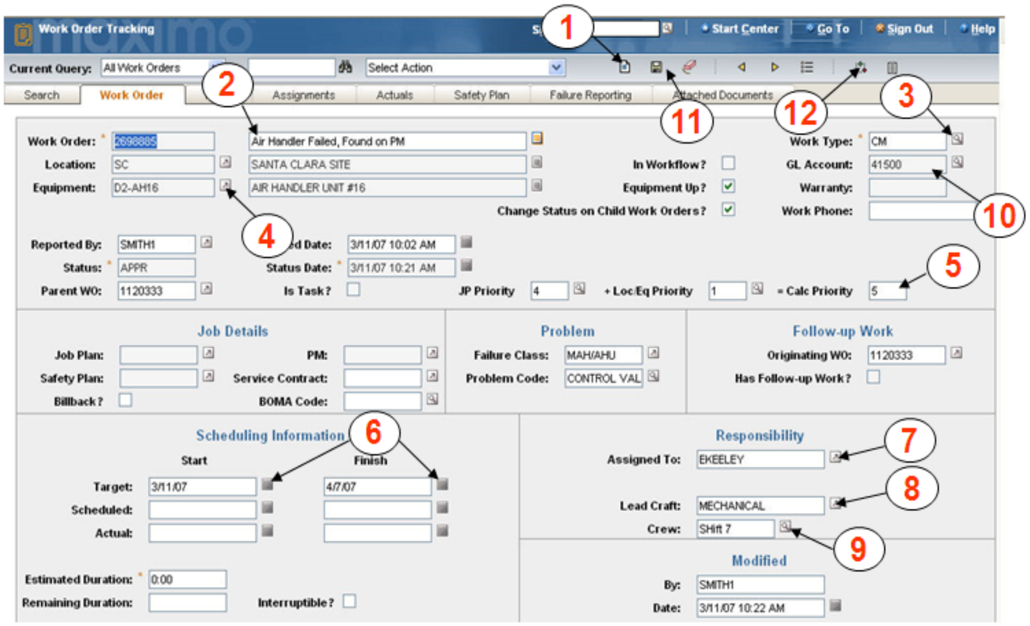
The proposed research methodology can be summarized in the following steps:

- Data Collection: Field technicians recorded maintenance and work order event data in the CMMS database every shift per normal. The technicians were assigned, and began using, wirelessly connected tablet PCs.
- Data Analysis: An “Operations” meeting was held every morning. The technicians, their manager and at least one engineer would meet to review the CMMS data collected from the previous 24 hours. The review allowed all stakeholders to collaborate on standardization of descriptions and vernacular used to document events. Every four weeks

equipment engineers reviewed and analyzed all events to identify trends or areas of improved efficiency.

- Engineering trend package: An engineering trend package was reviewed monthly with the technicians. This review was accomplished in a verbal presentation at every shift meeting during that week to ensure all technicians (night and day shifts) were aware of the importance of the information they were gathering and had the opportunity to discuss questions and concerns. During these “passdown” meetings, technicians were recognized as the experts in working with the affected equipment, and their feedback was applauded as a crucial element when interpreting the performance trends.
- Solution models: The technicians used this performance information to determine the solution models for equipment incidents, and adjusted their work schedules to respond in the appropriate manner. This was a large change from technicians’ previous work schedule of waiting to be directed by management on how and when to respond.

The technician role had not changed its core function to respond to the CMMS maintenance schedule and input the work order findings per the standardized worksheet (shown in figure 4.3).



Current Query: All Work Orders

Work Order: * 2698885 Air Handler Failed, Found on PM
Location: SC SANTA CLARA SITE
Equipment: D2-AH16 AIR HANDLER UNIT #16
In Workflow? ☐
Equipment Up? ☑
Change Status on Child Work Orders? ☑
Work Type: * CM
GL Account: 41500
Warranty:
Work Phone:
Reported By: SMITH1
Status: * APPR
Parent WO: 1120333
…ed Date: 3/11/07 10:02 AM
Status Date: * 3/11/07 10:21 AM
Is Task? ☐
JP Priority 4 + Loc/Eq Priority 1 = Calc Priority 5

Job Plan:
Safety Plan:
Billback? ☐
PM:
Service Contract:
BOMA Code:
Failure Class: MAH/AHU
Problem Code: CONTROL VAL
Originating WO: 1120333
Has Follow-up Work? ☐

Target: Start 3/11/07 Finish 4/7/07
Scheduled:
Actual:
Estimated Duration: * 0:00
Remaining Duration:
Interruptible? ☐
Assigned To: EKEELEY
Lead Craft: MECHANICAL
Crew: SHift 7
By: SMITH1
Date: 3/11/07 10:22 AM

1. **Generate New Work Order**
2. **WO Description** – Detailed Description about the WO. (Use the Long Description if necessary)
3. **Work Type** – Default is CM. Change to OPS if work order is for non-corrective actions.
4. **Equipment** - Enter Equipment number. (ALL CM WORK ORDERS MUST HAVE EQUIPMENT NUMBER)
5. **Adjust Priority** -- (High Priority: 10 and above, Medium Priority: 6 – 9, Low Priority: Less than 6)
6. **Target Start and Target Completion** – Set realistic start and completion dates. (Dates can be adjusted to match expected parts delivery)
7. **Lead Craft** – Select main Lead craft assigned to the WO. (CONTRACTOR for vendor supplied services) (A PERSON IS NOT A CRAFT)
8. **Crew** – Select Crew ID.
9. **Assigned To:** Assign to self if completing work or assign to supervisor for assignment, (DO NOT LEAVE BLANK)
10. Ensure GL Account is accurate. (DO NOT LEAVE BLANK)
11. **Save** Work Order
12. **Change Status** to APPR

Figure 4.3. Standard CMMS input

With the well defined and standardized input of work order information being collected by engineers responsible for system ownership, management was able to review the data, analyze the information and report any findings or trends every four weeks.

The primary data collection tools and methodology used were:

- The CMMS database: Current job expectations require technicians/stakeholders to input equipment incident events into the database at the completion of each job event. This data collection tool is instrumental as the core raw data for analysis and trending of performance metrics.
- The CMMS database is updated real-time (24/7) as a current, well practiced and re-enforced employee expectation. This effort focuses on the opportunity to gain insight into the accuracy of labor models with actual versus estimated time to execute job plans.
- For every PM, CM or PD event, the following methodology was applied: (a) All incident information was captured in CMMS by the technician performing the work. The data was reviewed, normalized (verified for accuracy with first person) and summarized for management review within 24 hours of incident occurrence. (b) Post management review - all incidents and corresponding follow up actions, if assigned, were tracked to ensure closure with the intent of capturing “lessons learned” and mitigating repeat incidences in the event of a CM. In the event of a PM or PD, “lessons learned” were reviewed for efficiency improvement and incorporated in the task checklist and/or the labor model estimates.

The gap in the status quo versus this simple yet often overlook data analysis process was that stakeholders would rarely follow through to gather and interpret the available dominant information in the CMMS. Management would only review CMMS data in the event of a significant event; a safety incident or system failure that resulted in detrimental product or cost impacts. In the status quo, it was not expected, nor was it a regular practice, to review the CMMS data for continuous improvement efforts.

In the new process of having CMMS data review meetings, all stakeholders assessed the information provided and gave suggestions for improvement. In the status quo model, management reviewed data and made decisions.

Chapter 5

Leadership

In this chapter, the author compares obtaining knowledge associated with applied leadership attributes taught by Arizona State University (ASU) professors William Badger and Dean Kashiwagi to the management status quo received in his work environment at Company ABC. The author's objective is to highlight the leadership characteristics, techniques and tips brought to light by these professors that ultimately enabled him to understand and integrate academic findings for more effective performance in his work environment as a facilities manager.

From a leadership perspective, the status quo micro-management cycle was changed to support efficiency of data driven equipment down repair solutions while eliminating, or at least significantly reducing, management decision making. The status quo micro-management cycle was a negative image and suffered from a deficiency of content expertise participation and management understanding of the necessary respect required to make a work quality performance break-through.

It was acknowledged that management viewed equipment maintenance as a cost, a necessary evil, not as a contributor. Most managers felt that the role of maintenance is 'to fix things when they break,' and when things break down it is because maintenance has failed (Blann 2003).

The key concept to promoting the tested leadership model proposed in this dissertation was to establish a "No rules leadership style" where accountability of performance overrides the need to follow a prescribed procedure (Hays 2000). The leadership research experiment in this study confirmed that the larger an organization, the more rules and control mechanisms were in place to manage people. It was found that over time the number of rules and levels of bureaucracy increased, which also increased the attraction for micromanagement, resulting in decreased efficiency, accountability, and innovation.

The leadership findings associated with this hypothesis testing utilized the published leadership principles documented by Dr. William Badger during his service in the United States Army (Hays 2000). They are:

- have no rules
- never set the height of the bar
- practice complete openness
- decentralize and delegate
- select people based on their leadership and people skills

One of the collateral objective's of the author's study, after witnessing the program's effect equipment availability improvement, was to understand the program's affect on organizational behavior. Specifically, how leadership versus the status quo micro-management style affected employee satisfaction. The goal with a minimized rules environment was to enable business decisions at the content expert level and remove the environment of constant management direction setting. Reducing tactical micro-management decision making increases employee accountability and empowerment, resulting in increased organizational pride. The hypothesis testing in this study found the new model of leadership versus the status quo micro-management style was significant with effective resolution to improving facilities equipment availability though better maintenance information. The collateral effect to be explored was to understand if this leadership model would increase employee satisfaction. While the leadership model tested aligned with Professor Badger's findings of holding people more accountable through reduced complexity of management decision making, would it be successful with employee job satisfaction?

As a manager at Company ABC for over 15 years, the author was engrained with the management culture of his environment as it related to micro-management and the habitual expectation to control and influence others. It took the collective of classes obtained in ASU's Facilities Management (FM) master's program curriculum to help him understand the pros and cons of the management style he had been demonstrating. More specifically, courses taught by Professor Badger and Professor Kashiwagi helped the author understand the leadership style that is most effective with others. The personal break-through, application, and practice of new techniques with his staff at Company ABC resulted in significant win/win/win results. This dissertation explores the status quo for the author's situation pre-ASU FM course and the current situation with measurable actions from his staff and bosses.

Chapter 6

Hypothesis

This dissertation proposes utilizing leadership principles that were found to significant improve facilities maintenance equipment availability and job performance indicators through more effective information flow and working relationships. The primary references for comparison are “management” and “leadership.”

