MUIR DATA SYSTEMS, INC.

Wind Industry Work Order Information Flow Survey

Muir Data Systems / Wind Energy Technologies Sandia National Laboratories

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Background

Through a wide variety of activities and interactions, Sandia National Laboratories has observed limited adoption of electronic work orders in the wind industry. To explore the current use of work orders in the wind industry, the Continuous Reliability Enhancement for Wind (CREW) team at Sandia commissioned Muir Data Systems to develop and execute a survey on the topic. This report summarizes the responses and findings from that survey, including an overview of the work order information flow and assessments of the field, office, storage, and reporting aspects of work order use. This report is one of the steps in driving a culture change toward the electronic collection of accurate work order data and the development of a "full data picture" for the wind industry.

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1.0 Executive Summary

This document summarizes the findings of a preliminary survey of wind turbine maintenance management. The US wind industry has been growing rapidly but little information about current maintenance practices is available.

Human generated work order data has been one of the more challenging data streams to integrate from the technician in the field to a database appropriate for merging with SCADA and Condition Monitoring Systems.

The overarching goal of the survey was to better understand how maintenance management information flows in the wind industry and the potential benefits of wind Computerized Maintenance Management Systems (CMMS).

The survey broke the maintenance management process into four steps which included:

1) Field – How inspection and/or repair data is recorded by technicians
2) Office – How the office processes work orders and with what other office systems work order data is shared
3) Storage – How and where completed work orders are stored and how often they are accessed to inform future maintenance decisions
4) Reporting – What analysis tools are used to generate what kinds of work order reports

In each of the four steps of the maintenance management information flow survey model, an emphasis was placed on determining technology utilized, time required to complete each step, and survey respondent level of satisfaction.

The online survey was completed by 51 respondents from a variety of wind companies and employee backgrounds. The company types included: independent service providers, owner operators, and original equipment manufacturers, and the employee types included: technicians, engineers, managers, executives, and industry consultants.

It was found that the average work order information flow starts with a paper form which contains "Moderately Accurate" data, which is transcribed by the office into a "Somewhat Digital" hand-off to other office systems. The now "Digital" work order is stored on a server in a manner that is often not searchable and then reports are generated using templates in Excel, which typically takes 30 minutes. These reports are "Sometimes" used to help inform future maintenance decisions and the industry is "Moderately Satisfied" with this maintenance management scenario.

Key findings for each one of the information flow steps were as follows:

Field:

1) Respondent satisfaction was found to be the same for small companies processing few work orders and large companies processing large numbers of work orders

2) The top three pieces of information recorded in the field by technicians were:
    a. Inspection / Repair Information
    b. Time Spent
    c. Employee(s) Present
3) In only 30% of the cases were work orders used to inform future maintenance decisions
4) Given current maintenance management tools, there was no perceived increase in work order accuracy as technology sophistication increased
5) The more time that technicians spent filling out work orders in the field, the greater the accuracy
6) Field satisfaction generally increased as work order accuracy increased

Office:

1) The top three systems that work order data was shared with were:
    a. Inventory
    b. CMMS
    c. Finance & Accounting
2) There was a slight positive trend in office satisfaction as technology automation increased

Storage:

1) Work orders that were stored digitally were typically accessed more often
2) Regardless of whether work orders were stored at the wind plant, corporate headquarters, or both locations, there was no increase in how often work orders were accessed to help inform maintenance decisions

Reporting:

1) 57% of respondents performed no work order analysis or spreadsheet analysis
2) The top three work order analyses performed were:
    a. Parts Usage
    b. Downtime
    c. Budget
3) 45% of respondents share reports internally only, while another 36% share reports both internally and externally, and the remaining 19% was a mix of external sharing, not shared, internal database, and other

Respondents ranked the most important benefits of CMMS in the following order:

a. Scheduling & Planning
b. Predictive Analysis
c. Accuracy

The survey results support the conclusion that a wind specific CMMS, when properly implemented, could reduce costs, increase uptime, and improve employee satisfaction. Properly implemented CMMS in other industries have demonstrated operations and maintenance cost reductions approaching 50%.

The wind industry needs to demand better CMMS solutions. With current mobile technology CMMS can solve many of the challenges associated with the harsh and remote environment in which many wind turbines function.

Currently, development of CMMS in wind is lacking a focused effort. A committee dedicated to supporting the development a tailored wind maintenance management system would be a step in the right direction. Such a standardized system could significantly help lower the cost of wind energy.

Recommended follow on work included expanding the survey effort to increase statistical significance, and performing a case study of a wind maintenance organization before and after CMMS implementation. Standardization of data intake is important for wide industry adoption of CMMS and it is suggested that companies develop flowcharts of their current maintenance information trajectories such that an official taxonomy can be established.

In order to overcome the current implementation issues, the value propositions of CMMS must be better understood by the wind industry. The cultural barrier is one of the most difficult hurdles when convincing the wind industry of the value of data driven maintenance decision making.

2.0 Introduction

Proper maintenance management of utility scale wind plants is a difficult task. Wind turbine plants tend to be located in remote areas, are highly distributed, have a significant number of moving parts, operate in harsh environmental conditions, and present numerous safety concerns. These issues are not only challenging from a reliability standpoint, they are also a problem for the maintenance crews who keep the turbines functioning properly.

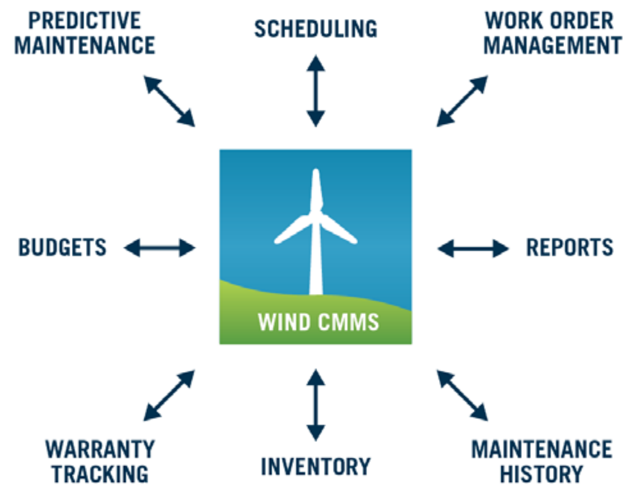

Figure 1: Wind CMMS Functionality Overview

The total installed capacity of wind turbines is rapidly growing, and in 2012 wind was the leading form of newly installed electricity capacity in the United States.[1] Furthermore, a large number of the turbines installed in the last decade are now coming out of warranty, and as a result, US operations and maintenance spending is poised to double to nearly $6B by 2025.[2]

The wind industry in its current manifestation is relatively young and has been suffering from growing pains. The demanding nature of wind turbine maintenance management in conjunction with the large number of wind turbines coming out of warranty has created a cross roads in which the long term variable costs associated with operations and maintenance can mean the difference between a successful investment in the wind industry and a failed one.

Properly implemented Computerized Maintenance Management Systems (CMMS) provide increased maintenance management efficiency. These software solutions streamline a host of maintenance management tasks into a single system (Figure 1). In other industries CMMS has demonstrated operations and maintenance cost reductions as high as 50%.[3] One of the cornerstones of CMMS is the usage of digital work orders that can be tracked in real-time and later analyzed to help inform predictive maintenance.

Understanding the status of a remote and complex electromechanical system such as a wind turbine requires a substantial amount of sensor data. Typically this data takes the form of Supervisory Control and Data Acquisition (SCADA) information, and more recently, specialized additional sensors such as Condition Monitoring Systems. These two sensor feeds are used to develop a partial understanding of how a wind turbine is aging.

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[1] Office of Energy Projects Energy Infrastructure Update. Federal Regulatory Commission, December 2012.
[2] O&M Spending To Double to Nearly $6 Billion By 2025. IHS Emerging Energy Research, July 2012.
[3] The Power of Infor EAM. www.infor.com/solutions/eam/, September 2013.

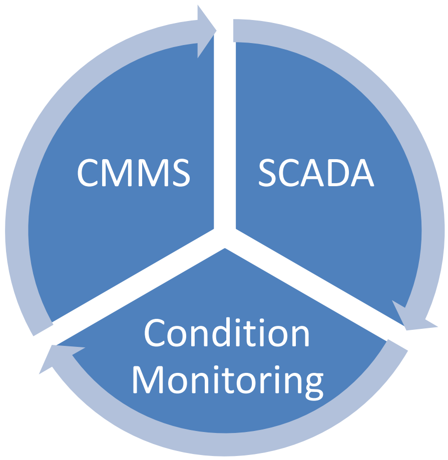

Figure 2: The Three Primary Data Feeds Required for Predictive Maintenance

In contrast, the source of CMMS data is the field technician performing the inspection and/or repair. Using CMMS, the technician documents the details of the physical work that was performed. This human generated data can be added to the two existing sensor feeds to drastically increase the understanding of how to best maintain the system while minimizing costs. Simply put, CMMS captures what maintenance was done to the turbine by the technician beyond the purview of the SCADA and Condition Monitoring Systems.

