Building Automation Systems and Data Analysis

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Executive Summary

This paper is presented to the reader as a proposed policy towards Building Automation Systems and Data Analysis. This topic is one that lends itself well to the goals of furthering sustainability efforts, especially those laid out in the United Nations Sustainable Development Goals. Now, more than ever, being mindful of energy consumption is a cornerstone of sustainability for the individual and the corporation operating in the 21st century. One of the places we consume the most energy are the very buildings in which we live and work. This extends beyond just the cost and energy of construction, as 90% of the costs of a building come during its lifetime, and that lifetime includes costly energy consumption, maintenance and operation. As such, we felt it pertinent to propose policy for building owners and operators that lays the groundwork for how to either become more sustainable or improve their sustainability efforts. This policy is constructed such that it does not serve any one consumer, rather it proposes specific actions relative to three categories of consumer, as with varying size of buildings, number of buildings, etc. come varying needs. Of course, the idea that one should look to operate their buildings more efficiently is not novel, in fact it has a strong history where our research began.

To be able to propose effective policy for the future, it is paramount that one understand the past and present, which is exactly where our research began. Building Automation Systems (BAS) have been in existence since the 1960s with Honeywell being the first to offer digital control systems, followed shortly thereafter by many others. Looking into the history of BAS, a trend becomes apparent as one gets closer and closer to present day; building automation is

becoming digital, highly technical, and evolving to leverage new technologies. This trend becomes blatantly obvious upon real-life case study work which was our next course of research.

State College, Pennsylvania, within the state and in many respects beyond the state, is a beacon of sustainable efforts and building automation. With both the Pennsylvania State University and the Borough of State College in close vicinity, interviewing experts in the field of building management and building automation was a logical step in understanding the development of the field. Meeting with Tim Pryor, head of Building Automation Systems at the Penn State Office of the Physical Plant (OPP) and with Tom Brown, State College Facilities Supervisor, in conjunction with Alan Sam, Environmental Coordinator and Arborist for the Borough, formative knowledge was gained about the economies of scale at play in the field which helped to develop our policy. Penn State is one of the largest universities in the country and has tremendous resources to carry out its numerous active sustainability efforts, especially in the realm of its buildings. Operating with a full dedicated staff, the OPP division that Tim Pryor works within manages and automates 600+ buildings with 42 million sq. ft. to uncanny precision. They are one of few institutions looking to carry out full big data analysis on their buildings' data to allow its operation to become truly predictive versus just preventative in nature. State College has a preventative maintenance operation on a much smaller scale with fewer staff and fewer buildings to manage. Nonetheless the State College Borough was exemplary in terms of it sustainable building initiatives relative to other municipalities of its size. The Borough adapts practices from the industry forefront and implements them to suit their needs while still remaining cost effective. These types of strategies are covered in depth in our proposal, but the important takeaway was that a policy for building automation and data analysis would have to be modular and cater to the multiple different players in the market.

With research conducted and with a strong foundation in a field that is highly technical, a three-pronged policy emerged for building automation and data analysis. The policy has one main focus, which is to find ways to adapt technologies and techniques for buildings to save energy and become more sustainable. It achieves that purpose in 3 ways, with one proposal for each of the three categories of building owner that this policy describes.

Category One is single buildings with minimal staff. The policy for this category is catered towards the understanding that the application is small and lacking in vast resources. Energy savings and sustainability are achieved with a priority of being cost effective. This will often boil down to leveraging new technologies such as smart thermostat systems, which are easily managed but still offer machine learning capabilities of bigger applications. This can also be coupled with implementing more mindful energy consumption practices within the building. While this policy may feel minimal, its energy savings impact applied to one building will be large.

Category Two pertains to multiple facilities with a dedicated staff. This category is inspired by the likes of State College Borough where there now exist multiple buildings under one jurisdiction of building management staff. When the number of buildings grows under one management's control it often becomes difficult to manage the energy consumption across the portfolio. As such, the policy proposes that a dedicated staff be brought on or simply assigned to adding building automation software to all the buildings within their domain. This software will allow for preventative maintenance to take place. What this means is that a system of alarms will be in place to alert the dedicated staff when building critical components are on the verge of failure so that staff can step in an correct them. It's important to note however that these BAS applications to each building are to be disjoint. While it is advantageous to combine them into one network of information and management, it is simply not cost effective to do so given the resources of a category two application, and is best left for category three.

Category Three applies to large scale facility management with large staff. These kinds of applications have a large network of buildings to monitor which requires immense resources and manpower such as Penn State's OPP. What is proposed for these applications is that building automation software be applied to each building and linked in one combined network of building management software that allows for comprehensive analysis and control within the network. This then allows for the proposal of large scale data analysis. Upon the creation of a network of buildings, an immense amount of data is being generated for each building and can be fully analyzed. By building a data lake, one can collect all generated data and apply learning models to said data. This brings the management of buildings into predictive maintenance, where one no longer needs to wait for near failure as in preventative maintenance, but instead learning algorithms can predict and detect anomalies in performance well before they are of issue. These proposals, among others, outline the policy laid out in this paper.

There are of course always limitations and considerations for a policy of this scale. Should one wish to implement it, one should always consider the age and the lifecycle of a building. It is not always possible to accomplish a cost effective retrofitting of an aged building. Furthermore, one must consider the cost itself of the laid out proposals and whether the goal is short-term or long-term sustainability given the available funding. Finally, one should consider that this is not a comprehensive policy on building automation. There are many notable conferences and gatherings of experts that can be consulted in conjunction with this policy to learn more and achieve a more sustainable and well automated future of buildings.