By aligning the correct resources to actively review trends and categorize information, imminent and probable facilities equipment problems become more obvious. By enabling a more proactive approach, fewer surprises are encountered; resulting in less emotion (especially negative emotion). This effort suggests that the FM that strives for organizational preparation and proactive responses might spend more time characterizing and accurately understanding the initial conditions of business events. This would result in proportionally less time required to execute a solution for future event occurrences.

During the author’s program studies, there were two classes that made significant impact on his personal and professional life:

- Professor Badger’s Leadership class
- Professor Kashiwagi’s Information Measurement Theory (IMT) class

These two courses were most influential because they demonstrated the best “bang for the buck,” the most power with efficient effort. By practicing the knowledge obtained in these courses, the author, almost immediately, gained positive results with the organization at work. The key concept in common with these two courses encompassed the power of correct alignment with those around you. The people around you, in this case, are the stakeholders and partners that must be maintained for mutual success on your challenge. These people can be thought of as orbiting your center or, as Dr. Badger stated (2010) are “on your molecule” (figure 6.1). They are involved with you and surround you in some frequency during your quest. The intent is to empower the people in your immediate environment to be responsible for their own decisions versus relying on management direction. Conversely management can learn to stop making decisions and micro-managing staff, thereby increasing efficiency at the correct level of the organization.

Figure 6.1. Diagram of “Who’s On Your Molecule” (Badger 2010)

Dr. Badger and Dr. Kashiwagi established this concept as part of the IMT philosophy, which serves as a means to holistically improve one’s life by minimizing decision making in lieu of the obvious choice. During these highly effective courses, the author’s new found role was not to make decisions but to help the organization, through the facilities maintenance team he managed, see the existing dominant information within the initial conditions of an event and arrive at the correct solution. Dr. Kashiwagi (2002) defines dominant information as irrefutable fact, which is easily explained. Often times a problem has existing conditions (facts) that simplify the choice to be made in solving an issue. The problem arises when management (almost always blind to all of the facts in each situation) makes decisions based on experience or emotion – regardless of the dominant information specific to the issue. This micro-management results in complexity because the manager often sets a different direction than the obvious choice because he/she is blind to the complete picture. When the manager directs work for the content expert, decision making by the manager dis-empowers and removes accountability from the content expert. The key lesson here is that the manger should strive to ensure transparency of all dominant information associated with an event. Let the content experts perform their duties to arrive at the correct response, given all factual data up front, so they can evaluate the initial conditions of an event without bias.

The most challenging aspect of the IMT methodology is that it is not obvious to most people. The simplicity of leadership is inherently against human nature and what many of us have been taught as managers. Managers or persons in "power" positions are taught to control the details of each situation as a gesture of authority and expertise. IMT teaches us that people cannot influence others without their consent (willing agreement of concept).

Managers make the fatal assumption that they know more than their subordinates, and they assume they have the ability to influence people's decisions long term. The IMT philosophy teaches that this perception is false, people cannot control others. We cannot change a person from who they are. Following are some insightful quotes from *As a Man Thinketh*, by James Allen, that were used in the IMT course that bring this concept into perspective:

- All that a man achieves and all that he fails to achieve is the direct result of his own thoughts.
- A man's weakness and strength, purity and impurity, are his own and not another man's. They are brought about by himself and not by another; and they can only be altered by himself, never by another.
- His condition is also his own, and not another man's. His sufferings and his happiness are evolved from within.
- As he thinks, so he is; as he continues to think, so he remains.

By understanding this philosophy, striving to role model IMT leadership and utilizing the “Whose on Your Molecule” diagram (figure 6.1), the author achieved a personal and professional break-through.

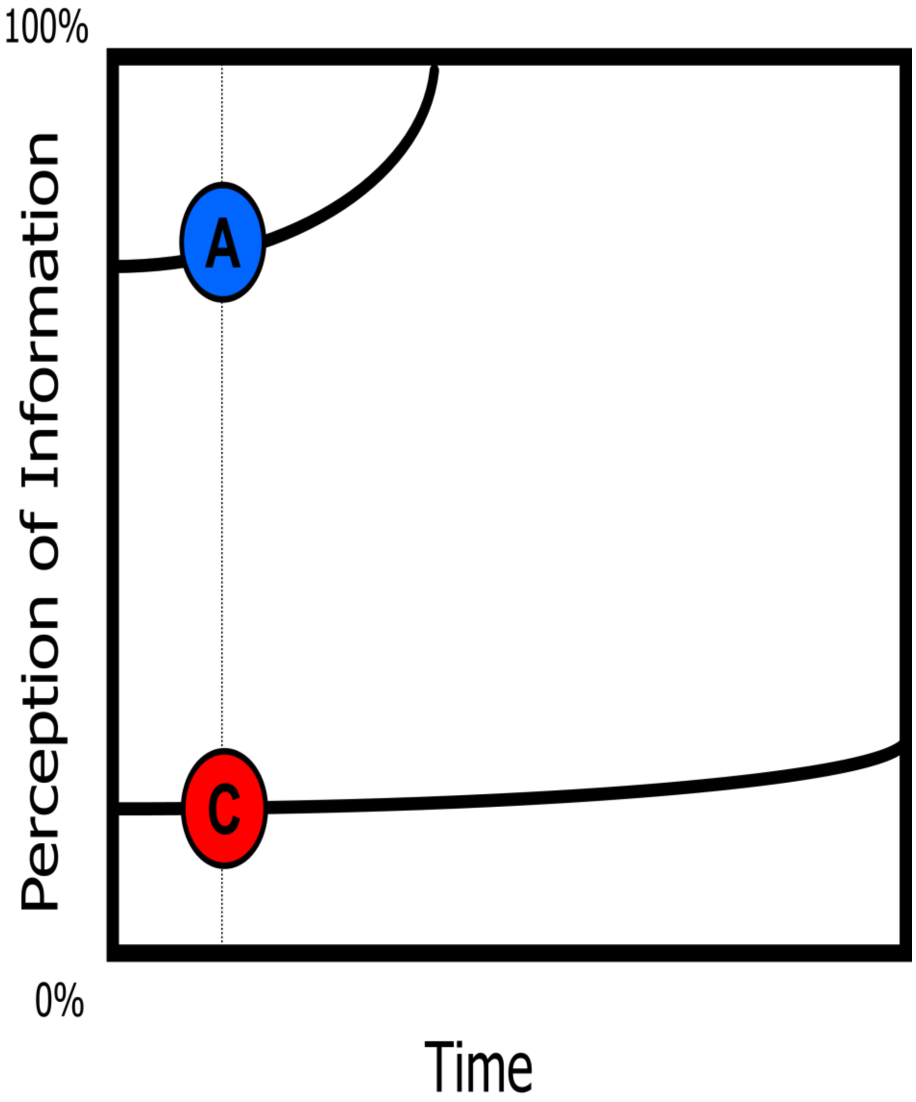


Figure 6.2: “A” and “C” type people (Kashiwagi 2002)

Figure 6.2 illustrates the “A” type personality, where a leader who quickly perceives the dominant information in a situation applies the facts to known natural laws, and then applies the knowledge or change in order to arrive at a logical conclusion (or prediction) without the need for decision making. The IMT philosophy recommends that a true leader minimizes decision making, with the understanding that if you don’t know, use deductive logic to arrive at the obvious choice. The “C” type personality in this figure utilizes very little dominant information and uses past experience or emotion to determine his/her next steps. This person experiences a significantly slower rate of change to arrive at a logical and proactive solution.

As stated in Chapter 4, the first thought the author had when he learned about this new scope was, “the breadth of responsibility is vast.” At Arizona State University, the author learned that leadership meant he needed to align people to their passion and empower their brilliant minds to unleash their true capability.

As a result of this new perspective, the author spoke to technician and engineering team members in the most problematic facilities discipline group. Historically the “subfab” group experienced more incidents of disrupting factory operations than any other group. As with any manufacturing industry, Interruption To Production (ITP) is a problem. Anytime the production line is stopped, the revenue stream is impacted. Capital intensive and competitive industries require intensive efficiency and utilization of resources (Chen 2008). The solution to optimize revenue is eliminating downtime. Optimized production uptime results in lower cost of ownership and increased availability to manufacture product, thereby enabling revenue potential.

Downtime on any facilities system always results in cost to production. Whether it is parts and labor to repair the equipment or inducing manufacturing constraints due to unavailable equipment, the result equates to loss in potential revenue. Through the use of correct leadership principles and development of equipment performance information, the research showed a predictive maintenance approach that increased production availability by reducing unscheduled corrective maintenance (CM) incidents. This resource alignment approach enabled facilities managers to better predict failure causes before the equipment failed. The result was maximized equipment availability with greater use of resource talents and accountability.

Shifting the Paradigm

The maintenance and facility management methodologies at Company ABC's Arizona subfab facilities department involves equipment data collection and review that is held on a prescribed frequency, considered less than real-time. The current level of performance for documentation and measurement is a reactive response, where equipment event data is collected in the Incident Management Tracking (IMT) document and reviewed quarterly by management. During data review meetings, managers assess the information and give direction to technician and engineering system content experts. The two most obvious process problems with this model are that equipment performance information is not reviewed at an optimal frequency, and the technical experts are being directed with decisions from managers who are usually less familiar with the equipment.

An existing technician work report database, the IMT, is utilized by Company ABC to track all downtime incidents and generate equipment availability performance metrics. Maintenance technicians and engineers are required to input standardized equipment incident reports into the IMT database.

The status quo with this system required equipment technician personnel to fill out an IMT report any time an unscheduled event occurred, whether the incident induced product scrap or not. The report has a check box to signify whether or not product was scrapped, and unscheduled events where product was scrapped were the only events reviewed by management. The gap in the status quo data analysis process was that it was not expected, nor was it a regular practice, to review the non-scrap downtime events. In 2008 there were 366 IMT downtime events logged and 57 involved scrap. Any trend or signal in the remaining 342 non-scrap IMT events were not reviewed for predictive opportunity and learning. At that time the business unit measured performance on the ability to reduce scrap events; however, the focus of IMT trend review was not fully leveraged to reduce ITPs or improve efficiency and cost savings.

In the situation explored with Company ABC, management was not taking into consideration the non-scrap, NM downtime events. The status quo was that NM events were considered insignificant to management because they did not interrupt factory operations. In reality, all ITP and NM events affect production costs and resourcing models as technicians are required to respond. The paradigm shift to greater performance prediction is that all downtime events must be captured as pertinent performance information. Capturing all downtime events by category provides a better understanding of system performance over time and the ability to trend repeat failure instances which promotes prediction.