Work order data has been one of the more elusive data feeds to get smoothly flowing from the technician in the field to a database suitable for merging with SCADA and Condition Monitoring Systems data (Figure 2). Recent developments in mobile electronics, cloud computing, and wireless connectivity, however, are making modern CMMS more capable of properly dealing with the remote field work that is the staple of the wind industry.

The growing wind industry is now compelled to reevaluate its own best practices with the goal of reducing costs and increasing overall confidence in wind technology. This paper investigates how wind maintenance management is currently being performed through two specific depth areas:

1) What are the demographics of the companies and the employees in the wind industry?
2) How do different company types currently manage their maintenance efforts?

An industry survey was performed to address these questions. The survey provides a preliminary investigation of wind maintenance management with an emphasis on how work order data flows through different company types. An overarching objective was to improve the understanding of current methods in order to inform how CMMS could be beneficial to the wind industry. These data provide an initial benchmark of what processes are currently in place and how they might be improved.

3.0 Survey Methodology

The foundation of the survey was a five box flowchart model that outlined the general architecture of the survey process (Figure 3). The survey asked questions with an emphasis on technology, average time required to complete a task, and the level of satisfaction at each stage of the work order information flow.

The first four steps revolved around how work order data typically flows through a wind operations and maintenance organization. This included:

1) How maintenance records are documented in the field by technicians
2) How the office processed work orders
3) Where completed work orders are stored
4) What approach was used to generate reports from the work order data

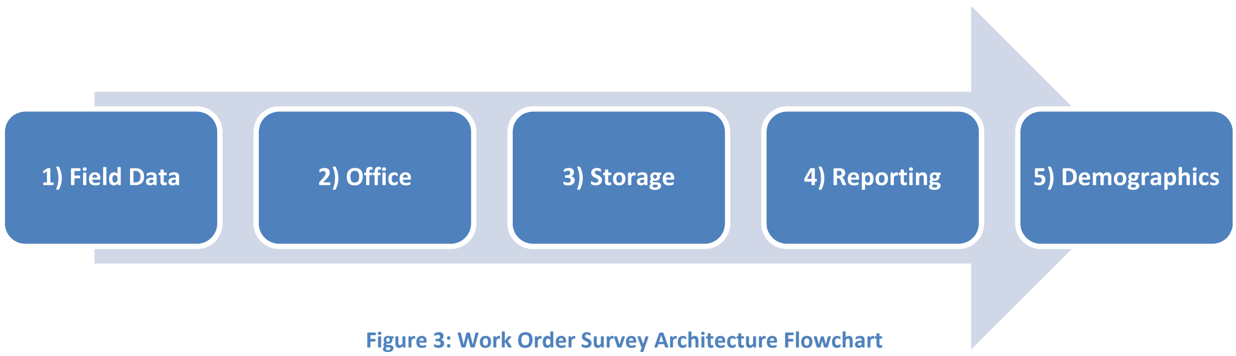

Figure 3: Work Order Survey Architecture Flowchart

Actual information flowcharts in the wind industry are drastically more complex; the four-step model was intended only to approximate real world processes. The final section captured the company and employee background information of the individual completing the survey.

The online survey contained about 35 questions, had 51 respondents, and took an average of slightly over 12 minutes to complete. The survey was designed to adapt based on real-time responses. The questions were a mix of multiple choice, checkboxes, ranking, short answer, and comment fields.

The survey was distributed to three primary wind company types which included:

1) Independent Service Providers (ISPs)
2) Owner Operators (OOs)
3) Original Equipment Manufacturers (OEMs)

A particular emphasis was placed on gathering data on OOs with the goal of OOs representing half of all respondents.

Within each company type, the intention was to get a balanced mix of the following employee types:

1) Technicians
2) Engineers
3) Managers
4) Executives
5) Industry Consultants

For companies and employees that did not match any of the categories an "Other" option with a fill-in-the-blank field was provided.

The survey was distributed on wind oriented forums, online publications, email, and personal network connections. The yield relative to the number of people who were contacted was approximately two to three percent.

Historically the wind industry has had difficulty getting work orders properly filled out, and the survey turnout reflected the industry's aversion to paperwork. Given these factors, the individuals who did complete the survey may have been predisposed to be interested in maintenance management efficiency, and this potential bias should be considered in interpreting the resulting data set.

An additional caveat should be considered regarding the statistical significance of the data that follows. Basic statistical analysis was performed using the Student's t-test. The Student's t-test is a data analysis tool used for comparing data sets and enables a statistical justification about whether the means of two data sets are actually different from one another. Data scatter and variability are taken into consideration when using the Student's t-test, which a simple average comparison would overlook. In general, the lower the scatter and the greater the number of data points, the stronger the conclusions that can be drawn.

For the survey data, p-values less than 0.05 were considered statistically significant and are reported below. All analysis was performed using a two tailed, two-sample unequal variance Student's t-test. Where not reported, p-values were greater than 0.05 and data can be considered to indicate a trend rather than a statistically significant difference. Once the 51 responses were properly parsed for plotting, much of the survey data did not have a p-value greater than 0.05.

4.0 Survey Findings

4.1 Survey Respondent Details

Demographic data collected in the survey suggests a range of respondents representative of the wind industry as a whole. As intended, the majority of these were affiliated with OOs. Importantly, less than fifteen percent of survey takers did not fit into one of the three company categories established in the survey and less than two percent (Figure 6) did not occupy one of the five job types that the survey identified, suggesting that the survey was a reasonable fit for the intended respondents.

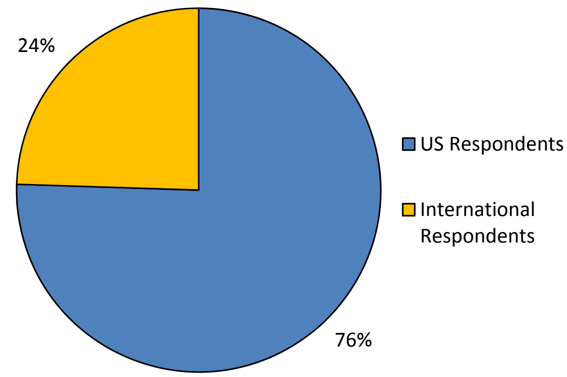

Figure 4: Comparison of International versus Domestic Survey Respondents

Surprisingly, about one out of four respondents were located outside the United States (Figure 4). Although international respondents were not deliberately targeted, the survey reached Europe, India, Australia, and beyond. In general, the trends in the domestic data were found to be similar to the international responses suggesting that maintenance management challenges are not just limited to the United States.

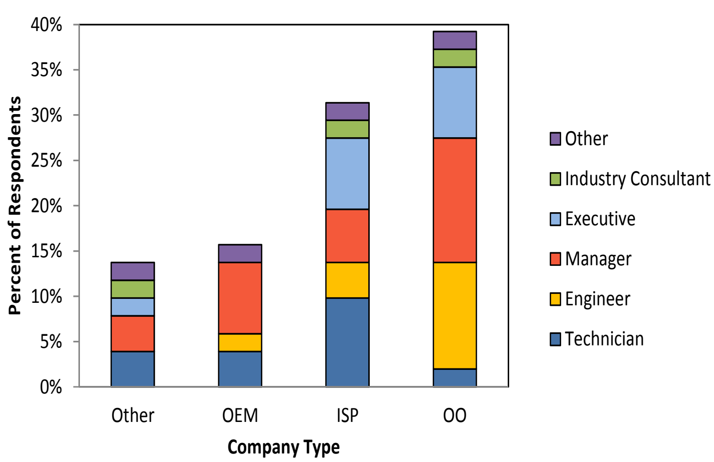

Figure 5: Company & Employee Type Distribution

The company and employee type of the individuals who completed the survey are presented in Figure 5. The category "Other" with regards to company type included companies outside the three primary segments with examples including consulting, engineering, and software.

Each bar in Figure 5 is divided into colored sections that represent the different employees that work for a specific company type. As an example, surveyed OOs were found to be composed of 5% Other, 5% Industry Consultant, 20% Executive, 35% Manager, 30% Engineer, and 5% Technician. "Other" employee types included director, liaison, etc.