Chapter 1: Introduction

While the topic of sustainability might not be a new concept, it is one that has been of growing importance as we continue into the age of globalization and mass industrialization. The environmental impact of countries growing in size, industry, and GDP has brought about a number of implications that vary from climate change to increasing inequalities in gender, education, and health. So many of these issues have become the focus for our ideas about sustainability and are driving a demand for action and change. As a result of this, there is growing support for renewable energy, reduction in greenhouse gas emission, and zero-waste or zero-energy buildings (Aste, Manfren, Marenzi, 2016). All of this is achievable under practices and implementation of sustainability and most especially in regard to Building Automation Control Systems.

Energy is a key target for sustainable practice and much of it can be captured in industry and buildings. A combination of residential and commercial buildings account for 30% of global energy usage (Aste, Manfren, Marenzi, 2016). Buildings are a great focal point for implementing more enhanced sustainable methods that would have significant impact in communities and in an even broader sense, cities as a whole. With the introduction of building management systems in companies, institutions, and even smaller municipal localities, there are significant gains to made in energy efficiency and reduced global energy usage impact.

1.1 History of Building Management Systems

Building Management Systems were first introduced in the 1960s and were mostly in the form of primitive, physical controls (T. Pryor, personal communication, April 9th, 2019). These systems operated to meet the necessary function and standards for a building. During these early stages of facility management, the most common practice was to have a dedicated building monitor who was familiar with every aspect of one or two buildings specifically under their jurisdiction. These individuals can be thought of as building administrators who oversaw any issues or general maintenance of the building. Just a decade later, Honeywell launched the first digital control system in which they profited $4 million and changed the future of building management (T. Pryor, personal communication, April 9th, 2019). Since then, building management systems have continued to evolve to meet the demands of the industry and match the development of new technological capabilities.

The integration of advanced technology in building automation systems has changed the operation of facility management. In today's time, the practice of having dedicated building managers is slowly fading. Instead of having an operator who is knowledgeable about the needs and utilities in a specific building, software systems are being implemented in order to match the remedial and mundane functions typically performed by the operators, allowing modern operators more freedom to address maintenance concerns and innovation . With technology that is just as capable as human labor, there is little to no demand for these traditionally styled building managers. Additionally, a decline in the trade of dedicated building managers means there is little supply of these individuals as well. While building system management was once conducted by an individual trained through years of experience, it now takes place in the form of modern technology and software.

Another example of a shift in facility management as a result of technology is the use of the Internet of Things (often referred to as IoT) in building management systems resulting in greater connectivity. We are currently in the midst of seeing IoT devices take their stake in our increasingly interconnected world, and for the focuses of building management they serve great purpose. Before we explore those applications, it's important to understand the meaning of Internet of Things. In its simplest sense, IoT is the act of bringing the internet to everyday objects. What that means, more explicitly, is bringing the ability to send and receive internet traffic to those everyday objects. These objects can be like Nest home thermostats which leverage IoT to make heating and cooling "smarter," increasing efficiency and providing basic analytics. Similarly, personal home assistants like Amazon's Alexa use IoT to control lights, locks, and music in a home. In this example, it's important to recognize that Alexa, the software, is not itself IoT, rather it makes use of separate sensors and controllers to make physical changes to your world upon your command. It is these sensors and controllers which are a part of the Internet of Things. They are able to receive data, alter some state or make small computations, and send data back to the internet. All of these sensors and objects together, which are connected to the internet, comprise the Internet of Things. With this discussion hopefully providing a foundation of understanding in IoT, one can now look into its application in Building Automation Systems (BAS).

With regards to the monitoring and control of a building, IoT serves this function well. Within a building, a number of individual systems are well suited to IoT application. These include lighting, occupancy monitoring, heating, ventilation, and cooling, which are the primary focuses of building automation systems and facility management systems, as these are the most energy intensive operations of a building. Devices used to monitor these systems need not be over-engineered or terribly expensive. With the advent of inexpensive hardware such as Raspberry Pi which serves as a low power, cheap, and modular computer, combined with open source software, prototyping IoT devices configurable to numerous systems is flexible and practical for building management (T. Pryor, personal communication, April 9th, 2019). It is, however, impractical to run an entire network of building management operations based entirely on these technologies as they lack serious computing power and technical support. As such, there is a large market for building management controllers that are specifically equipped to monitor systems and process higher volumes of data. With large volumes of information, depending on the scale of a building automation system, a number of things can be done to process that data with the goal of greater energy efficiency in mind, a primary topic of discussion within the paper.

These IoT devices, in this scope most notably building automation systems, are valuable beyond just the times when a building is meeting performance expectations. They are also able to identify and report malfunctioning or underperforming units in a building. This information can be passed along accordingly to a Computerized Maintenance Management System (CMMS) where a decision on how to respond can be made by a human operator. This is an important improvement in maintaining optimal performance of a building during its lifetime. Previously, in most cases, one had to wait for a malfunction or failure to occur in order to become aware of and diagnose an issue. While maintenance could be predicted based on prescribed machine lifetimes, unforseen failures could critically damage building systems and their operational capacity for significant periods of time until repairs can be conducted. One is now able to monitor real time data and issue alerts when that data deviates from its expected value. This can allow a technician to intervene and determine whether a real issue exists long before a critical failure occurs. In the future, for building management systems of sufficient scale, predictive maintenance is a primary focus of innovation. Predictive maintenance is hinged upon creating a data lake of sensor information and applying machine learning to detect trends in the data. In these ways, explained further within the policy proposal of this paper, facility management have evolved dramatically from its original basis and is continually evolving.