Proposed Alteration Methodology for Predictive Maintenance

This research tested the potentially significant business process improvement to current data acquisition and analysis procedures within the facilities management organization at one of the semiconductor's manufacturing sites. The improved data analysis tool would provide greater opportunity to identify facilities equipment performance trends that would result in cost savings, efficiency improvements, and bureaucracy reduction prospects across multiple business groups. Furthermore, the proposed change in management approach would aim to transfer the responsibility of assessing equipment failure solutions from management to expert field technicians.

As described in Chapter 4, the proposed research methodology was described in the following steps:

- Data Collection: Field technicians recorded equipment event data in the IMT database every shift. They documented findings real-time, accessed critical documents and reviewed system trends without leaving the area. More information was logged. Technicians were asked to be diligent about recording NM incidents, which included all unusual equipment findings, and they responded very well. An example of a typical NM finding: a technician noticed that a piece of rotating equipment was operating in a counter-clockwise motion versus the normal clock-wise motion. He/she noted the finding even though there was no detrimental impact.

- Data Analysis: An “Operations” meeting was held every morning, with technicians, their manager and at least one engineer, to review the CMMS data collected from the previous 24 hours. The review allowed all stakeholders to collaborate on standardization of descriptions and vernacular used to document events. Every four weeks equipment engineers reviewed and analyzed all events to identify trends or areas of improved efficiency.
- Engineering Trend Package: Monthly the trend package was reviewed with technicians, in a verbal presentation at every shift meeting during that week, to ensure all technicians (night and day shifts) were aware of the information and had the opportunity to discuss questions and concerns. During these “passdown” meetings, technicians were recognized as the experts in working with the affected equipment, and their feedback was applauded as a crucial element when interpreting the performance trends.
- Solution Models: The technicians used this performance information to determine the solution models for equipment incidents, and adjusted their work schedules to respond in the appropriate manner. This was a

large change from technicians' previous work schedule of waiting to be directed by management on how and when to respond.

Beginning in early 2009, the author initiated an effort to perform trend analysis on all ITP and NM downtime events. The IMT database was used to identify and track all these events. A quantitative research methodology was utilized, with statistical regression and trend analysis on data from the IMT database. This was done to review ITP incident performance in the 2008 and 2009 timeframe, with experimental performance results applied in 2009.

The primary data collection and methodology tools used were:

- The IMT database: Job expectations required technicians/stakeholders to input equipment incident events into the IMT database. This data collection tool was instrumental in collecting the core raw data for analysis and hypothesis testing.
- Technician/employee documentation into the IMT database: In the event that an IMT incident occurred, technicians took the necessary action to record the incident. It was ascertained that all incidents were captured and data integrity was met based on the job expectations and existing daily incident and IMT report compliance reviews.
- The IMT database was updated real-time (24/7) as a current, well practiced and re-enforced employee expectation. This research/data focused on the opportunity to gain proactive failure rates primarily through NM incidents in the IMT database. In the event of an incident,

> the following methodology was applied: All incidents were reviewed/normalized (verified for accuracy with first person) and summarized for management review within 24 hours of occurrence. As a post management review, all incidents and corresponding follow up actions, if assigned, were tracked to ensure closure with the intent of capturing “lessons learned” and mitigating repeat incidence.

The gap in the status quo data analysis process is that it only reviews and measures IMTs that have wafer scrap impacts. It is not expected, nor is it a regular practice, to review the non-scrap events. As noted earlier, there were 366 IMTs logged in 2008, and only 57 events involved scrap. Any trend in the remaining 309 IMTs was potentially lost because the information was not reviewed for predictive opportunity and learning. Because the business unit measures performance on the ability to reduce ITPs, the focus of an IMT trend review is not leveraged to reduce ITPs or improve efficiency, cost savings, etc. The intent of this research was to use all the pertinent information available to build a predictive preventative maintenance model.

Improved Manufacturing Up-time

By allowing the content experts to document, analyze, and view both ITP and NM incidents, the primary failure signal for each system in the facility was significantly more obvious. Maintenance technicians no longer were unaware of long term performance trends, and now were able to input all the performance information into standardize related failure categories. By identifying common causes of equipment failure, technicians were able to predict preventative maintenance actions that would reduce the frequency with which downtime incidents were encountered.

This suggested program was allowed to “test” experiment in one facilities department for nine months during 2009. As a result, the site facilities group adopted the experiment process and progressed from 22 ITP events in 2008 to two ITP events in 2009, 2010 and 2011. Figure 6.3 summarizes the improvement “at a glance” and also shows that NM events were reduced by the process of measuring both ITP and NM instances, categorizing the specific root causes, and then acting accordingly to solve the main issues.

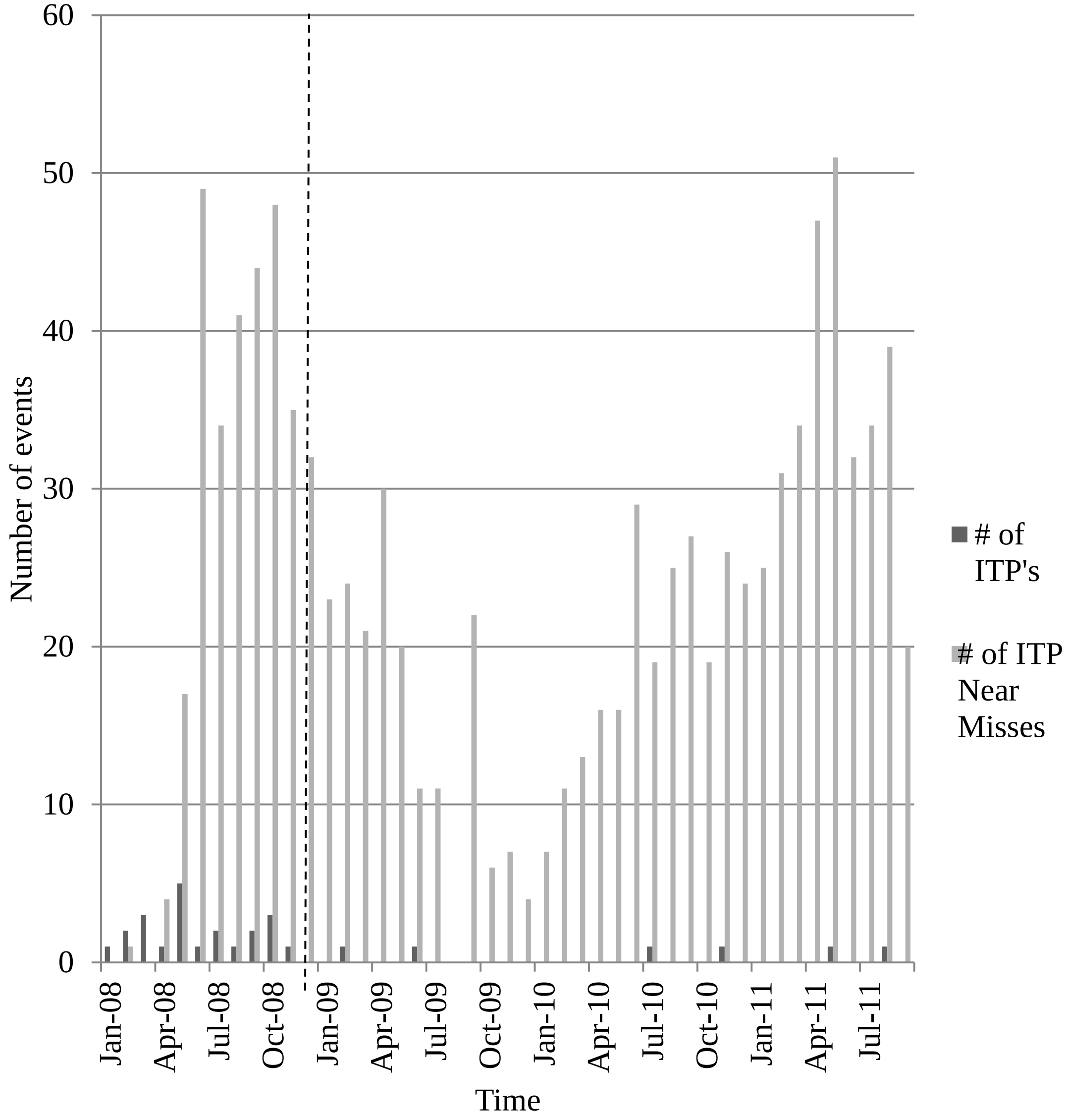


Figure 6.3. ITP frequency of status quo 2008 versus hypothesis testing duration through 2011

Improved Leadership through more Effective Resource Alignment

ASU’s FM course gave the author a new leadership perspective; the status quo micro-management cycle he was in changed drastically to support the empowerment of reduced management decision making. Figure 6.4 illustrates the status quo with problem solving and communication of information in the author's organization at Company ABC.

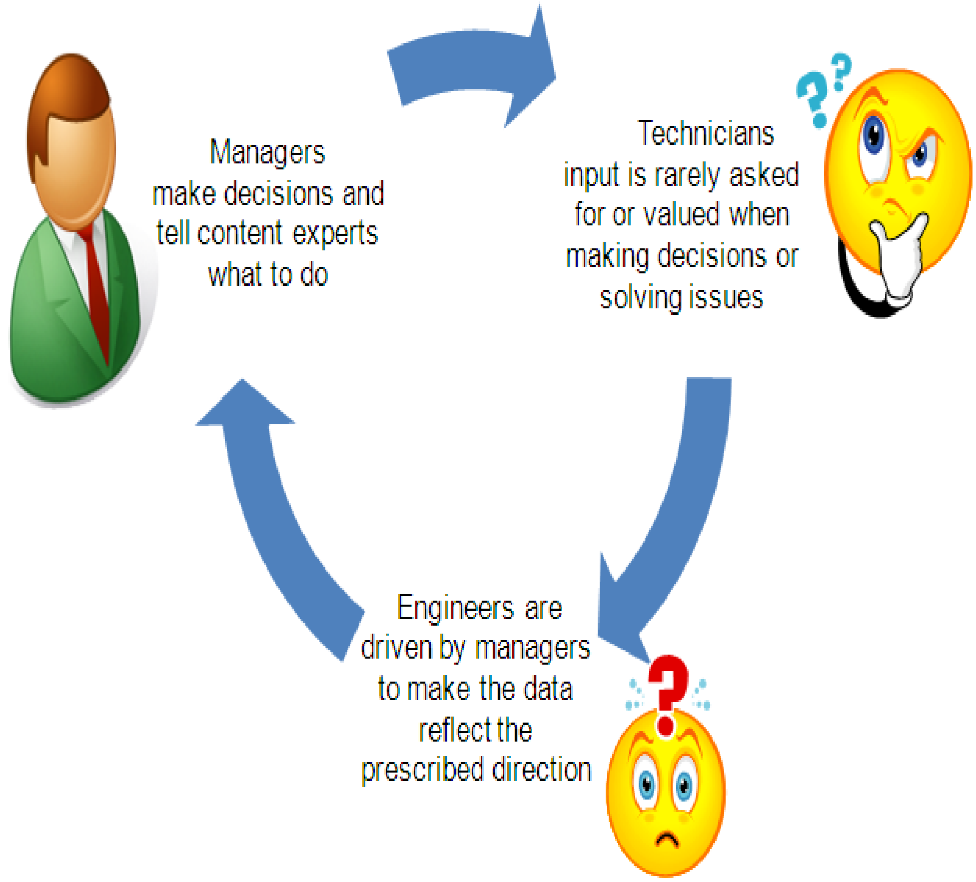


Figure 6.4. Status quo management decision making

Figure 6.5 demonstrates the leadership model learned through ASU's FM program. Through the use of resource alignment and minimized decision making, the author's facilities engineering and technician team were able to more effectively solve issues by responding to dominant information and utilizing the content expertise of the people closest to the problems.