Figure 6 provides an overview of the employee type distribution for all survey participants. It was interesting that the survey was completed by nearly one and half times as many managers as technicians. One possible explanation is that technicians spend more time in the field away from computers, making completing an online survey more difficult.

Figure 7 shows the relationship between company types and how long employees have been in their current position as well as working in the wind industry. The general trend is that larger companies such as OOs and OEMs often have the most experienced employees who have been in their current position the longest. The "Other" category has a high amount of wind industry experience, but the least amount of time spent in the current employment position.

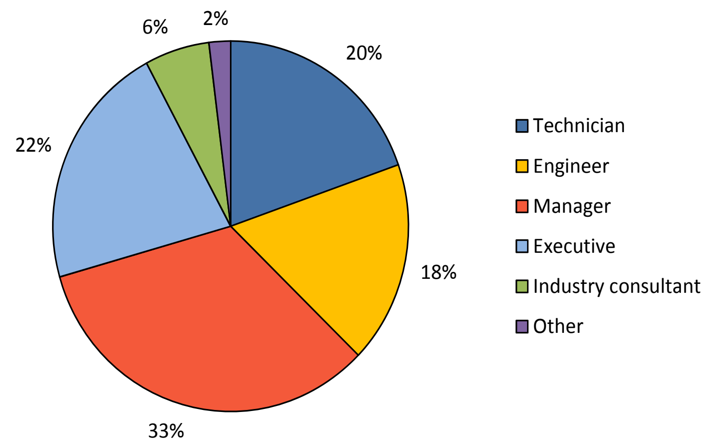

Figure 6: Employee Type Summary

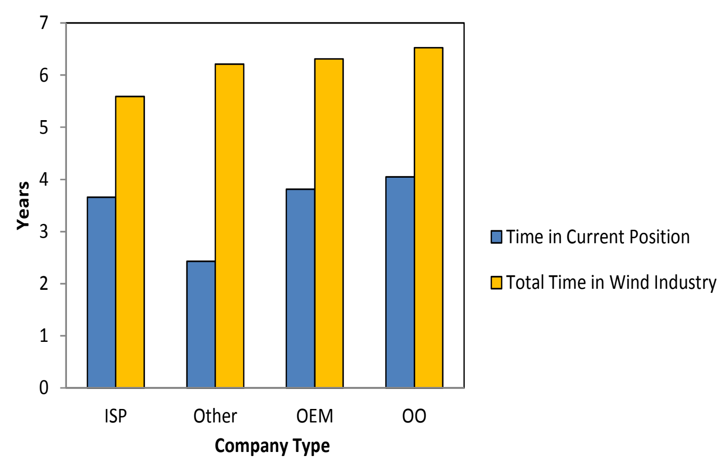

Figure 7: Duration of Employment Based on Company Type

Further supporting the fact that the wind industry is relatively young, the average employee has only been in their current position 3.5 years and has worked in the industry a total of 6.2 years. This implies that wind employees have typically been at their current job about 50% of their total wind career. The data was not captured by the survey, but some employees may have additional experience in other energy sectors prior to joining the wind industry.

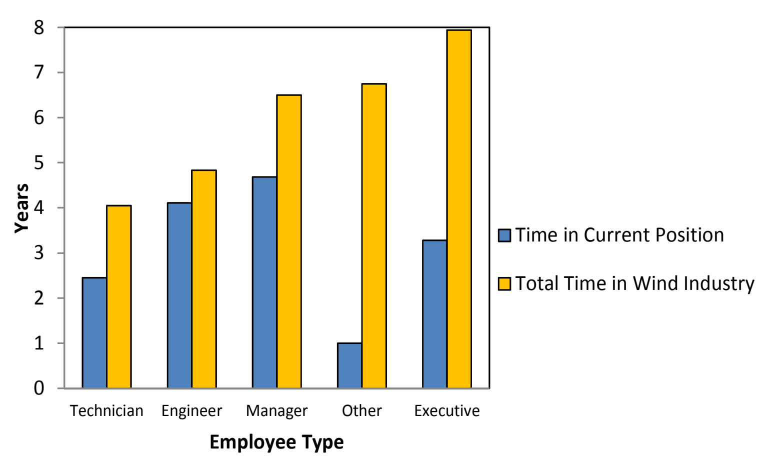

Figure 8: Duration of Employment Based on Employee Type

Wind turbine systems have an expected life of 20 years and the high amount of employee turnover suggests that the "tribal knowledge" of a given wind turbine plant is consistently being lost. CMMS can help reduce this issue by making all past digital work order records readily available to new employees. The work order data can bridge the gap between newly hired employees and those who are departing the company.

Figure 8 summarizes similar data with regard to duration of employment as Figure 7 but from the perspective of employee type. The seniority of the position closely follows the average amount of industry experience, suggesting that upward mobility rests at least in part on time spent in the industry rather than at the current job. Executives were the most experienced having spent an average of 7.9 years total in the industry, which further supports the youthful nature of the wind industry.

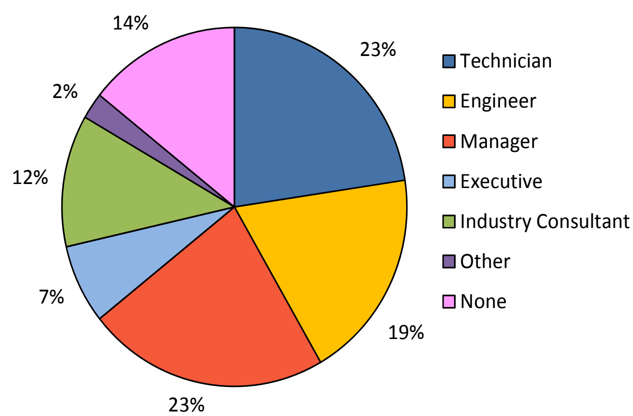

Figure 9: Previous Employee Type Summary

The distribution of previous employment positions for the entire data set is presented in Figure 9. When comparing the current employment positions in Figure 5 to the past positions in Figure 9 it becomes clear that the most significant changes are occurring with managers and executives. Both technicians and engineers are nearly unchanged, while managers saw a 10% increase and executives saw a 15% increase in their employee type contribution to the total.

These changes suggest that employees are generally moving up the ranks to become managers and executives for the first time as opposed to making a lateral move from one manager or executive position to another. The wind industry is changing at such a rate that the number of repeat managers and executives appears not to have stabilized.

The employee data also suggests a 50% reduction in how many individuals were consultants in the past versus their current position. The consultants have notable experience, but the data supports a general consultant migration to other company types. Additionally, 14% of all employees surveyed have never previously worked in the wind industry. Based on the average current position data, first time wind employees have likely worked in the wind industry a total average of 3.5 years.

Manufacturing generally takes much more manpower than service based businesses, and Figure 10 suggests that this trend holds true in the wind industry. When comparing the capacity under maintenance management compared to the number of employees, OEMs had by far the least capacity per employee. An average of 1.7 megawatts per employee for ISPs, 2.5 megawatts per employee for companies in the

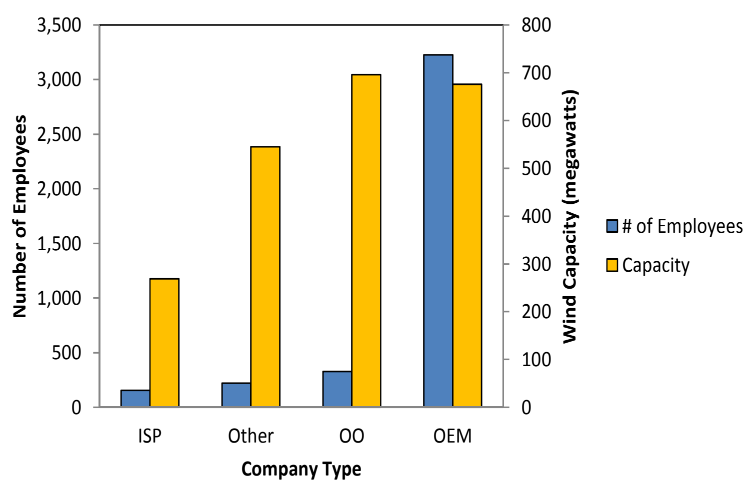

Figure 10: Number of Employees and Wind Capacity Distribution

"other" category, 2.1 megawatts per employee for OOs , and 0.21 megawatts per employee for OEMs. It should be noted that an employee in this case is not limited to the employee types previously mentioned in this document, but to anyone who is associated with the wind energy side of the company.