Facility management has also changed in the how controls are accessible. Previously, the controls could be accessed on the utilities themselves or within a control room. However, current building automation systems allow the consumer to use remote controlling. The controls can even be accessed on a mobile device with the use of building automation systems. This technological advancement allows facility management to take place outside the building and without ever having to be physically within or familiar with the building to monitor controls.

The progress made in building automation management has replaced some individuals in the workforce with software, increased connectivity, and provided hands off controls with oversight from just about anywhere. Many of these changes contribute positive benefits like increased efficiency and greater allocation of time and resources that tie into the values of sustainable management.

1.2 Current Application of BMS

As they function now, building management systems (BMS) are mostly concerned with data gathering, reducing cost, and improving energy efficiency. Building Automation Systems (BAS) operate with the lighting, HVAC, gas, and other energy sources in a building. Some of most common BAS softwares are from controls producers such as Honeywell, Johnson Controls, and Automated Logic with associated supporting softwares such as the Linux operating system, 25Live, Events2HVAV, etc (T. Pryor, personal communication, April 9th, 2019, T. Brown, personal communication, April 16th, 2019). Given that these systems center around increasing efficiency, reducing cost, and implementing building intelligence, they can be easily tied into sustainability management initiatives. Many of the systems in practice today operate in conjunction with a calendar system that set the time frame for operations. For example, if a building opens at 6:00am, the systems can be set to begin working at 5:30am so it reaches an ideal temperature before anyone enters. Occupancy detection is also an important integration into building management systems in which the lighting and cooling/heating can be launched only when a space is being occupied. This technology is great for not only effective energy usage, but decreasing energy cost for a building.

To further expand on cost, it's important to note that 90% of costs associated with a building are accrued during its operational lifetime (maintenance, operations, fixed costs) whereas construction accounts for only 10% (EDIS, n.d). Any group that is looking to reduce their expenses can only really do so under maintenance and operation which is where there is incentive to adopt a building management system. With the ability to reduce energy usage and provide data and targets for a group to work in, there is room to reduce costs and improve the life-cycle of a building.

1.3 Procedure of Research

Without direct interest, ties, or background in facility management, building operations, or management software, it can be difficult to have a fully developed grasp or understanding as to how the practice of this industry occurs. This is largely why forming a policy in this field required literature review and in-depth interviews from local professionals. As useful as data analysis would be, this is not feasible for this project. Much of the pricing information of systems and automated controls is done on a quote basis regarding specific project requirements. Additionally, analysis of energy savings data resulting from building automation would require consideration of a large number of factors, including location climate, usage, and building age, which would require a considerable sample size beyond the scope of this proposal's level of analysis. Although building management systems constantly collect and gather data to show trends and analysis, there is an overload of data such that can only be stored for a short period of time until it is overwritten. This also poses an issue to gathering hard numbers and estimations for the purposes of research. Overall, much of the information presented was provided by published scholarly journals, online databases, or by qualified and experienced local professionals.

The main goal of our research was to understand the varied levels of facility management that exist within different groups and how this variation plays a role in operations and implementation of building management systems for the purpose of proposing plans for innovation at varied levels facility management. The variation of levels was based on scale of industry and operation of building managers. To better understand facility management at these different levels, we utilized a case study approach. To represent large-scale facility management, we looked to and met with individuals of the Penn State Office of the Physical Plant which oversees 658 buildings and 42 million sq. ft integrated with automated controls (T. Pryor, personal communication, April 9th, 2019). The State College borough and their facilities director would provide insight to facility management on a median scale. With a more clear picture and understanding of facility management across multiple scales, we have developed a policy and plan for facility management innovations and initiatives that vary based on the level of resources available for a given operation.

The proposed policy for a small scale facility is to consider the benefit of building management systems and to implement these programs within the respective capabilities. We believe that there is incentive to having a building management system at any viable facility regardless of scale, but there are varying degrees of applications which are not feasible or cost-effective. Beyond this, we have highlighted initiatives within median and large scale facility management operations to provide context to the state of the industry and suggestions for operations of varied size. As part of the proposal, we provide strategic suggestions that would allow the reader to determine in which scale of industry they fall, and how they can go about introducing building automation systems into their facilities. To determine feasibility for a group, we also have provided the counterarguments and scenarios in which building automation systems are not ideal. We hope that this proposal will be effective for providing a plan for implementing building automation systems for small-scale industries so that they will be able to effectively practice facility management that is more sustainable.

1.4 United Nations Sustainable Development Goals

With a clear reality of what is to come of this planet without intervention and consideration of major global issues, the United Nations developed a set of goals with a focus in sustainability. Sustainability is centered about protecting and ensuring the well-being of our planet for future generations by making necessary changes today. The Sustainable Development

Goals provided by the UN lay out a plan for addressing major global issues by 2030 and contain a number of subgoals and targets for countries to meet in order to ensure common progress.

The implementation and practice of Building Automation Systems can encompass a number of these goals. The most related goals to this practice include Industry, Innovation, and Infrastructure (#9), Sustainable Cities and Communities (#11), and Responsible Consumption and Production (#12). Technological progress is key to lasting economic and environmental problems via promoting energy efficiency (UNDP, n.d). This is exactly what building automation systems aim to achieve. This software brings about opportunity for an institution to effectively manage their buildings and assets by providing data analytics, reducing cost, and improving energy efficiency. Essentially, the processes that takes place regarding the use of building automation systems set the framework for sustainable management.