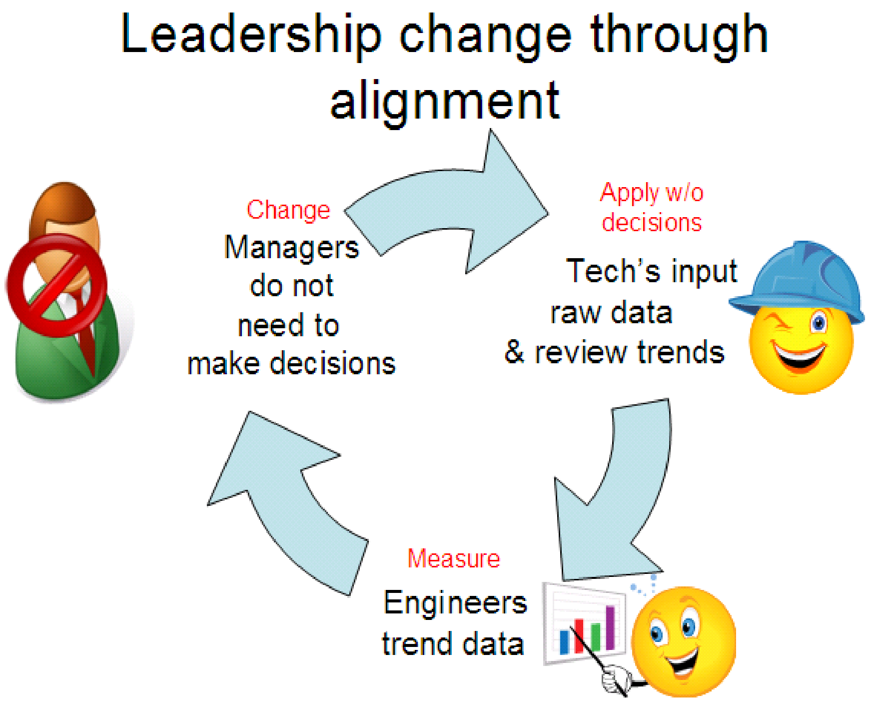


Figure 6.5: Leadership versus management

This research demonstrated how more effective performance measurement, with a leadership versus management approach, at a semiconductor facility could result in greater system availability. The results are not limited to the semiconductor industry; there is great potential to apply this methodology in a wide range of facility management operations across different industries. Performance measurement is a critical component to enabling facility management teams to quickly and clearly identify equipment issues. If management provided more opportunities to engage technician content experts, the technicians would be more effective in real-time performance impacts and priority setting. They would also gain the ability to strategically address root-cause unscheduled downtime failures without the need for management intervention.

By aligning the correct people to the right level of work, overall performance greatly improved at Company ABC. Problems were solved by the correct, most technically knowledgeable owners. The collateral and unexpected benefit was that this system brought a sense of inclusion, which fostered a win/win work environment. After implementing this leadership technique into Company ABC’s daily program, to deal with the multitude of technical challenges, employees provided overwhelming positive feedback about feeling “empowered” and “appreciated.” More problems were solved and the author’s management scores increased.

Chapter 7

Findings and Results Discussion

Removal of Tacit Knowledge in a Dynamic Engineering Environment

The new work routine process satisfied the initial objective to reduce ITP events. The only shortfall of the work routine was that it was not sustainable. Kotter (1995, 1996) proposed that change is only sustainable when the new ways of thinking about change become part of the social culture. These new ways of thinking must result in new behaviors and approaches that become institutionalized.

Consistent with an action-research methodology, the author intended the case study to advance current theories on organizational change and provide practical guidance to leaders as change agents. However, it should be noted that the study was limited to the examination of one organization with very little socio-cultural diversity. While the study did enable the identification and examination of a finite number of independent variables, and their relations with an outcome variable, the findings relied on the observations, analyses, and inferences of the author as a consultant and participant in the change process for the organization’s leadership and management hierarchy. The author was too connected to the organization hierarchy to identify for the work group those factors that appeared most relevant to the change process. However, the author did not design the study to enable researchers to draw specific conclusions about the causal connections and outcomes of those factors, but rather to achieve a specific business deliverable.

As a result of the hypothesis experiment, the author received multiple recognition awards, culminating from the Chief Executive Officer at Company ABC. The author was acknowledged for owning and driving a strategic leadership objective that was implemented across technology areas with outstanding results. The author also received recognition in that his individual manager feedback scores were significantly improved. The manager feedback is an anonymous survey of the author’s direct reports. The survey revealed that due to reduced decisions made possible by the program change, technicians felt more freedom and job ownership in their direct reports. The author’s personal health and family life also improved due to lower stress levels; knowing that a balanced leadership system was in place to address project and people management tasks. A future recommendation from the manager feedback survey was to have the program implementation pursued at other facilities groups associated with the author’s business unit at sites around the world.

As a facilities manager, the author’s engineering and technician staff members routinely confront him with a wide range of organizational issues and opportunities. For example, the organization consistently goes through cycles of new product development integration referred to as “process transfer.” During a process transfer cycle, the technical staff must integrate new facilities process requirements and capital equipment to start production of next generation devices. While the cycle is fairly robust in methodology, it is always difficult tactically.

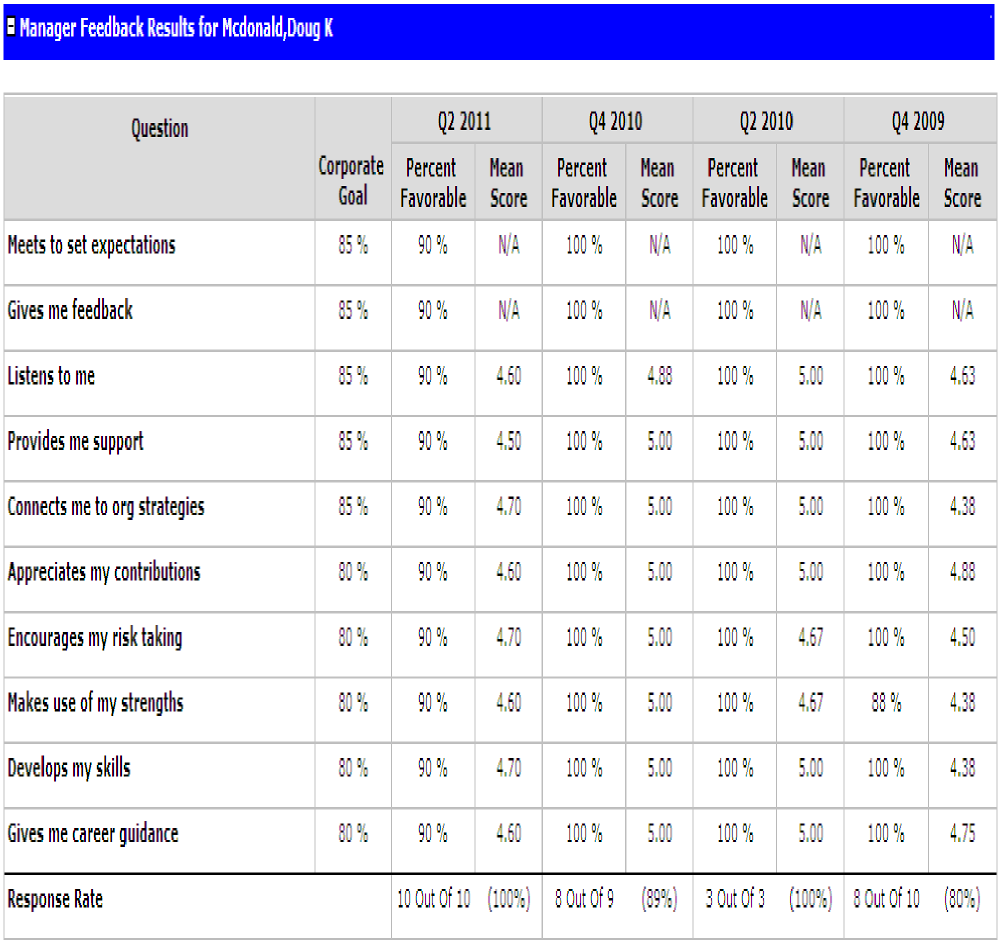
As a leader of the organization, the author referred his staff to the Kashiwagi Solution Model (KSM), and confidently explained that the organization was in the initial conditions phase of the event. The author's group appreciated the empowerment and insight provided by knowing that a more holistic plan was in place and by knowing where they stood in the organization. Organization members agreed to support each other by identifying all dominant information in order to minimize decisions. Overwhelming feedback indicated that this process transfer was forward looking and "the process was unlike previous transfers in that organization members were taking a proactive position." As a result, the transfer progressed on-track and for the first time ever, this facilities group did not incur a constraint to the production start-up. When critical systems that were deemed high risk were reviewed before they broke-down, people felt better about the challenge and what exactly they should be looking for as possible failure issues.

A clear measure of improvement that the KSM method brought for the author at work was a much calmer disposition versus reactive emotional surprise. When he felt surprised and started to get frustrated, he remembered the KSM concept that "it is his fault for not perceiving and predicting the result." By focusing on leadership versus managing, the author talks to his staff one-on-one monthly and asks them to predict the accomplishments they will attain in the next six months. He asks them what road blocks or constraints exist that are beyond their control. The responses have been amazing; exceeding beyond what the author would have recommended as goals.