ISPs and OOs perform similar maintenance tasks; however the amount of outsourcing varies greatly between the two company types. Figure 11 presents how much maintenance work is outsourced based on the company type.

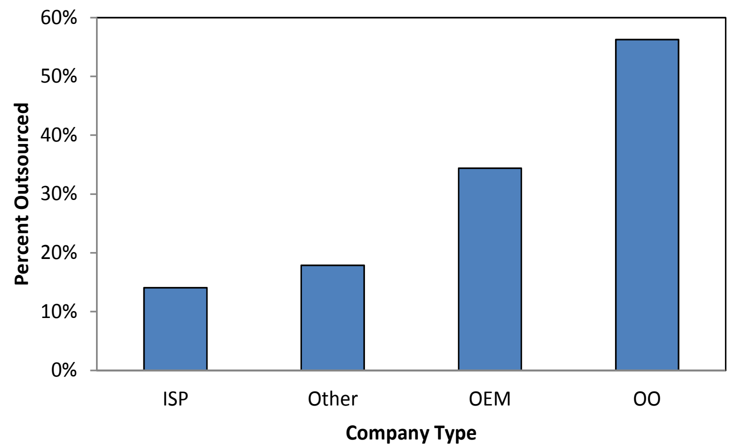

Figure 11: Outsourcing by Company Type

As expected, OEMs and OOs outsource a significant amount of their maintenance to third parties, but interestingly, ISPs also outsource slightly over 14% of their work to other companies.

The natural question is to whom are ISPs outsourcing their work, as they are by definition already third party service providers? A reasonable guess may be that ISPs are simply outsourcing their more specialized maintenance work such as blades, gearboxes, generators, etc. to specialized ISPs with particular subsystem experience. Further investigation into outsourcing within the wind industry with an emphasis on ISPs would be necessary to answer this question.

4.2 Work Order Information Flow - Overview

The survey separated the work order information flow into four discrete steps as previously described in Figure 3. The purpose of the four step structure was to better understand how work orders are filled out in the field, processed at the office, stored long term, and how the work order data is used to generate reports. Figure 12 shows the survey results for satisfaction, time, and technology at each of the four steps for the entire data set. The following three sections will look at each of these topics in more detail.

4.2.1 Satisfaction

The objective of the satisfaction portion of the survey was to better understand the expectations of the industry with regards to maintenance management and determine if there is a particular step in the information flow that is perceived to be the least favorable.

The levels of satisfaction of the survey respondents for all four steps of the information flow process were found to be “Moderate”. This is surprising given the task variety, the varying levels of sophistication of the systems utilized for each step, the breadth of people involved with processing work orders, and the heterogeneous group of respondents taking the survey.

The standard deviation of the entire satisfaction data set is around one point on a five point scale where “Moderately Satisfied” = three. This suggests that there is much more variability in the raw data than the average data in Figure 12 suggests.

To put this in perspective, responses within one standard deviation of the mean include everything from two, or “Slightly Satisfied” to four, or “Very Satisfied”, which indicate very different levels of satisfaction.

The only statistical difference in satisfaction level is between the field and reporting (p=0.026). Recall that any p-value less than 0.05 is typically considered statistically significant when using the Student’s t-test.

Obtaining more data on this particular topic would be valuable to better understand what the majority opinion really is. Given the current data set, the strongest conclusion that can be made is that satisfaction levels are nearly all equal and on average, employees are only “Moderately Satisfied,” leaving room for improvement.

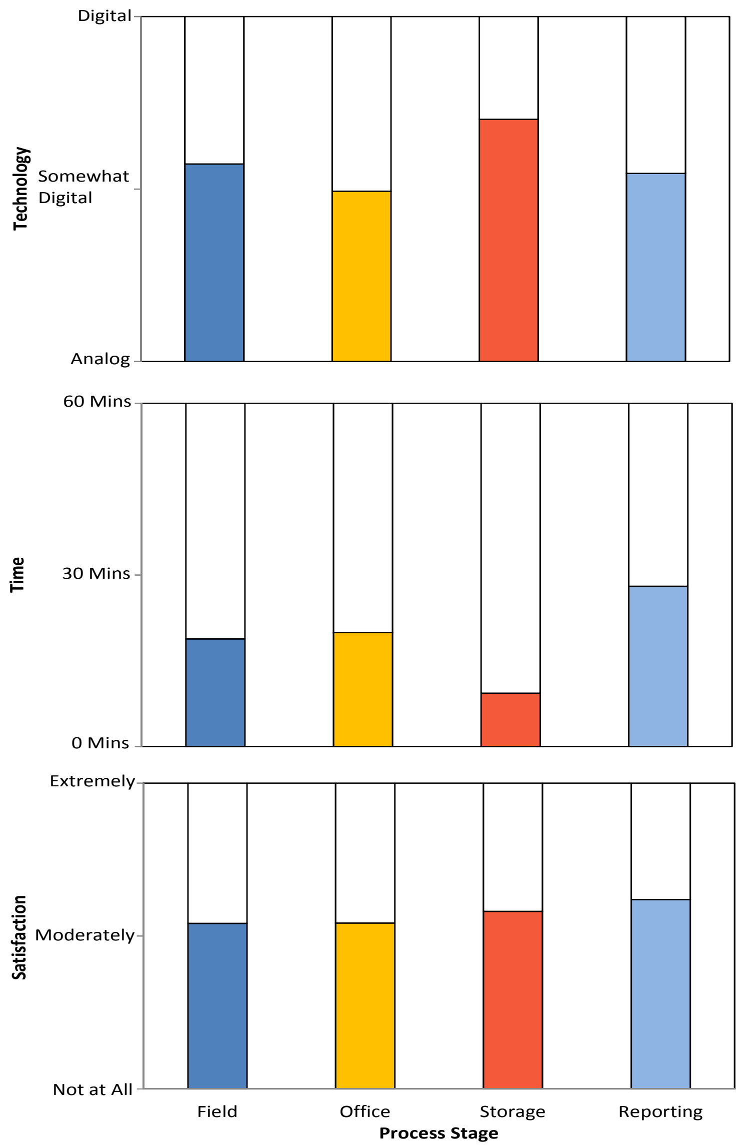

Figure 12: Work Order Information Flow Overview

4.2.2 Time

Time is a very useful metric because it sheds light on the amount of downtime that could come from the field documentation process, the cost to pay an employee to complete the task, or the barrier to gaining access to work order data to help inform maintenance decisions. Wind maintenance organizations tend to keep very busy and this data shows where there might be opportunities for CMMS to increase efficiency.

The time spent in the field and the office were statistically nearly identical, with all of the other average times being notably statistically different from one another. One point for additional exploration could be to better understand how time within a given step is utilized. For example, are technicians in the field spending their time only filling out work order documents or is time also spent filling out safety forms or calling back to the office for additional instructions?

The current time to store work orders of less than ten minutes suggests that they are either already transcribed by the office into a database, the paper work orders are quickly scanned into a digital storage location, or that the work orders are being physically filed. With the proper system in place the time spent to store a work order would be intrinsic to the process and require nearly no additional time.

The time to generate a report based on work order data was found to average half an hour. This is a clear opportunity where reducing the time to generate a report would be exceedingly useful. If it takes half an hour to generate the report, time to review the resulting report, and additional time to conclude the action items, it may be reasonable to assume that work order data will rarely be used to make "game day" decisions.

Reports need to be generated in a matter of minutes and be concise enough that translating the data into actionable information is straightforward, thus making predictive maintenance significantly easier. Reporting would ideally also include the ability to quickly compare work order data with SCADA and Condition Monitoring Systems data to further increase situational awareness.

4.2.3 Technology

The survey made estimates regarding which technologies were likely used within each of the steps to add context to the typical work order process. As represented in the top plot of Figure 12, all of the technology levels are statistically the same, minus storage which is considerably more advanced than the other three steps.

The storage step involves the highest level of technology, significantly more than the office or reporting stage ($p=0.0002$, $p=0.009$), but only slightly more than the field step ($p=0.035$). As a general conclusion, nearly every stage of work order information flow is a mix of analog and digital technologies. This hybrid solves some information flow problems, but makes the transitions from one technology to the other labor intensive.

Additionally, though many of the work order storage systems are digital, industry research suggests that in many cases the "digital" work orders are not searchable. Having work orders readily searchable makes the entire process more valuable, and in conjunction with a competent reporting system, can be a huge asset to any maintenance organization.

Table 1 lists the choices presented in the survey regarding technology for each stage of the workflow, as well as how these responses were quantified by assigning a rank from one through five. The numerical average of the responses as well as an approximation of which level of technology this represents can be found in the bottom two rows.