1.5 Sustainable Development Goal #9

The ninth goal of the UN under their Sustainable Development Goals is Industry, Innovation, and Infrastructure. A key target listed under this goal that is directly related to Building Automation Services is upgrading infrastructure and retrofitting industries to make them sustainable, resource-use efficient, clean, and environmentally sound according to respective capabilities. The most important aspect of this target to underscore is “in accordance with respective capabilities”. Building automation systems, or at least the usage of automated control systems are becoming a necessity for creating technologically modern buildings, no matter the scale of the institution. They provide information and details that are important to operations, including occupancy data, utility function, and issue reports. However, there are varying degrees to which these systems can be applied to provide crucial information about the function of the building. There is a different demand for this software depending on the age, state, and resources of the building. Facility management is an important tool for sustainable and efficient use of a building, but how this process takes place can vary depending on scale and resources available. Facility management with the use of building automation systems can improve the infrastructure and energy use of a building, but must be introduced according to feasibility.

1.6 Sustainable Development Goal #11

The eleventh goal of the Sustainable Development Goals is Sustainable Cities and Communities. Cities are the hub of social activity and interaction. The city has become home to more and more individuals globally. In fact, half of humanity lives in a city (UNDP, n.d.). Cities provide people with more than just a place of residence. They provide jobs, community, education, and culture. However, the issue of mass urbanization means that cities can also provide poor air quality, declining infrastructure, and inadequate allocation of resources and space. To counteract much of the issues posed by rapid urbanization, building automation systems set forth a standard and method of action for proper maintenance and use of resources and space. By doing so, institutions practice a level of energy efficiency that can reduce pollution, ensure effective resource use, and provide integrated sustainable management. Building automation systems include an enhanced method of planning and sustainable management in urbanization and resource use that foster improved communities and cities.

1.7 Sustainable Development Goal #12

The twelfth goal proposed by the UN is Responsible Consumption and Production. A key target listed and focused upon within facility management is an efficient use of natural resources, sustainable management, and sustainable practices that integrate information into a reporting cycle. In conjunction with a calendar system, building automation systems report any issue or areas of concern and can do so within a prioritized time frame. By having a system that naturally reports data and can communicate to operators through other softwares, an institution stays informed about the function of their space and has the opportunity to benefit from this easily accessible knowledge. For example, understanding that energy is being used in a space that is not being occupied can give an institution the chance to implement automation software that includes motion detection and will only provide energy when the space is being occupied. Building automation systems provide the information and reports that allow an institution to manage their resources and energy in a way that is sustainable.

Chapter 2: Methodology, Research, Case Studies

2.1 Understanding Economies of Scale

Implementing a building automation system or automated controls will include vastly different challenges and feasible outcomes based on the size of the institution taking part. In this section, we will outline the effect of having few resources, including time and personnel, as well as having an expansive network of resources. We will display and analyze the practices and procedures of the Pennsylvania State University and the operations of the Borough of State College regarding facility management. Penn State will represent a large network with lots of resources and a very efficient facilities management system. The Borough of State College will have similarities to Penn State, yet on the scale of a smaller system that does not have the same data collection and analytical capabilities as the university. To understand why Penn State is able to be more efficient than State College, we must explore the concept of economies of scale.

Economies of scale is a popularized idea in economics concerning the reduced marginal costs incurred as a corporation (or in this case, a university) grows in size. It is generally accepted that average total costs decrease for all industries at least to a certain degree. This is a result of several contributing factors. First, fixed costs represent costs that stay the same no matter the investment in production. These costs are most significant while total costs are low, as they represent a large portion of total costs. As further investment is made, marginal costs first decrease. This is usually a result of specialization, such as a factory assembly line versus a home production strategy out of a garage. Later, as investment gets much larger, marginal costs increase. This is a result of "squeezing" all of the utility out of production, making it costly to achieve the next unit of production. While marginal costs may start rising, average total costs will continue to drop as the total fixed costs become a smaller portion of total investment. Generally, this trend of decreasing marginal costs as well as average total costs leads to a phenomenon called economies of scale. This consists of smaller firms having higher long run average costs compared to larger firms. Larger firms are therefore more effectively able to produce goods at lower costs. A common example of this is Walmart versus a local retail store. Walmart has massive resources so can reduce costs per unit, selling them at lower prices. This also affects employment, as Walmart has the ability to employ individuals for many different tasks, while a local retail store can not.

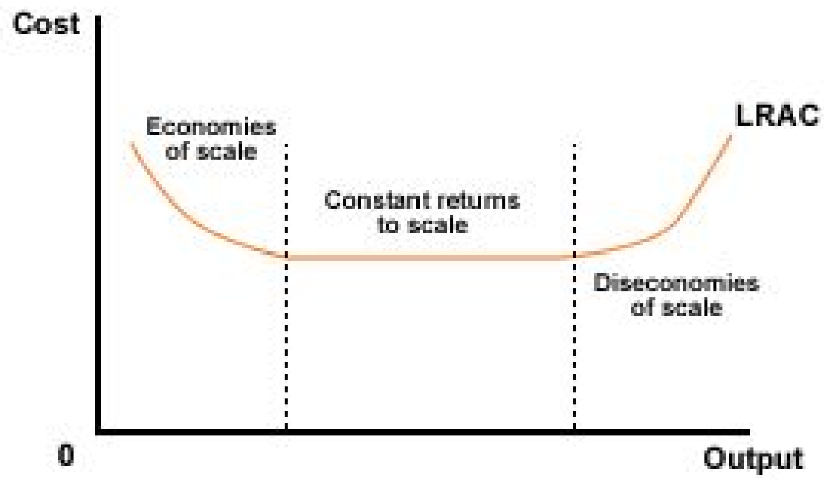

Figure 1. Graphical interpretation of economies of scale (Kenton, Will)

2.2 Case of Penn State

Penn State is a large organization with lots of resources, and thus it will act as a case study for other such large organizations. Penn State's Office of the Physical Plant (OPP) manages more than 22,000 acres of land and and more than 42 million square feet of buildings. Their system consists of over 600 buildings with automation systems. Managing such a large operation has considerable challenges as well as opportunities. The University's nearly 100,000 students are affected daily by changes in OPP policies.