Figure 7.1 illustrates improvement of leadership skills through this program with the survey results referred to as “Manager Feedback Tool” (MFT). Every six months all employees are asked to rate their manager (using a ten question survey). The survey results weigh heavily on the manager’s annual evaluation. Most managers in the organization believe that the employee assessment really boils down to an employee’s most recent experience with his or her manager; rarely do employees “keep score” during the entire year.

During April, May, and June of 2010, the author was studying, implementing and attempting to role model the KSM concepts. Figure 7.1 shows his manager feedback scores. While there has been significant improvement in facilities equipment availability from Q4 2009 to Q2 2011, the author attributes the KSM concepts for ability to maintain existing high scores. Notice the Q2 2011 scores dropped from 100 percent to 90 percent; this was due to one of ten survey responders acknowledging to the survey exactly opposite. After submitting the survey, the respondent realized he had selected the lowest possible score versus the intended highest score. The respondent made significant attempts to amend the submitted survey but system integrity policy made the editing effort unsuccessful.

During the past three years, the author's focus has been on "aligning people to their best positions" and "leading versus managing."



⊟ Manager Feedback Results for Mcdonald,Doug K

Question	Corporate Goal	Q2 2011		Q4 2010		Q2 2010		Q4 2009	
		Percent Favorable	Mean Score	Percent Favorable	Mean Score	Percent Favorable	Mean Score	Percent Favorable	Mean Score
Meets to set expectations	85 %	90 %	N/A	100 %	N/A	100 %	N/A	100 %	N/A
Gives me feedback	85 %	90 %	N/A	100 %	N/A	100 %	N/A	100 %	N/A
Listens to me	85 %	90 %	4.60	100 %	4.88	100 %	5.00	100 %	4.63
Provides me support	85 %	90 %	4.50	100 %	5.00	100 %	5.00	100 %	4.63
Connects me to org strategies	85 %	90 %	4.70	100 %	5.00	100 %	5.00	100 %	4.38
Appreciates my contributions	80 %	90 %	4.60	100 %	5.00	100 %	5.00	100 %	4.88
Encourages my risk taking	80 %	90 %	4.70	100 %	5.00	100 %	4.67	100 %	4.50
Makes use of my strengths	80 %	90 %	4.60	100 %	5.00	100 %	4.67	88 %	4.38
Develops my skills	80 %	90 %	4.70	100 %	5.00	100 %	5.00	100 %	4.38
Gives me career guidance	80 %	90 %	4.60	100 %	5.00	100 %	5.00	100 %	4.75
Response Rate		10 Out Of 10	(100%)	8 Out Of 9	(89%)	3 Out Of 3	(100%)	8 Out Of 10	(80%)

Figure 7.1. MFT Survey results for the author during hypothesis testing

In the absence of a program champion, new business processes demonstrate initial inconsistent and unsustainable behavior. While all stakeholders agreed that the new process of NM logging was the only change and ultimately delivered the significant reduction in ITPs, approximately six months later, during 2010, the model results concluded that there was a fundamental fault with the ability to sustain the process. While there was success in the primary objective of reducing facilities ITP events, a detrimental human behavior element was also becoming apparent. The behavioral impact to the new process was highlighted when the process champion/leader/author was removed for ten weeks while on sabbatical. Figure 7.2 illustrates the first half of 2010 where ITP performance was consistent with the progress made on ITP reduction in 2009, confirming effectiveness at reducing unscheduled facilities equipment failures. The spike in ITPs during the third quarter of 2010 occurred when the program owner took a sabbatical, from June to early August. During the sabbatical period, ITPs shot to 14 incidents, more ITPs in that short duration than all of 2009 (13 ITPs).

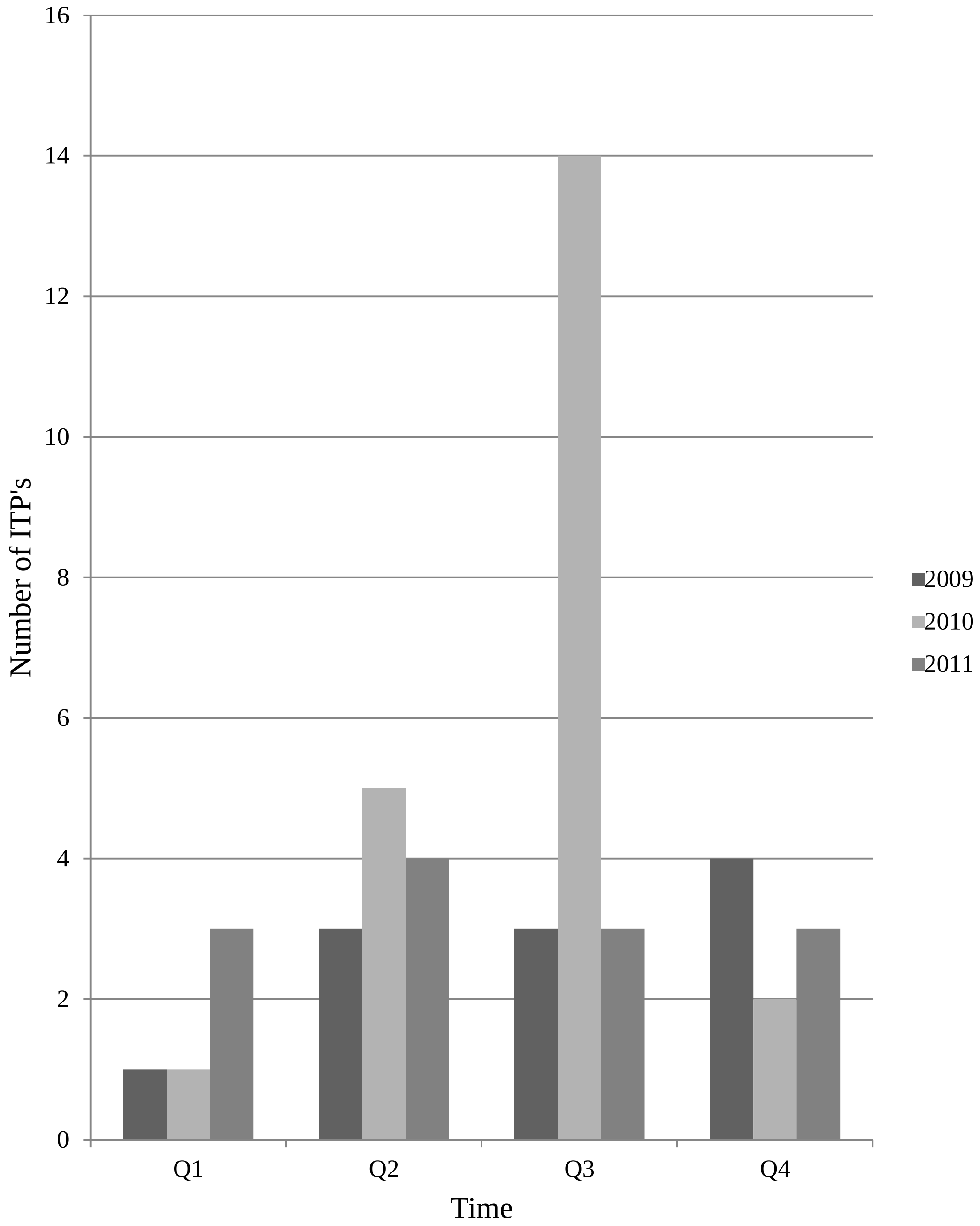


Figure 7.2. 2009, 2010 and 2011 ITPs by quarter with new work routine in place

As the program owner returned to the facilities organization post sabbatical, the performance indicator for ITP reduction had drastically

deteriorated and the overwhelming hypothesis was, “When the leader is not present, the population will revert to old ways or habits of doing work.”
The hypothesis as to why this behavior occurred was multi-faceted with the need to better understand if the mere presence of someone who is known to measure and drive accountability was required to change behavior or if there was a socio-cultural feature the work routine model failed to consider?

At a holistic level, the only performance comparison was ITP downtime events 2009 versus 2010; this was the primary success indicator. However, what was not expected or considered was the impact to the technicians performing the work. How would the new process consider the various socio-cultural perspectives that comprise the user population? Was there a need for greater user orientation and process setup or training to establish a foundation for understanding the cultural diversity within the group? Given the socio-cultural features of the user group, would individual participation among group members be enhanced or limited?

One of the key learning’s along this perspective was the relationship of varying participation within the user group. Every person in the user group participated in the author’s testing of the predictive model; however there was not statistically significant correlation to participation rates comparing user’s age or shift worked.

Chapter 8

Conclusion

From 2009 through 2011, the proposed study for predictive equipment failure hypothesis testing program was allowed to "pilot" as an experiment in one facilities department at Company ABC. As a result, the site facilities' group adopted the experiment process and progressed from 22 ITP events in 2008 to two ITP events in 2009, two ITPs in 2010 and two ITPs 2011. Figure 8.1 summarizes the ITP improvement by year.

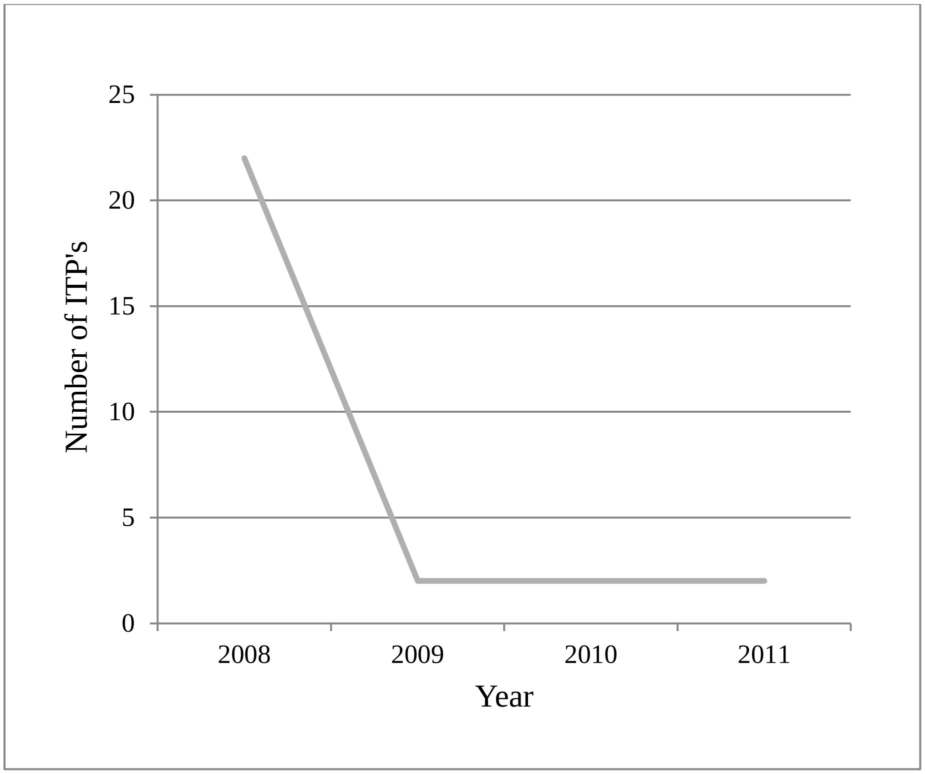


Figure 8.1. ITP improvement 2008 through 2011

The box plot chart in figure 8.2 illustrates the total number of service calls per week for all facilities equipment in the 2008 status quo system versus the

KSM leadership methodology experiment in 2009. The result is a significant decrease in the number of equipment failures through alignment of priorities at the proper job level. This alignment more effectively allocated resources, predicted failure and determined the root cause of failures by utilizing all dominant failure information.