Table 1 Technology Details

	Numerical Rating	**Field**	**Office (scale adjusted for only having 4 responses)**	**Storage**	**Reporting**
Response #1	1	Paper form	Not automated	Paper filed	No work order analysis
Response #2	2	Digital photos	Somewhat automated	Paper scanned onto hard drive	Basic spreadsheet
Response #3	3	Paper form & digital photos	Mostly automated	Paper scanned into database	Extensive spreadsheet
Response #4	4	Laptop	Completely automated	Digital work order hard drive stored	Basic database
Response #5	5	Mobile device (smartphone, tablet)		Digital work orders database stored	Complex statistical database
Numerical Average		2.9	2.5	3.5	2.7
Technology Average		**Paper form & digital photos**	**Somewhat/ mostly automated**	**Paper scanned into database/ Digital work order hard drive stored**	**Basic/extensive spreadsheet analysis**

The average technology summary in the bottom row confirms the prevalence of paper work order forms in the field. The problem with paper as the seed of the information flow is that it eventually requires partial or complete transcription into a digital system as evidenced by the relatively high technology level at the storage stage. This introduces a notable labor requirement, error is introduced during the transcription process, and there is no inherent quality control in a paper system as would be present with a digital system to ensure that all necessary information is entered correctly before submission.

This data regarding the industry as a whole provides a preliminary benchmark of what the typical wind company is doing to process work orders. This document is one of the first publically available investigations on the subject, and while it characterizes the present state of the art, it also points to ways to improve the current process. Along these lines, the next sections investigate each of the four steps of the work order information flow in a higher level of detail.

4.3 Work Order Information Flow – Field

This section and the following three focus on the details that the survey reveals about the four steps of the information flow. The first of these steps is the entry of work order data in the field. Regardless of the volume of work done by technicians, respondents tended to be only "Moderately Satisfied" with work order data (Figure 13). This suggests that there is a systemic problem with the work order system at the field level that is present regardless of company size.

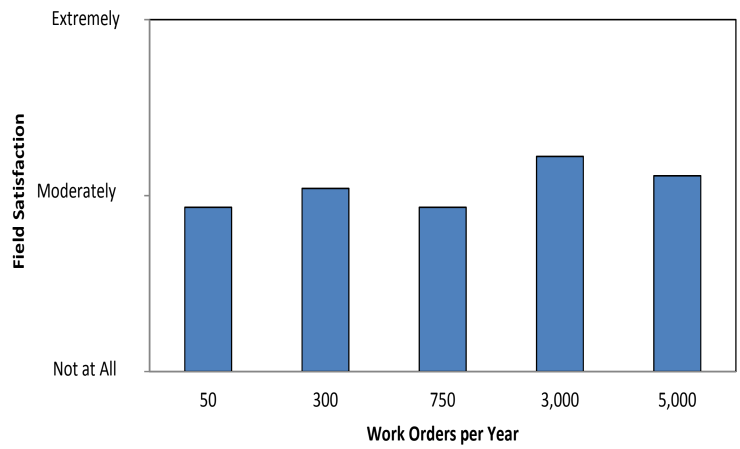

Figure 13: Field Satisfaction Verses Number of Work Orders Processed

One of the intentions of the survey was to better understand what technicians actually record in work orders. Figure 14 details what type of data is recorded in the field.

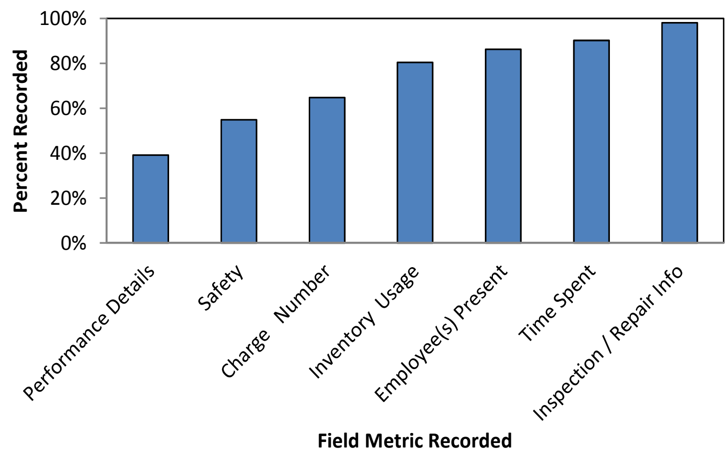

Figure 14: Technician Metrics Recorded in the Field

Unsurprisingly, emphasis is placed on information important for billing and record keeping, such as inspection and repair information and time spent by whom, but curiously less importance is placed on recording safety information. A separate safety check document could be useful, but might be difficult to implement, as it would lead to additional paperwork. Here the internal checks of a CMMS could ensure that safety data is properly recorded.

Although inspection and repair information showed the highest likelihood of being recorded, industry experience suggests that this portion of the information flow, although present, is often imperfect and not often revisited. According to Figure 15 only 30% of the time work orders are used to inform future maintenance decisions "Often" or "Always". These data do not delineate where or by whom the work orders are accessed and in many cases technicians do not have access to past work orders in real-time to better troubleshoot repairs.

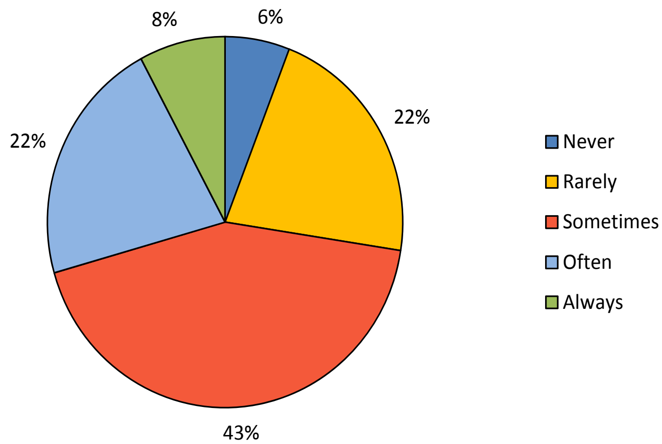

Figure 15: How Often Work Orders are used to Inform Future Maintenance Decisions

In the case of specialty ISPs, documentation is a key part of the company's accountability in billing for the work completed. The scenario is much different for long term maintenance contracts where field documentation is often seen as being less directly important to the bottom line of the organization.

In order to truly reap the full benefits of CMMS there will need to be a cultural shift placing increased importance on proper documentation. Without proper completion of work orders, the ability to benefit from the analysis enabled by a digital system is impaired.

Knowing which type of information is recorded and to what other systems this type of information is typically handed-off, provides a better understanding of how CMMS might improve wind maintenance management. In order to have a successful digital field system, there are three primary pieces of information that should be automatically handed-off to other office systems. These include, but are not limited to financial systems, inventory management, and the high level summary of the work performed. Much of the other information is a subset of the primary information. More details on this topic will be discussed in the next section (4.4).

As a company transitions to a CMMS they have the option to replace their existing systems with the functionality provided by the CMMS or more often the CMMS is woven into the existing company infrastructure. Getting the data to move seamlessly through the systems can be challenging and looking for a CMMS offering that has well developed interfaces can make the task notably easier.

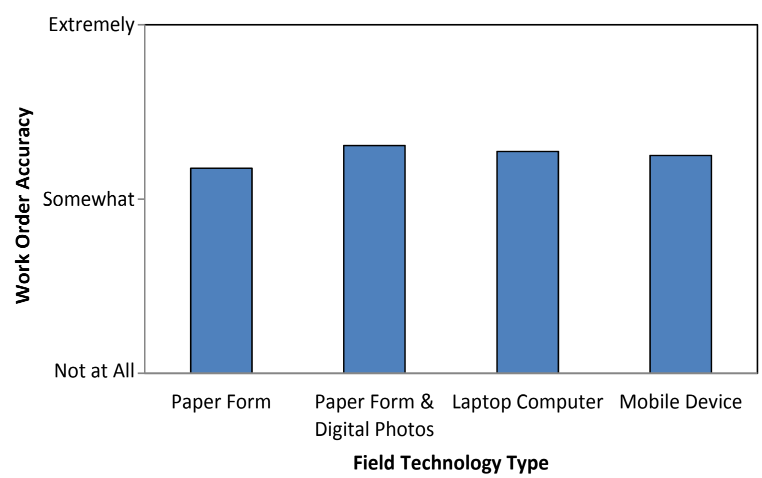

Figure 16: Field Technology Type Compared to Work Order Accuracy

The expectation was that as technology became more sophisticated in the field, work order accuracy would generally increase. The data suggests, however, that in all field technology cases, the accuracy is nearly the same and is only considered by respondents to be "Somewhat" accurate (Figure 16). One explanation for this trend is poor implementation of existing technologies; another is that the technologies in their present forms are not a good enough fit for the wind industry to benefit from them.