Tim Pryor is in charge of Building Automation Systems (BAS) at Penn State and is working with OPP towards a common goal - save energy. Tim met with us to highlight the successes of Penn State's systems. Penn State has a tremendous BAS network that has evolved over several decades. The systems are acute enough to provide alerts to managers not only when things go wrong, but has artificial intelligence built in to test possible causes and find the root of them problem, and provide this information to the user. This sort of whole-system integration is one that can only be done by large organizations through their economies of scale.

One of the biggest successes of Penn State's Facility Automation Services subdivision of OPP has been the improvement in use of empty spaces. According to Penn State's use of 25Live, a room booking and monitoring service, 60% of classrooms are empty at any given time. Upon investigation, the majority of students and teachers want to use buildings on Tuesday and Thursday from 10am-2pm, resulting in shortages of space during these hours and challenges to put buildings to use during off hours (T. Pryor, personal communication, April 9th, 2019). Once this simple scheduling error was recognized, calls for entirely new multi-million dollar facilities to add additional spaces could be corrected through simple schedule analysis within an already existing Penn State department. As one of the several organizations in the United States doing true big data analysis, Penn State's OPP was able to disperse room usage more evenly, improving energy usage dramatically. Additionally, as exemplified by the case above, when university employees approach OPP to request new building construction, OPP is able to conduct analysis on data regarding current space usage and assess the viability of requests. This direct evidence has helped limit costly new construction by allowing for improvement of the efficiency for the buildings that are currently in place.

Penn State has tremendous potential for energy conservation as well as cost savings. Because of its large size, Penn State has low average total costs, and is able to employ a large, well-qualified OPP department. This large staffing department can perform data analysis that other smaller organizations are unable to perform. This allows the university to implement many more monitors on building statuses with specific and numerous security and maintenance alerts.

Holding information for only 90 days is an extraordinary feat of storage capacity as the information gathered from building automation systems (BAS) amasses to approximately 500 terabytes before needing to be cleared (T. Pryor, personal communication, April 9th, 2019). With many professionals trained and ready to handle equipment failures as well as ensure the security of this information, Penn State can manage its building efficiency very well. Even small initiatives such as the Holiday Heat Reduction Initiative saved the university $226,489 over the 2015-2016 winter break because the university is able to implement them with extreme precision (T. Pryor, personal communication, April 9th, 2019)..

The economies of scale are so advantageous for the University Park operations of Penn State that it is in the process of onboarding its other campuses into central monitoring in order to reduce marginal costs for these campuses. These campuses have been struggling to implement their own Facility Automation Services, so they are being brought under University Park's umbrella of resources. Because so much of the technology is centered on monitoring the status of systems, University Park OPP personnel are able to oversee the general administrative processes of commonwealth campuses and employ only a few maintenance employees to perform repairs and upgrades to commonwealth campus equipment. This system of "onboarding" smaller organizations to larger ones or simply combining many smaller systems into one can help organizations medium scale organization, like the Borough of State College, and small scale organizations discover more profitable economies of scale. This strategy will be further analyzed and proposed throughout this paper.

2.3 Case of State College

The Borough of State College maintains a considerably smaller portfolio with fewer resources than Penn State's OPP due to its nature as a division of a local government instead of a facility management office within a massive state-wide entity. The Borough manages roughly thirteen facilities, of which three have building automation systems in place (T. Brown, personal communication, April 16th, 2019). Considering the contents of their portfolio and noting the inclusion of multiple parking structures with automated controls, an integrated building automation system is not viable for all their buildings. With so few buildings providing a viable framework for integrated automation systems, it is not logical to implement the same whole-network integration that an organization such as Penn State possesses. For this reason, the approach for energy conservation must be different from that of a large organization.

Tom Brown, the facilities supervisor for State College, oversees building management in the Borough and met with us to give his insight on facility automation in the Borough. Alan Sam, the Borough Environmental Coordinator and Arborist, provided insight into the nature of sustainability initiatives and resource management for entities of the size of the Borough. Some of the most important limitations to the Borough's actions include high fixed costs of investment. For example, buildings have been constructed according to Gold LEED Certifications from the ground up, but only received Silver LEED Certifications. This is a result of the borough not having the resources to monitor the status of the buildings energy emissions for an extended period of time sufficient enough to receive the gold certification (T. Brown, personal communication, April 16th, 2019). While up front costs can be a barrier to entry into the world of building automation services, the Borough of State College still makes effective efforts to limit these barriers.

When State College makes energy improvements, they make an effort to receive rebates and assessments from Energy Service Companies (ESCOs) whenever possible (T. Brown, personal communication, April 16th, 2019). ESCOs such as Honeywell and Johnson Controls are often willing to cover the upfront costs of energy improvements and guarantee energy saving to help smaller organizations make technological upgrades to improve energy efficiency (T. Brown, personal communication, April 16th, 2019). State College has worked with these organizations to write Energy Savings Performance Contracts (ESPCs). These contracts are set up so the State College borough can have some of the upfront costs of innovation covered, and then pay back the company portions of the energy savings for a set period of time (T. Brown, personal communication, April 16th, 2019). State College benefits from this because it does not need to raise additional funds or receive approval to make improvements to their buildings' energy efficiencies.