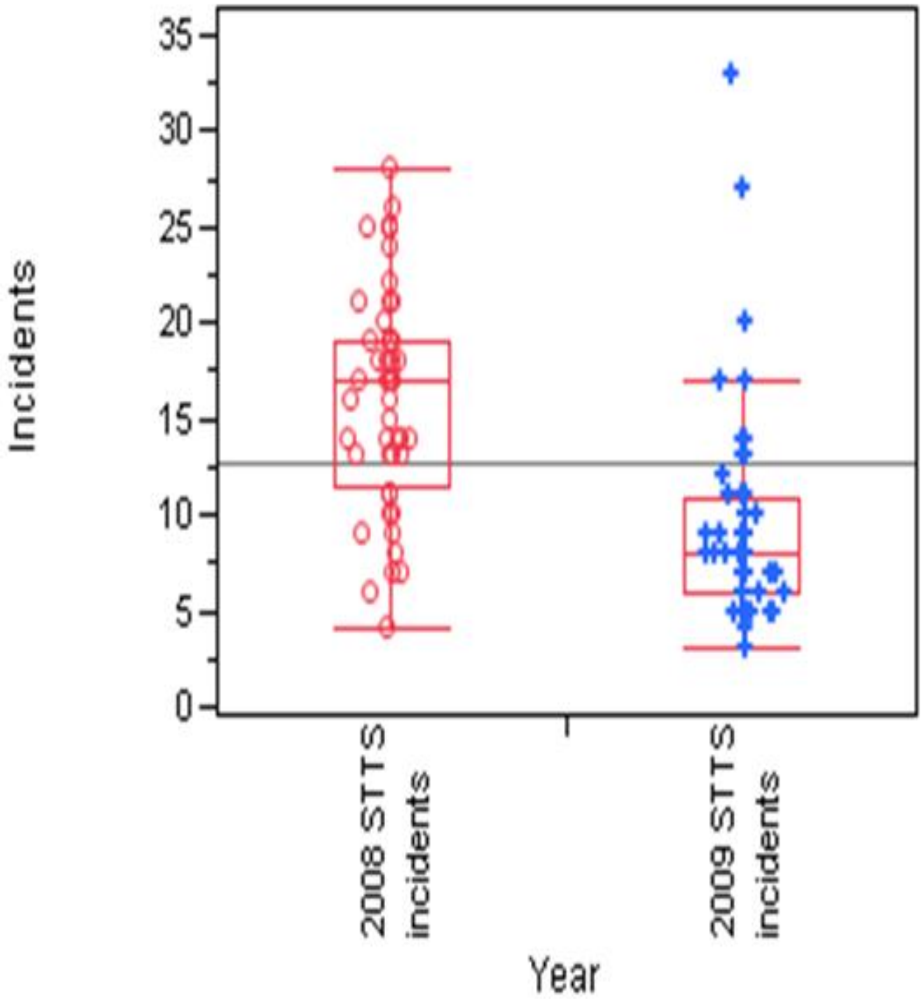


Figure 8.2. Box plot of status quo 2008 versus hypothesis testing 2009

The facilities' team of engineers and technicians found the new model of data collection, review and availability monitoring to be an indispensable tool. It was determined that this method of decision-less priority setting for equipment worked very well for equipment that is mature and well understood. New equipment which had not been well characterized, or was performing significantly below expectations and had multiple causes of downtime, required an initial quantitative model or game plan roadmap for goal setting. Evidence from the program's success indicates that the time from problem identification to permanent solution can be significantly reduced through the near elimination of repeat interruption events, thereby increasing tool reliability.

Scatter plots in figure 8.3 illustrate the total number of unscheduled CM downtime events per week for all facilities equipment in the 2008 status quo system versus the KSM leadership methodology experiment in 2009. The result is a significant decrease in the number of unscheduled equipment failures.

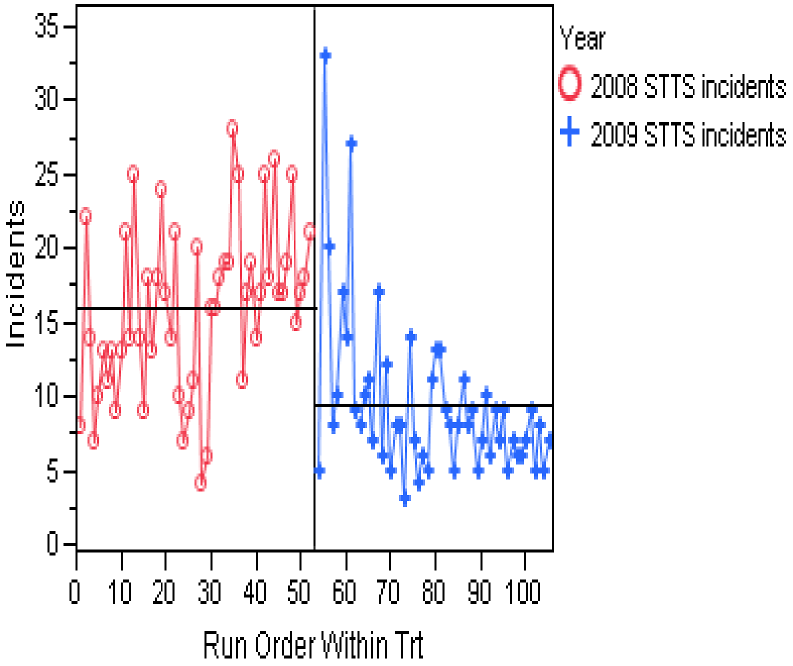


Figure 8.3. Scatter plot of status quo 2008 versus hypothesis testing 2009

The hypothesis testing associated with this dissertation provided improved data tracking and review to minimize complexity and variation associated with facilities equipment downtime and maintenance activities. The typical tool availability variation illustrated in figure 8.4 was improved through the use of process kit pre-builds and parts availability. PM performance tracking charts also came into play after technicians and engineers were given full accountability for tool availability and maintenance system ownership.

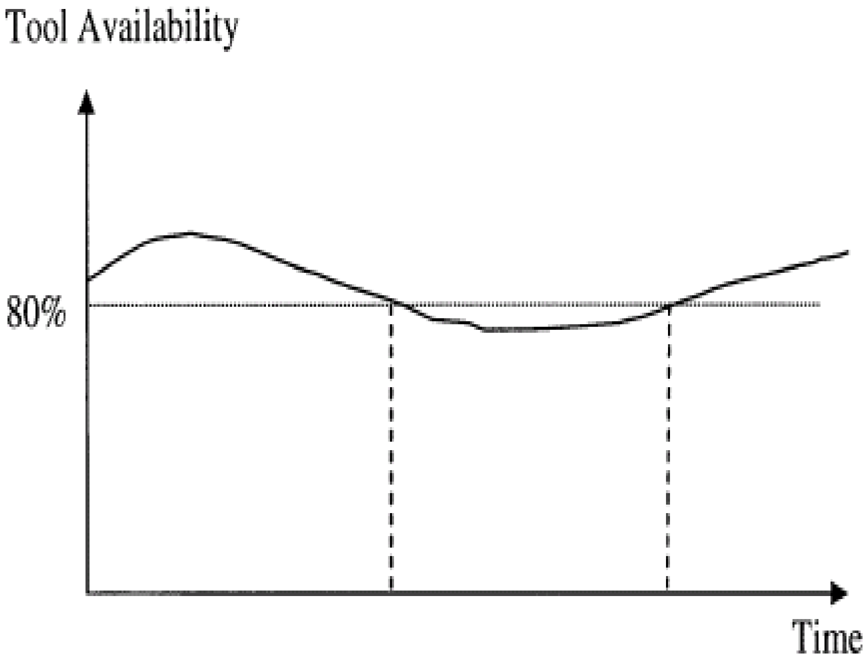


Figure 8.4. Semiconductor industry tool availability variation (Kwong 2004)

Commercially available automation programs and monitoring systems often used with fab maintenance operations were not employed. General feedback from the facilities’ technician population went further with suggestions for testing various off-the-shelf tool supervisor software packages that allowed operators to more efficiently troubleshoot tool problems. These packages provided greater access to all subsystem data without having to create separate database networks across multiple tool components, which were separated physically but connected in the manufacturing process. Semiconductor manufacturing standards organizations should strive for future plans to include developing a draft standard for equipment software integration to a fab maintenance system and demonstrating implementation in a real fab environment that includes associated facilities systems (Mosley 1998).

The hypothesis testing provided improved (reduced) inconsistencies across the average tool availability of the previous year. Because of the progress achieved in the new maintenance and data review models, standardized usage-driven PM events and calendar based planning were met with a combined data collection review. The result was reduced variability and significantly improved tool availability through facilitation of performance tracking and accountability aligned to the correct level of the organization – technicians and engineers were able to ensure consistency in decision making with minimal communication.

Figure 8.5 demonstrates the findings from the resultant ITP reduction effort in approximately $2.87M saved in 2010 (after the change) as compared to the status quo process of 2008 (before the change).