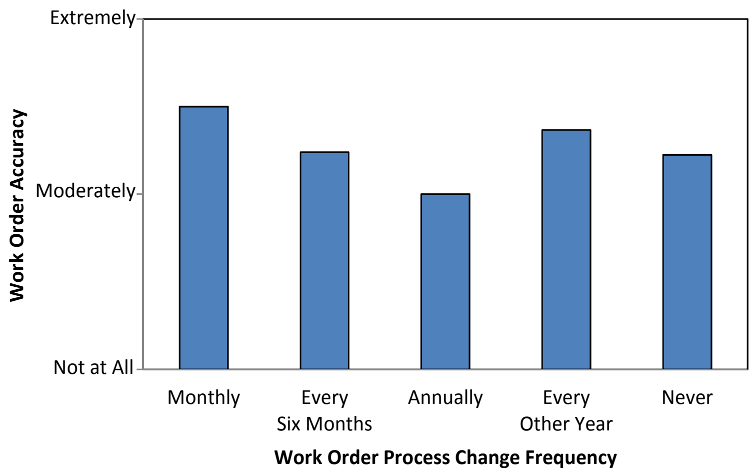

Figure 17: Work Order Process Change Compared to Accuracy

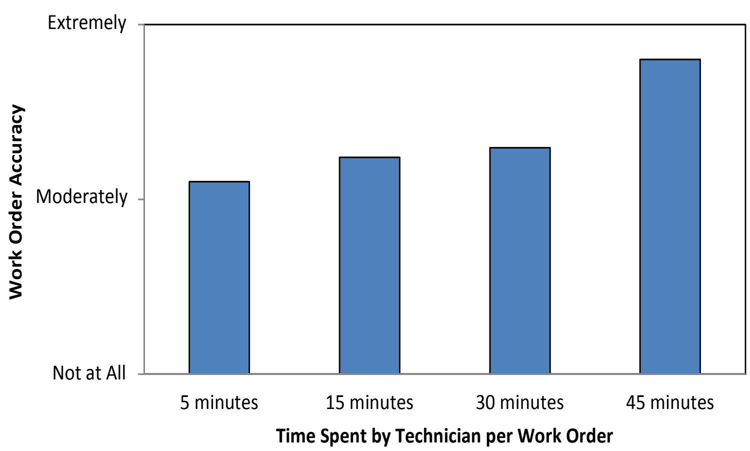

Figure 18: Technician Time Spent Compared to Accuracy

Figure 19: Field Accuracy Compared to Technician Satisfaction

At the moment, it may be true that the accuracy of a paper form and a mobile device are similar, but this is not likely to be the case in the long term as mobile electronics become better integrated into the technician workforce. Importantly, this low level of accuracy cripples downstream work order analysis. Simply put, "Somewhat" accurate work order data is never a good start for analysis.

Perhaps it is lack of attention to the work order process that leads to the limited accuracy previously described. Figure 17 suggests that there is some correlation between the frequency with which the work order process is updated and how accurate the system is perceived to be. In future studies, it might be interesting to know if established companies are less likely to revisit the process, or if work order process change frequency could be correlated with the ultimate success of growing organizations.

One trend relevant to improved management of technicians is the amount of time allocated for completing work order documentation. Figure 18 suggests that if technicians spend more time filling out work orders, increased accuracy tends to follow. This places work order accuracy in opposition to technician "efficiency" and fundamentally getting the next job done. It is no wonder that work order accuracy is generally poor and it is more than likely going to take the combination of a corporate cultural shift in conjunction with a well-adapted CMMS to begin to resolve this issue.

There also appears to be a positive correlation between fieldwork accuracy and satisfaction (Figure 19). One facet of this is that as technicians feel they are doing more accurate work and performing better at their job, their satisfaction level would likely increase, which might improve their motivation to do even better work. The caveat being that Figure 19 represents how employees at all levels perceive their own satisfaction of the field process and work order accuracy. As a result, only a portion of the data comes from technicians. In general it is a positive indicator for the wind industry that improved work order accuracy is correlated with higher levels of employee satisfaction.

In summary, the survey reveals some key trends surrounding work order data in-take in the field: Past work order data is not often used to inform current maintenance decisions, technology level is currently having limited impact on work order accuracy, work order accuracy increases as the time spent to complete the work order form increases, and all employee types have a higher level of satisfaction with the field data in-take process when the data is more accurate.

4.4 Work Order Information Flow – Office

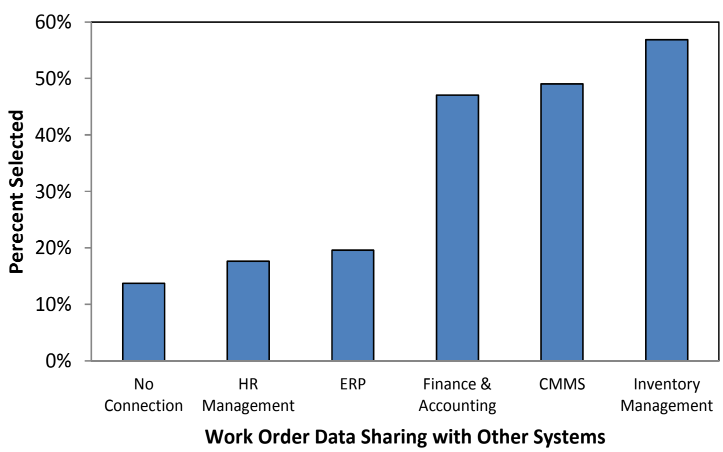

Figure 20: Work Order Data Sharing with Office Systems

When the work order data is handed off to the office for processing, it is sent to a variety of other company systems. Figure 20 provides additional insight into where the work order migrates after its receipt by the office. A point of clarification is that survey respondents were able to select multiple responses so the sum total on the figure does not add to 100%.

Inventory and financial systems were expected to top the list, but CMMS was not. The fact that CMMS appeared third on the list is a positive indicator with regards to the importance of these systems. Being that the survey asked in this section about tasks performed at the office, the best estimate is that the work order information is being manually transcribed into a CMMS at that stage. This process is time consuming and can be error prone. In the future much of the manual data parsing could be eliminated by mobile digital systems.

The data would be entered in the field in a single location and be automatically handed off to other office systems. The objective is to bring the CMMS into the field instead of the use case beginning in the office. It would be useful to further research how many companies are using any level of CMMS functionality in the field to help better understand the current CMMS use patterns.

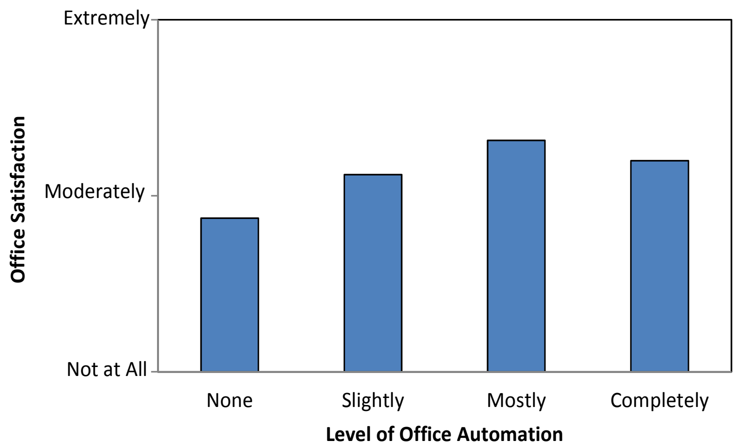

Figure 21: Office Automation Compared to Office Satisfaction

CMMS helps to automate processes that occur in the office. The assumption is that this automation will improve satisfaction, but this is still an open question. The data suggests that automated office systems are generally helping. Figure 21 shows some correlation between level of automation and office process satisfaction. Again, this is the level of satisfaction of the type of employee taking the survey and the responses are not limited to office staff. The satisfaction rating is the perceived level of satisfaction with office operations by all types of employees who completed the survey.

Being that office automation is a vague term, it would be helpful in future studies to probe further into which portions of the automated systems are the most useful and which might introduce more issues than they solve. A significant amount of office automation is likely to be the near term balancing point, but complete automation in such a dynamic environment like wind maintenance management may be difficult.

Taken together, the presence of CMMS in some wind offices and the increased satisfaction with increased automation are encouraging signs that CMMS is not only welcome in the industry, but also already poised to grow. Furthermore, the current challenge of transcribing paper field data into a CMMS at the office could be eliminated as CMMS gains more of a foothold in the field.