A popular method for improving temperature regulation costs is "pre-cooling". Pre-cooling is setting a room to an energy efficient temperature during non-usage hours, and then bringing the temperature back to a desired level slightly before the room will be in use. The Borough of State College does not typically utilize pre-cooling, except in large chamber meeting rooms, as much of the building space would not benefit from such efforts due to frequent use. However, they have been able to integrate holiday cooling and daily setbacks after the typical workday has ended into their HVAC systems. As governmental buildings have predictable holidays off from work, most systems in State College managed buildings will automatically adjust to energy efficient levels if buildings are scheduled to be unoccupied (T. Brown, personal communication, April 16th, 2019). This results in lesser energy loads for times when buildings do not need HVAC and lighting systems operating at full capacity. More opportunities are still available for improvements in this regard as technologies continue to develop to make individual space heating and cooling more viable on smaller scales.

One of the biggest challenges facing the Borough is a lack of staff to perform analytical work on building information. Even though they are able to store information on building statuses for 30 days, this information is largely left unused (T. Brown, personal communication, April 16th, 2019). A small staff is unable to analyze the data and create the most effective strategy for improving energy efficiency. As a result, State College has set up monitoring devices to alert operators only in the event of critical failures. Preventative maintenance, the act of replacing equipment before critical failure, is currently scheduled within an isolated database on the basis of machine runtimes and failure probability calculations, yet this information is not currently integrated into the BAS software for monitoring. In addition, if pieces of equipment are performing inefficiently but still functioning, energy may be lost until a critical alarm occurs (T. Brown, personal communication, April 16th, 2019). That being said, they are currently working on a preventative maintenance work order system integrated into their BAS software that will allow work orders and alerts from machines to be automatically sent when performance anomalies are noted by the BAS software. This innovation is further discussed in the next chapter. Overall, State College is above average in terms of energy use reduction for comparable organization sizes, and thus can serve as a model for integrating automated systems.

Chapter 3: Policy Proposal

3.1 Overview of Proposal Structure

Analyzing different scale organizations and their respective capabilities in reference to the availability of facility management resources, the conclusion was reached that organizations should be divided into three categories in order to identify applicable policy suggestions in the from of strategy. The first category best describes small entities, such as rural municipalities, that have a one or two facilities that would benefit from gathering data and implementing automated building controls. The second category, exemplified by a larger scale organization such as the Borough of State College, typifies organizations that have multiple facilities, larger facilities, and a greater pool of resources to apply to expanding the automation and data collection regarding management of these buildings. The third category represents organizations that primarily act in operation of facilities, controlling large quantities of buildings and potentially multiple campuses, as does Penn State's Office of Physical Plant. These operations are composed of a larger staff and greater amounts of resources, having subdivisions of their structure devoted to the implementation and maintenance of facility automation technologies and acting on the innovative front of facility management strategies.

3.2 Category One - Single Facilities with Minimal Staff

For a small scale entity typified by the first category, resources may not be present to have complex facility management systems and analytics software, much less support full-time facility managers. This category, specifically its low level of technological innovation, is surprisingly common within small-scale facility management. One explanation for this, a situation known as owner-operator buildings, is that single building owners who also act as operators often do not have the resources to support complex systems and strategies. Beyond this, these buildings may not have had updated technologies and equipment integrated into their design. Retrofitting these buildings is expensive, yet not integrating modern technology is both costly and counterintuitive to the fundamental nature of facility management, saving money and energy. On the most basic level, innovation can be as simple as updating lighting fixtures and equipment. It is noteworthy that numerous incentivised initiatives exist with power companies and government entities to upgrade equipment for the purpose of increasing energy efficiency, exemplified in part by the market trend towards installing LED lighting systems (T. Brown, personal communication, April 16th, 2019). Assuming managers already take advantage of these initiatives and programs, the next focus for Category One facility managers should be data collection and automation.

Even at the scale of an individual building, implementing data collection strategies and taking advantage of the resulting operation awareness is a feasible technological solution in regards to modernizing facility management approaches. These organizations have the opportunity to adopt modified versions of strategies used by medium and large scale entities. Organizations that have facilities with reservable spaces, predictable operations schedules, or commonly occupied systems, such as meeting rooms and offices, often have master calendar and booking softwares, a standard practice in modern workplaces. By recording times that spaces are commonly occupied or reserved in a database such as Microsoft Excel, this data can then be analyzed to find common patterns and trends in space occupancy and then be used to create a specific plan of when to heat, cool, and illuminate spaces. This type of analysis can be automated within a building automation system (BAS), a topic that will be discussed at the end of this section, yet it can be manually performed as described above.

Another strategy in regards to modernizing facility management techniques on a small scale is the installation of individual automated control systems in regards to non-linked HVAC and lighting systems. These automated controls are easily integrated and commercially viable for small scale operations, with the most basic of controls being a programmable thermostat system ranging in cost from $100-$300 (T. Pryor, personal communication, April 9th, 2019). Upon installing programmable controls, operational schedules can be linked with these systems to automatically operate the HVAC and lighting systems in the facilities when necessary. This allows operators to initiate energy setbacks during low-occupancy use and times when the building is unoccupied outside of typical operational hours. In addition to this, simple solutions such as motion sensors and in-person confirmation of room occupancy schedules can be recorded and analysed in conjunction with calendar system data to identify possible inefficiencies and erroneous operational schedules. For example, if a request is made to the automated controls to regularly prepare a space for occupants, yet the space is not necessarily used during every requested booking, verification of bookings can be used to reduce energy waste and discourage unnecessary requests for spaces to be environmentally prepared and then left unused. Preemptive management and monitoring of spaces based on operational calendars should be the standard of operation, as seemingly energy efficient solutions such as heating and cooling based on motion detection or manual activation once a space is already occupied is often action occurring too late for a controlled environment to be brought to a comfortable level (T. Pryor, personal communication, April 9th, 2019). Sacrificing comfort for energy efficiency is an avoidable occurrence, easily addressed in this case by data and pattern analysis derived from recording and verifying calendar entries and typical operation schedules coordinated with isolated controls of HVAC and lighting systems.