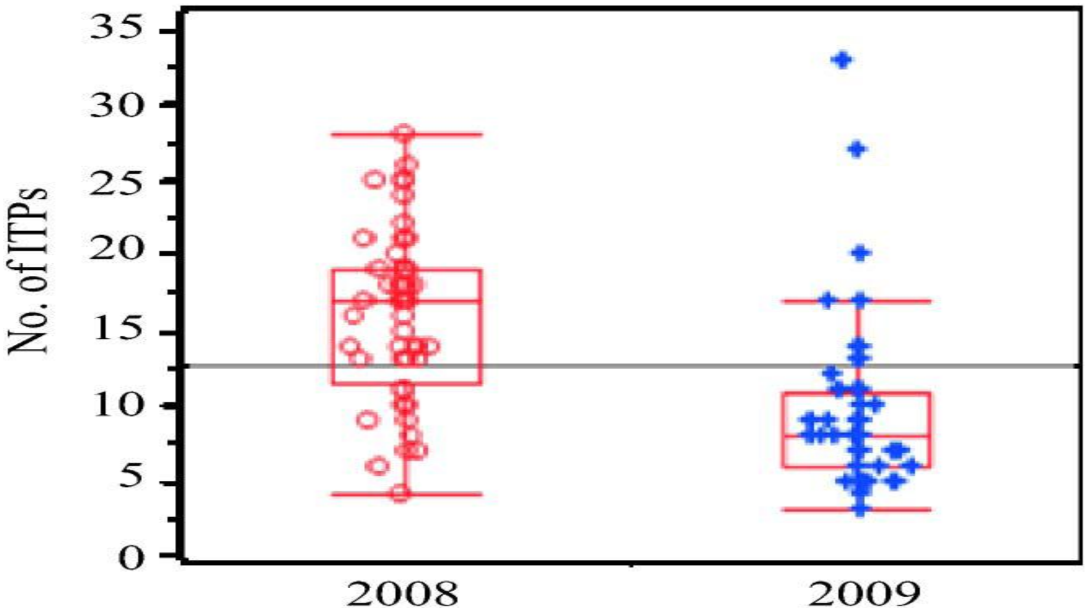


Figure 8.5. Work routing process change cost savings results

Key Leadership Learning

Nurture the talent: One of the key wisdoms obtained in the leadership model is that a manager needs to manage subtly and be as transparent as possible. This case study proved that a true leader could teach and develop best practices for his/her team by instituting his/her organization in the business process. This effort should give a manager insight into how to approach team members to best meet their needs.

Listen: Each company has its own language of business, even the best operate on perception versus dominant information. Learn how issues are defined and how goals are described in the corporate vernacular. Translate new ideas and data driven initial conditions into the language your employees already understand so they can translate it and apply it to themselves.

This research demonstrates how more effective performance measurement within a leadership versus management structure is able to improve the leadership processes with multiple collateral benefits. The results are not limited to the semiconductor industry; there is great potential to apply this methodology in a wide range of facility management operations across different industries. Performance measurement is a critical component to enabling management teams to quickly and clearly identify equipment issues. If management provided more opportunity to engage first hand content experts, there would be more effective real-time performance impacts and priority to support today's fast action environment.

By aligning the correct people to the right level of work, Company ABC's overall performance greatly improved. Problems were solved by the correct, and most knowledgeable, owners. The collateral and unexpected benefits were that this system brought a sense of inclusion, which fostered a win/win work environment that greatly improved the status quo. After implementing this leadership technique into the author's daily program, in order to deal with the multitude of resource allocation challenges, people gave overwhelming positive feedback about feeling "empowered" and "appreciated."

Future Recommendation

To pursue implementation of this leadership methodology to other facilities groups, associated with the author's business unit at sites around the world, one negative finding has, to date, been observed. That is the author's lack of patience with senior management who cling to controlling and emotional decision making, despite dominant information on the benefits of leadership versus management behaviors.

Survey Result Comments from Technicians involved in the Program

“I just want to say thank you. We very much appreciated you taking time from your busy schedule to sit down and converse with us. We felt the exchange was very constructive and we hope the end results will prove positive for all concerned. Again.... Thanks.”

“Just a note to let you know that it feels good to be included by you in your decision making, and my peer’s as well as my own opinion are taken under account before moving forward with the challenges that the maintenance group is currently facing with diminishing head count. There are a few examples to mention but the one that stands out for me is: you requested my input/ideas and collected data concerning the IR Scans on tools in the two operating factories plus the PD data collected from Maximo.”

“I have never felt that any of the managers are unapproachable, but you have demonstrated a unique way of meeting with our group, showing an open mind in listening to all of the ideas, no matter how insignificant or irrelevant they may have seemed at the time”.

“Recently we (our group) were approached by our manager, Doug McDonald, for help to assist him in providing documentation of our group’s activities in supporting the organization and its goals. He understands that we support all groups in CS, and that much of our support records are lost in the system due to various reasons. He asked us for our opinions and thoughts, and, if we could, to provide him with records to support his goal of promoting us to you and your staff and for justification for future head count. He helped us to understand his frustration in being able to adequately represent us without data. I am not sure when the last time we had a manager try to promote us (Electrical) with real data and show just how much we contributed to organization success. I just wanted to let you know how our group was surprised and pleased to be asked for help like this. This data is the real thing!"

Chapter 9

Concluding Remarks and Future Research Directions

The facilities' management team found the new model of data collection, review, and availability monitoring, to be an indispensable tool. It was determined that this method of decision-less priority setting for equipment worked very well for equipment that is mature and well understood. New equipment which has not been well characterized, or is performing significantly below expectations and has multiple causes of downtime, requires additional quantitative modeling for effective results. Evidence from the program's success indicates that the time from problem identification to permanent solution can be significantly reduced through the near elimination of repeat interruption events, thereby increasing tool reliability. The hypothesis testing provided improved (reduced) inconsistencies across the average tool availability of the previous year. Because of the progress achieved in the new maintenance and data review models, standardized usage-driven PM events and calendar based planning were met with combined data collection review. The result was reduced variability and significantly improved tool availability through facilitation of performance tracking and accountability aligned to the correct level of the organization – technicians and engineers were able to ensure consistency in decision making with minimal communication.

The new model, however, was not considered a success from a sustainable work group process for routine tasks. At this time, further modeling and communication needs to done to understand why the leader's absence from the process tends to enable people to regress to the status quo process. The leading hypothesis is that there is a general discomfort of technology, more specifically, the work group over age 45 may not feel comfortable with the added technology driven work load of logging critical information into the database on a regular basis.

The key learning from this endeavor is that the dynamics of socio-cultural features in a work group (even one with very little diversity) are multidimensional and are not static. The work group performance demonstrated multiple factors with one common denominator “change over time.” Within the improved environment, there was a delta of improvement found in leadership superior to former results; however, removal of leadership resulted in reversion to prior practice. The new process was more effective but demonstrated a less satisfying return to the leader. There was no other change except business data results. No negative or positive incentive performance immediately disclosed what caused this behavior scenario. Through the author’s knowledge, obtained in recent university courses, and the point that information is socially constructive, the author seeks to continue ITP reduction efforts with this work group, focusing on:

- Discovery of socio-cultural importance through performance measurement; sustained organizational change on micro scale with individual input to optimize and support employee strengths. Creating a program that is not “one size fits all.”

- Compare efficiency of change with better relationship driven processes like utilizing a buddy system of worker pairings, with the intent of understanding the factors that vary across age groups, and the data that can be observed.

In order to regain and retain a dominant position world-wide, the United States semiconductor industry must help itself. Research and high technology manufacturing prowess are under attack due to the high cost of entry and increasing intellectual property confidentiality standards. In order to capitalize on the current technical leadership in the United States, efficiency capabilities in these areas must be improved. There is no need for high capital technical breakthroughs to solve the majority of manufacturing constraints. Simple, logical structured and analytical approaches will provide the most effective solutions to increasing capital and manufacturing productivity (Kanagal, 1990).

A recommended future research direction is to pursue the business process analysis for standardization. Identifying key processes through direct observation of activities within the value chain and assigning responsibility of activities for inspections (or preventive maintenance), spare parts inventory, and purchasing policies to align the correct resources to projects and configure tools to support maintenance and facility management availability goals.

The work flow of maintenance and facility management operations needs to better exchange dominant information related to equipment history, warranties and regulatory requirements to be accurately compared to industry standards.

Utilizing a maintenance management database and computer aided facility management systems, with data openly shared for best known methods with other factories and industries, would assist in integrating the various data acquisition opportunities and give rise to a more comprehensive management system (Vogt, 2004).

Continuous improvement and business process re-engineering deserve attention as important parts of the framework. Innovative approaches need to be encouraged and adopted to support the ability for improvement in order to exploit new technological opportunities for modification to an environment where the systems operate in a short life cycle. The continuous improvement approach crosses all previously discussed areas and represents a leverage point to consistently implement a data driven maintenance strategy with the correct alignment of resources.

A standardized set of metrics should be implemented to monitor the most effective performance indicators, allowing a continuous real time tracking of the current situation versus targeted goals with minimal decision making. Based on this literature review, the following topics would be of great benefit for the next generation of maintenance and facility management systems:

- Standardization of maintenance specific to the facility management or industrial technician role with focus on sustainability.

- Return on investment studies for embedded systems for self diagnosis and self prognosis of expected failures through use of smart sensors and wireless communication.
- Development of diagnostic and prognostic algorithms especially for mechanical systems with well defined load and utilization ranges.
- Methods for cost optimization and safety risk control.
- Investigation into facilities availability impacts to the semiconductor industry as it relates to cost, impact to production, and resource planning.

To be most effective in today's PdM environment, smart devices should be used whenever feasible. With the intent of understanding initial conditions, accurate field information needs to be maximized to generate information about system conditions and the process equipment behavior. An intelligent network can relay this type of NM data to an asset management program. The data then can be used for predicting equipment life and scheduling repairs.

Utilizing asset management programs, CMMS, PdM and condition based monitoring are all proven technologies that provide real savings and efficiency improvements, but only if they are implemented by knowledgeable and experienced resources. With a good PM and PdM strategy in place, the focus on improving the reliability of critical equipment becomes easier as the biggest downtime issues become more obvious. The key to a good reliability strategy is to understand that it is a living program; that it needs to be continuously reviewed and improved by all stakeholders through reality based real-time observation.

References

Abdelmoez, Walid. 2007. Using maintainability based risk assessment and severity analysis. *IEEE International Conference on Software* 4244 (1031): 51-58. DOI: 1-4244-1031-2/07 IEEE.

Armenakis, Achilles A., Harris, Stanley G., and Mossholder, KevinW. 1993. Creating readiness for organizational change. *Human Relations* 46: 681–703.