4.5 Work Order Information Flow – Storage

Figure 22: Impact of Work Order Storage Technology on Maintenance Management

For the wind industry to move more towards predictive maintenance management, work order data needs to be more readily available. Figure 22 shows how using more sophisticated work order storage technology enables the work order data to be more readily accessible. As a reference, Table 1 outlines exactly what types of technologies were evaluated in the storage technology portion of the survey.

One limitation of the data set is that companies with more sophisticated systems may have a predisposition for using the work order data to make maintenance decisions. If a company has put the effort into building database storage technology for their work orders, then they are likely going to use it. As a result it is unclear whether the technology is at the root of the improved work order access or if that is driven instead by the values of the company.

Where should physical work orders be stored to maximize the likelihood that they are accessed routinely? It was initially thought that companies who stored work orders at both the plant and corporate headquarters would see the highest access rates. The trend in Figure 23 suggests that access most often occurs at corporate headquarters. In the best case, work orders are "Sometimes" used to inform future maintenance management decisions.

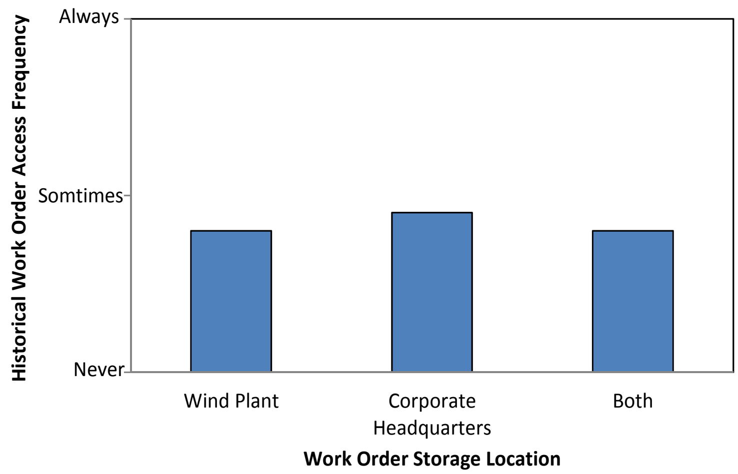

Figure 23: Impact of Storage Location on Work Order Access Frequency

Frequency, however, is not the only important metric of data access. It is unclear whether access at the plant level could be very useful and would be more likely to occur if records were in a more easily useable, searchable, form and if analysis tools were quick and simple.

One of the key benefits of CMMS is its ability to make data storage simple and universally accessible and to allow that stored data to be converted into actionable information with the click of a few buttons at any time or any place that has a wired or wireless Internet connection. If CMMS were widely adopted, the picture of data access and usage might change drastically from what is represented here.

4.6 Work Order Information Flow – Reporting

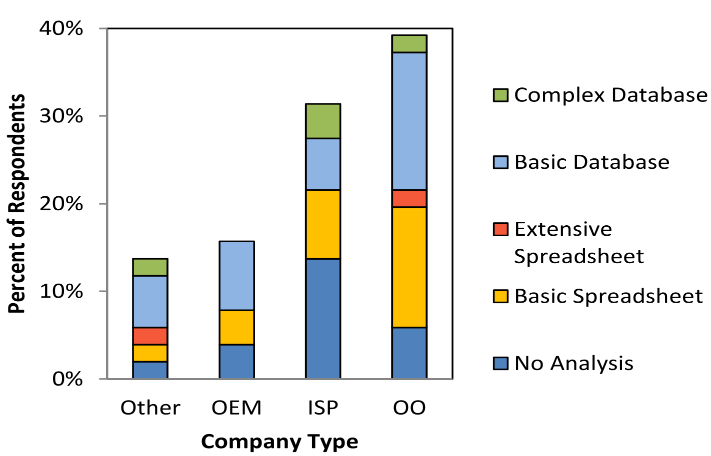

Figure 24: Range of Work Order Analysis Tools

The tools that are in place for work order analysis are typically fairly limited. Analysis techniques range from basic spreadsheet analysis to complex statistical database analysis. About 57% of all respondents either did no analysis or some level of spreadsheet analysis (Figure 24).

Out of the three company types, ISPs were the least sophisticated with respect to their work order analysis.

ISPs had the largest amount of "No Analysis" which makes sense given that they often do not have a long term stake in the assets they work on. OEMs only had slightly more sophisticated analysis tools than ISPs given that they are focused on getting newly installed turbines through the warranty period. On the other hand, OOs had by far the most sophisticated database analysis solutions in place being that they are most directly associated with the long term return on investment of wind plants.

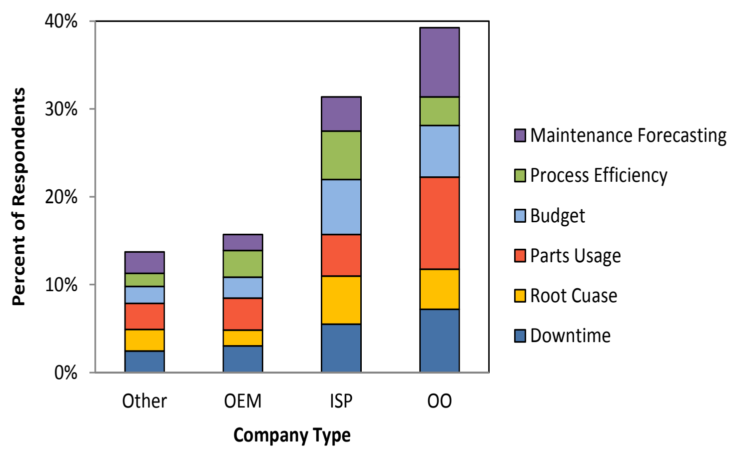

Figure 25: Types of Analysis Performed using Work Order Data

Most will agree that there are useful trends in the work order data and more sophisticated automated analysis tools may be able to tease out utility without adding significant time to the work order process. CMMS could help increase the number of companies taking advantage of a higher level of work order analysis by making the process of moving data all the way from the field to the database notably easier and in a more standardized format.

Given the tools described in the previous figure, respondents were asked what types of analysis their organization performs. These can be thought of as the standard reports that maintenance organizations produce. Figure 25 suggests that the most popular reports are:

1) Parts Usage
2) Downtime
3) Budget (nearly tied with Maintenance Forecasting)

These reports tend to be most directly connected to the company's bottom line. Reports on process efficiency, for example, are useful, but aren't required like a budget analysis for basic business functionality. The prioritization of necessities makes sense for a busy industry like maintenance management, however, according to the data in Figure 12, the average report still takes about half an hour to generate, hinting that even the necessities are somewhat difficult to obtain on a routine basis.

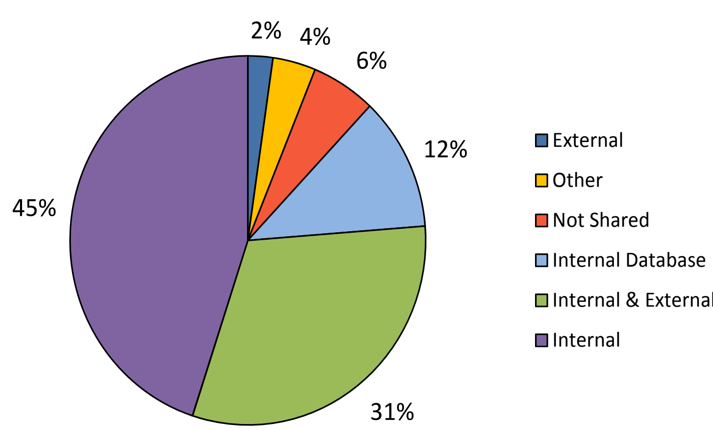

Figure 26: Report Distribution

After the reports have been generated, the next piece of the information flow is how completed reports are distributed (Figure 26). There are two primary distribution channels, internal and external distribution lists. It is not clear from this data specifically how the reports are being shared, but it is likely a mix of local server access, email attachments, and printed reports.

The data helps clarify that reporting is currently limited to necessities and is relatively simplistic across the board. This suggests that if the introduction of automated methods could enable sophisticated analysis at relatively little cost in terms of time or money, it could unlock new information for all levels of wind companies and their customers that is currently not being utilized.

5.0 Company & Employee Details

The choice to use computerized systems may also depend on employee or organization type. A comparison of employee type verses level of technology at each of the four work order steps indicates that consultants tend to use the lowest technology solutions while engineers tend to use the highest (Figure 27). In apparent conflict, companies in the "other" category use a high level of technology and consultants are typically part of this category. Clearly more information about this category and its usage of technology is necessary.