If a building has a complex BAS already installed, which is still a relatively high-end practice in new construction, these systems often have internal operational calendars capable of linking to common-user calendars such as Google Calendar. A variety of softwares provide this link such as 25Live and Events2HVAC, offering the above described services of predictive building operations in regards to building climate (T. Pryor, personal communication, April 9th, 2019). These services should be used to the greatest advantage possible to incorporate the verification of operations, periodical analysis of data trends, and report to facility managers relevant data to promote schedule optimization and prevent unnecessary occupancy requests. Despite the potential benefits of having a unified BAS control system, this is typically not common practice for Category One scale operations, nor is it necessarily feasible to suggest this as a recommendation for small scale entities. The solutions offered by the BAS in a building can be achieved with individually monitored systems that cost less than the overall licensing fee required for an integrated BAS. As mentioned above, inputting known operational schedules into these programmable HVAC and lighting systems allow for energy efficiency and savings using basic programmable control units. This is a practice that can easily be implemented on the simplest level of facility management and continued to the highest level. That being said, method of delivery and complexity of using occupancy data for a second and third category operation is very different, as integrated BAS licenses applied over a portfolio of assets is considerably more viable as a solution.

3.3 Category Two - Multiple Facilities with Dedicated Staff

The intermediary level of categorization is best explained as an organization that manages multiple facilities or has a complex BAS integrated into their facility management strategy. Exemplified by the Borough of State College, these organizations generally have a dedicated facilities staff, comprised of 7 members in the case of the Borough of State College (T. Brown, personal communication, April 16th, 2019). Similar suggestions to those applicable to first category organizations are plausible, such as continuing to implement BAS solutions and automated controls wherever applicable and taking part in energy savings initiatives. Within this category, buildings are still treated as individual entities, not necessarily having BAS programs integrated in one overall multi-building software as a network or even linking automated control system into a BAS within a building due to economic viability and missing software links (T. Brown, personal communication, April 16th, 2019). In regards to the economic viability of linking multiple buildings into one network, the explanation can be reduced to the fact that managing three separate BAS systems and the corresponding response alarms is often more feasible than purchasing a separate software license to integrate these multiple BAS platforms into one overall portfolio-wide facility management software (known as a CMMS - Computerized Maintenance Monitoring System) specifically for maintenance responses. The relationship between CMMS softwares, BAS softwares, and automated controls is shown below.

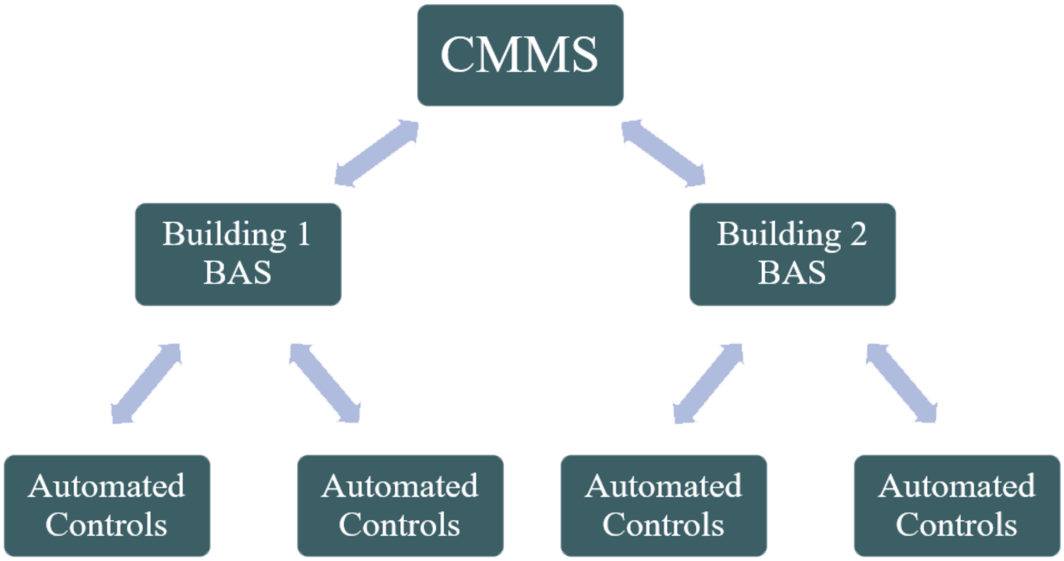

Figure 2. Flow diagram displaying relationships between CMMS software, BAS software, and automated controls

These software links, indicated in Figure 2 by the arrows, are a major source of delay for these operations, as automated lighting and HVAC controls may be installed as separate automated systems, yet the two systems are not necessarily linked into an overall BAS interface due to compatibility issues between them or pricing. These automated controls may either predate the installation of BAS software within a building or BAS software may not be installed at all due economic viability concerns, meaning that automated controls are present for individual systems, yet a BAS system centralizing their operations does not exist. In both cases, this lack of centralized linking serves as a hindrance to overall progress of modernizing facility management techniques. This source of delay is not one that can be typically solved internally at the scale of a second category operation without developer software updates or additional products, as Category Two facility teams do not have coding and developing staff (T. Brown, personal communication, April 16th, 2019). As technologies continue to develop, whenever possible and economically viable, BAS systems and automated controls should be linked as shown in Figure 2 in order to improve monitoring efficiencies and capabilities.