Blann Dale, R. 2003. Reliability as a strategic initiative: to improve manufacturing capacity, throughput and profitability. *Asset Management and Maintenance Journal* 16, no. 2. http://www.marshallinstitute.com/inc/eng/justforyou/Body/articles/reliability_str_init pdf (accessed October 13 2007).

Blegen, H. M. 1968. Organizing the maintenance function - an analytical approach. *The International Journal of Production Research* 7, no. 1: 23-32.

Bonora, Anthony. 2001. Automation optimization new tools and fabs demand 300mm. *Solid-State Technology Magazine 44.*

Bordia, Prashant., Hunt, E., Paulsen, Neil., Tourish, D., and DiFonzo, N. 2004. Uncertainty during organizational change: Is it all about control? *European Journal of Work and Organizational Psychology* 13: 345–365.

Chan, K. T. 2001. Maintenance performance: A case study of hospitality engineering systems. *Facilities* 19: 494-504.

Chen, Wen-Chih. 2008. Economic efficiency analysis of wafer fabrication. 2008 Winter Simulation Conference, 978(6): 2216-222.

Coch, L., French, J. 1948. Overcoming resistance to change. Ruman relations study: a critique and reinterpretation 1 (4): 512-32.

Cullen, S. March 16, 2009. Global semiconductor outlook. *Microprocessor Report*, Retrieved from http://www.mpronline.com/mpr/p/2009/0316/231101.pdf

Damodaran, Aswath. 2011. *Cost of capital - New York University*. Retrieved from http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/wacc.htm.

Davenport, Thomas H. 1993. *Process innovation: reengineering work through information technology*. Boston: Harvard Business School Press.

DiCecio, Riccardo. 2008. Changing trends in the labor force: a survey. *Federal Reserve Bank of St. Louis Review* 90: 47-62. (web April 7, 2011).

Dictionary of Human Resource Management. 2001.

Drucker, Peter F. 1995. *Managing in a time of great change*, M. Truman Talley, Truman Talley Books/Dutton.

Fischer, G. Beyond ‘couch potatoes’: From consumers to designers and active contributors. *First Monday* 7, 12 (2002); http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/1010/931.

FitzGerald, Mark. 2004. Semiconductor capital equipment industry overview. *Equity Research United States - Banc of America Securities*. New York: Bloomberg.

Frohman, Mark. A.,Sashkin, Marshall, and Kavanagh, M. J. (1976). Action-research as applied to organization development. *Organization and Administrative Sciences 7*(1/2): 129-161.

Ghazinoory, S. 2007. Fuzzy SWOT analysis. *Journal of Intelligent and Fuzzy Systems* 18 no.1: 99-108. IOS Press.

Glen, Paul. 2005. Computerworld. 39 (18): p41-41.

Godfrey, Philip. 2002. Overall equipment effectiveness. *Manufacturing Engineer* 81 (3): 109-112.

Gregory, Annie. 2011. The numbers game. *Works Management*, 22-24. DOI: www.worksmanagemeht.co.uk.

Hawthorne Effect.. (2001). Available from Business Source Corporate. (25505746). Master’s thesis, OxFord Universite. Retrieved from http://web.ebscohost.com/ehost/detail?sid=f37fa360-c253-44e7-a69c-008cf8c6b949@sessionmgr115&vid=1&hid=122&bdata=JkF1dGhUeXBlPWlwLHVybCx1aWQmc2l0ZT1laG9zdC1saXZl.

Hays, Garry. 2000. Interview with William Badger. *The Vietnam archive*. Retrieved June 5, 2010 from http://www.vietnam.ttu.edu/star/images/OH/OH0001/OH0001.

Intel, Press. (Photographer). 2008. *Moore's law continues*. Retrieved from http://www.intel.com/technology/mooreslaw/index.htm.

Jefferson, T. 1995. Using Simulation to analyze the components. Auto Simulations *SEMATECH* 7: 16-23.

Jefferson, T. 1999. Reducing labor requirements for 300mm factories with intrabay automation. *ISSM Proceedings*: 1-5.

Kanagal, Ashok. 1990. The Equipment improvement program. *IEMT Symposium*: 25-30.

Kashiwagi, Dean. 2010. *A Revolutionary approach to project and risk management*. Mesa: Kashiwagi Solution Model (KSM).

Kim, Yangkyu. 2005. Samsung outlays on chip facilities to hit $33 billion. *Wall Street Journal*, September 30, B4.

King, A.J. 1996. Use of goal modeling and reliability engineering tools to accelerate availability improvement in new equipment development. ASMC 96 Proceedings, IEEE/SEMI Advanced Semiconductor Manufacturing Conference.

Kotter, John. 1995. *Leading change*. Boston: Harvard Business School Press.

Kotter, John., and Heskett, James. 1992. *Corporate culture and performance*. New York: Free Press.

Kwong, William. 2004. Reducing variability in equipment availability at Intel using systems optimaization. Massachusetts Institute of Technology.

Labs, Wayne. (2009, December). Decrease unplanned downtime and get a leg up on the. *Food Engineering*, 55-62. Retrieved from www.foodengineeringmag.com

Lewin, Kurt, and Gold, M. 1948. Group decision and social change. *The complete social scientist: A Kurt Lewin reader*, ed. M. Gold, 265–284. Reprint Washington, DC: American Psychological Association, 1999.

Linton, Jonathan. 2006. Preventive and predictive maintenance tools. *Circuits Assembly* 16: 14-16.

McElroy, Martin. 2007. Quality strategies for facility operations and maintenance. *Buildings* 101: 92-96.

McGuire, John B. and Rhodes, Gary B. 2009. Transforming your leadership culture. San Francisco: Jossey-Bass.

Moubray, John. 1995. *Maintenance management - a new paradigm*: 1-12.

Mosley, S. A. 1998. Maintenance scheduling and staffing policies in a wafer fabrication facility. *IEEE TRANSACTIONS ON SEMICONDUCTOR MANUFACTURING* 11 no. 2: 136-323.

Mudrak, Thomas. 2004. Assessing the innovative ability of FM teams: a review. *Facilities 22*: 290.

National Center for Manufacturing Sciences, Inc. and Society of Automotive Engineers, Inc. 1995. Reliability and maintainability guideline for manufacturing machinery and equipment. 2nd ed. M-110.2. NCMS or SAE.

Nita, Ali K. 2002. Improving the business process of relative maintenance projects. *Facilities 20:* 251-262.

Nutt, Bev. 2000. Four competing futures for facility management. *Facilities 18*: 124.

Osborn, R. 1974. Environment and organizational effectiveness. *Administrative Science Quarterly* 19(2): 231-246. Retrieved from http://www.eric.ed.gov/ERICWebPortal/search/detailmini.jsp?_nfpb=true&_&ERICExtSearch_SearchValue_0=EJ099399&ERICExtSearch_SearchType_0=no&accno=EJ099399.

Osborne, M. (2011, March 02). Semi world fab forecast: fab capex forecasted at us$47.2 billion in 2011. *Semiconductor Media Limited*, Retrieved from http://www.fabtech.org/news/_a/semi_world_fab_forecast_fab_capex_forecasted_at_us47.2_billion_in_2011/?utm_source=feedburner&utm_medium=feed&utm_campaign=Fabtech – News

Pass, E. *"Extending heavy equipment life"*. (2011, September). Retrieved from http://www.ekpass.com/results/extend_equipment_life.php.

Piderit, Sandy K. (2000). Rethinking resistance and recognizing ambivalence: A multidimensional view of attitudes toward an organizational change. *Academy of Management Review* 10, 783–794.

Piplani, Rajesh. 2004. Simplification strategies for simulation models of semiconductor facilities. *Journal of Manufacturing Technology Management* 15: 618.

Production equipment availability - A measurement guideline. 2002. The Association for Manufacturing Technology 3: 1-31. Retrieved from AMT@amtonline.org.

Roethlisberger, Fritz J. and Dickson, William J. 1939. *Management and the Worker*. Cambridge, MA: Harvard University Press http://ieeexplore.ieee.org/search/srchabstract.jsp?arnumber=5220457&tag=1.

Rogers, Everett M. (1962). *Diffusion of innovations*. New York: Free Press.

Rogoff, Barbara. 2011. "Firsthand learning through intent participation." Annu. Rev. Psychol. 54. (2003): 175-203. Web. 7 Apr 2011. http://www.scribd.com/doc/22986905/Firsthand-learning-through-intent-participation.

Sachs, Jeffrey D. 1995. Predicting project availability establishes economic viability. *Pulp and Paper* 69: 77-82.

Seeley, Ivor H. 1976. *Building Maintenance*. Macmillan Press Ltd, London.

SEMI. 1996. Standard for definition and measurement of equipment reliability, availability, and maintainability. Semiconductor Equipment and Materials International.

Singh, A. 1991. Capital equipment reliability. *IEEE/SEMI Advanced Semiconductor Manufacturing Conference* 72-76.

Smither, Robert D., Houston, J.M., McIntire, S.A. 1997. *Organizational Development: Strategies for Changing Environments*. New York: Addison-Wesley.

Stevens , H. (2009, December). Gartner says worldwide semiconductor capital equipment market growth is accelerating *Gartner Newsroom*, Retrieved from http://www.gartner.com/it/page.jsp?id=1252913.

Toole, D. 1989. Characterization of the manufacturing worthiness semiconductor process equipment. SEMI International Standards 2, no. 4: 73.

Vavra, Bob. 2007. Beyond the 'break-fix' mentality. *Plant Engineering* 61, no.7: 1-9.

Vogt, Holger. 2004. A New method to determine the tool count of a semiconductor factory using fabism. *Proceedings of the 2003 Winter Simulation Conference* 174, 1925-1929.

Vorster, Michael. 2007. Availability and utilization. *Construction Equipment* 50: 1.

Winter, P. 1998. Risks soar in growing semiconductor market. *National Underwriter* 102: 26-29.

Wroblaski, Kylie. 2010. Thinking outside the (industrial facility) box *BUILDINGS magazine*, Retrieved from http://www.buildings.com/ArticleDetails/tabid/3334/Default.aspx?ArticleID=9808.

Yang, Zimin. 2007. Maintenance priority assignment utilizing on-line production information. *Journal of Manufacturing* 129: 435-455.

Yufan, Wang. (2011). Optimal preventive maintenance strategy based on. *IEEE Transactions on Reliability*, *978*(9283), DOI: 978-1-4244-9283-1/11/$26.00 ©2011 IEEE.

Zakuan, Norhayati. 2009. Lean manufacturing concept: the main factor in improving manufacturing performance. *International Journal of Manufacturing Technology and Management* 17 no. 4: 353-363