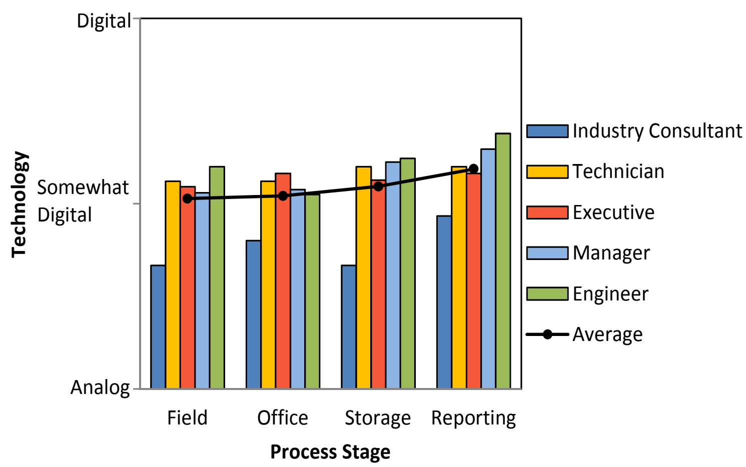

Figure 27: Technology Based on Company Type

Although it shows poor adoption of technology overall, the fact that the average across all four steps represented by the black line in Figure 27 is nearly flat and falls around the middle value ("Somewhat Digital") suggests at least that the survey's designation of technology options reasonably fit the distribution of the respondents.

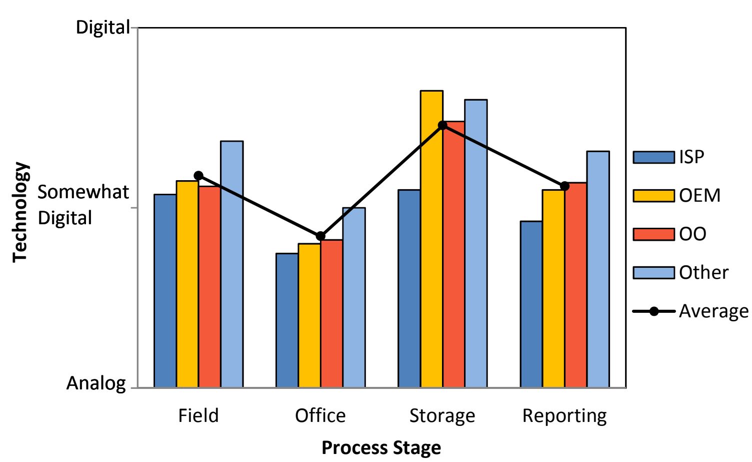

Figure 28: Technology Based on Employee Type

The average represented by the black line in Figure 28 is similar to that in Figure 12, but shows which types of companies are above and below the average for a given step in the work order process. Of particular note, ISPs tend to have the least sophisticated solutions, while OOs and OEMs tend to have the most up to date technology.

In order to gauge what the perceived value of CMMS might be to the wind industry, respondents were asked to rank six qualities of CMMS based on an increasing level of benefit to their company (Figure 29). Comparison of the average value for each company type (bars) versus the average over all company types (black line) indicates how various aspects of CMMS are important to different company types.

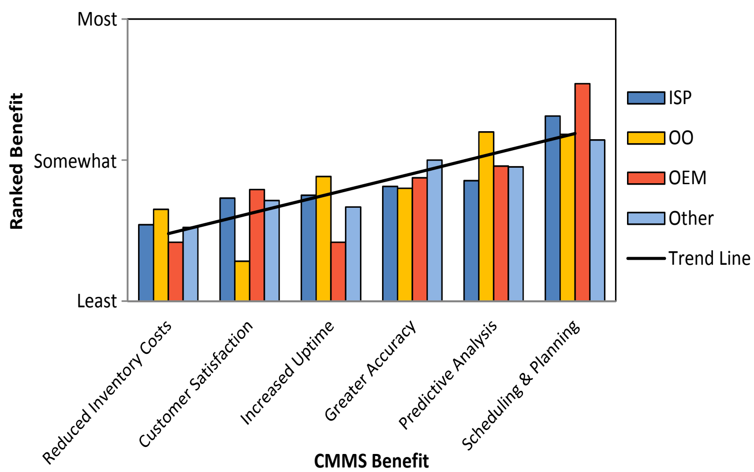

Figure 29: Ranked CMMS Benefit

For example, ISPs are the least interested in predictive analysis, but the most interested in customer satisfaction, and scheduling and planning. OOs are least concerned with customer service perhaps because their customers are primarily utilities bound by long term power purchase agreements. Instead, OOs are most concerned with increased uptime and consequently predictive analysis. Ironically, OEMs who sell turbines to OOs have the opposite priorities for a CMMS. OEMs see uptime as the least important and customer satisfaction the most important while the priorities of their OO customers are directly opposite.

This finer scale understanding of the pivotal aspects of CMMS in different segments within wind will be important for designing solutions that fit the industry well and hence may actually be adopted.

6.0 Conclusion

This survey provides a first look at the use and value of CMMS in the wind industry. The survey confirms many prior assumptions while indicating opportunities for improved maintenance management systems, and brings up more unanswered questions.

The low yield of survey respondents out of the total that were contacted in itself is symbolic of the fundamental barrier to achieving consistent high quality work order data – this is a busy industry with little time for paperwork, digital or otherwise. Importantly, the fact that the survey was quick to complete and resulted in very few "other" responses, indicates that the simplified survey structure was a reasonable match the actual flow of data in the industry; a good sign for implementation of CMMS systems that will necessarily have to fit more than one company type without becoming overly complex.

Demographic data confirmed that the industry is young, and showed a trend toward high turnover and upward mobility. This dynamic industry could benefit from tailored systems that can bridge the gap in "tribal knowledge" as people shift within organizations or seek alternative employment.

Given that wind has not yet broadly adopted CMMS whereas other energy sectors have, one might argue that the current systems may be viewed as adequate and might be used in all the ways CMMS could be. The data indicates that this is most likely not the case. Although the data does suggest that more automation leads to higher quality data, average satisfaction hovers around "Moderately Satisfied" in all cases. Perhaps automation alone is not enough if a well-designed CMMS is not available and this distinction should be further investigated.

The average work order information flow starts with a paper form which contains "Moderately Accurate" data being transcribed by the office into a "Somewhat Digital" hand-off to other office systems. The now "Digital" work order is stored on a server in a manner that is often not searchable and then reports, which typically take 30 minutes to create, are generated using templates in Excel. These reports are "Sometimes" used to help inform future maintenance decisions and the industry is "Moderately Satisfied" with this maintenance management scenario.

This suggests that there is a genuine problem with how maintenance data is managed in the wind industry. Wind companies should demand better performing digital systems designed using evidence based knowledge of the interplay of CMMS and the wind industry.

Today, development of CMMS in wind is fragmented; it is happening at a grass roots level spearheaded by individual companies developing systems for internal use, or by small software companies serving a limited number of clients. To increase the effectiveness of CMMS in wind, the knowledge of what it needs to look like has to improve. To do this, more research should be done, perhaps by a committee of stakeholders from all levels of the industry dedicated to designing and implementing a tailored wind maintenance management system. Such a standardized system could improve reliability, reduce variable cost, and improve implementation of predictive maintenance. This would help lower the cost of wind energy and improve the stability of the wind industry.

7.0 Future Work

The survey presented here provides a primarily subjective view of work order management. Many of the suggested trends are not statistically justified due to the limited size of the dataset. The power of the survey could be improved if more resources were directed towards increasing the number of respondents. Also, more objective data might be obtained through a review of actual work orders searching for evidence to support or refute trends found in the survey.

Even more beneficial would be if this historical work order review could be combined with a prospective trial of wind-tailored CMMS implementation. This would enable the average quality and downstream usefulness of work order data to be compared before and after implementation for the purpose of validating the utility of CMMS for wind.

Although the workflow diagram utilized for this survey approximated real-world systems relatively well, it is clearly a very limited view of the actual usage of work order data. Future investigations might involve obtaining detailed workflow diagrams from a variety of wind organizations in an effort to find the best average of these systems, and hence the best design for a useful CMMS.

Similarly many details are lost in a high level survey such as this. Interviews or focus groups of all the different players mentioned in this survey could reveal new insights that are lost in this first pass. One such insight might be a better understanding of the cultural barriers to successful adoption, integration, and usage of CMMS, as these may be as important as actual system design for its ultimate success.