Even despite these software communication barriers, once facilities have automated systems incorporated into their controls, a more robust strategy of data collection can be realized by the software. If an overarching BAS is present, individual mechanical components such as fans, heater, and lights can be sampled for data at a rate of hundreds of times per minute. If isolated automated control systems are present without a BAS, assuming the controls are of a higher caliber than basic automation systems and capable of relaying internally collected information, this same data collection can occur, yet it will need to be manually processed by an analyst. However, regarding integrated BAS platforms, collected data can be internally analyzed within the BAS, have trends noted, and alerts sent to controllers if machines begin to operate outside of what has been logged as normal performance by the BAS (T. Pryor, personal communication, April 9th, 2019, T. Brown, personal communication, April 16th, 2019). Currently, one major issue with this, explored in-depth in the next section regarding the innovations possible for third category operations, is that with hundreds of mechanical components per building, even pure binary data can only be stored for around 30 days to 90 days before current data storage methods reach a capacity (T. Pryor, personal communication, April 9th, 2019, T. Brown, personal communication, April 16th, 2019). If sampled at a rate of 500 times per minute over 365 days, 262,800,000 data entries will be recorded for each individual machine within a building. On the scale of one or multiple buildings, the amount of information quickly becomes too large to be viably stored. Additionally, Category Two operations currently often do not have the capability to analyze the data that is recorded due to limited staff and resources (T. Brown, personal communication, April 16th, 2019). With the inability to conduct proper analysis of recorded data expressed as a major concern within Category Two entities, partnering with other organizations may offer solutions to lack of analysts. Despite this technological and resource-based limitation to data analysis, there is a potential solution to this setback. In the case of State College, collaboration with Penn State's Sustainability Institute and the AmeriCorps organization allow for dedicated analytics staffing (T. Brown, personal communication, April 16th, 2019). Finding these partnerships or outsourcing data analysis to external organizations if possible is one potential solution to addressing the scale of data collection present within these entities. Having access to data analysis resources and the information that could be reported from data that is already temporarily monitored could allow for greater energy efficiency and operational awareness.

Despite the current inability to store data long-term, regular investigative facility inspections and preventative maintenance schedules can be used by Category Two organizations in order to extend facility lifetime and save energy. In the case of State College, preventative maintenance information is currently processed by a standalone database schedule, as is common practice even for considerably advanced entities (T. Brown, personal communication, April 16th, 2019). The current initiative to modernize this system by State College, one that should be held as exemplary for operations of a similar magnitude, is integrating a maintenance work order system within the BAS software. This would require that preventative maintenance data is pulled directly from BAS monitored machines into a work order system, with communication occuring in the other direction as well. The objective of this is to adopt a preventative maintenance system that, instead of relying on an isolated database, communicates with BAS data and internal analytics, issuing required work orders for individual components as needed. This saves energy and time, as mechanical components will automatically submit work orders if they are detected by the BAS to be operating outside of their normal range of operation. Inspectors and maintenance staff will then be easily able to identify underperforming elements and replace them as soon as the work order system is notified by the BAS system.

3.4 Category Three - Large Scale Facility Management with Large Staff

The third category of organizations that operate BAS systems is typified by entities that extend beyond operating a few buildings, but rather operate tens or hundreds of buildings on complex networks that are continually innovating in order to properly serve the vast network of buildings within their network. Operated from a remote, centralized location, the BAS technologies for each building are used to their fullest capabilities within these entities. Regarding the calendar systems discussed in the prior categories, organizations of this scale can implement the linkage of multiple calendar systems into their BAS for a particular building and then, based on system-confirmed trend and patterns, implement daily automated functions on a time schedule matching typical occupant loads (T. Pryor, personal communication, April 9th, 2019). These systems continually record, analyze, and learn from their usage patterns in order to maximize energy saving efficiencies when applicable to the building type.

Offering hundreds of data sources per building in regards to building equipment (fans, pumps, HVAC units) and creating software links capable of interpreting hundreds of hertz of data points per source into a digital language comprehensible for BAS subsystems, organizations within this third category have the ability to properly process inconceivable amounts of information as they continue to develop new technologies and methods to store this data (T. Pryor, personal communication, April 9th, 2019). Defined by the common practice in computer technologies known as creating an Internet of Things, this creation of a network of softwares that typically would not communicate is possible at the scale of Category Three organizations due to inhouse development and software teams (Evolution of Building Management, 2017). Upon the installation of new equipment, data tags are assigned to individual machines in both language referenced by internal BAS operations and CMMS softwares and human-logged tags (Manning et al., 2019, p. 72). This allows CMMS softwares, which act as a common notification interface between multiple BAS systems across a portfolio of buildings, to enact preventative and predictive maintenance strategies, as they can refer to machine-learned trends from monitoring individual machine in order to identify any anomalous performance changes and even predict failures before anomalous behavior begins (T. Pryor, personal communication, April 9th, 2019). Referencing Figure 3, known as the Performance-Failure Curve for a component's operation lifetime, the CMMS software can alert operators of an issue noticed by a BAS software, as was the case for the Category Two innovation of integrated BAS preventative maintenance work order systems. With this link already existing between work order systems and BAS softwares in Category Three operations, BAS and CMMS systems can also include predictions regarding when a critical failure will occur within a particular machine, creating a system of priority within automated work orders (T. Pryor, personal communication, April 9th, 2019).

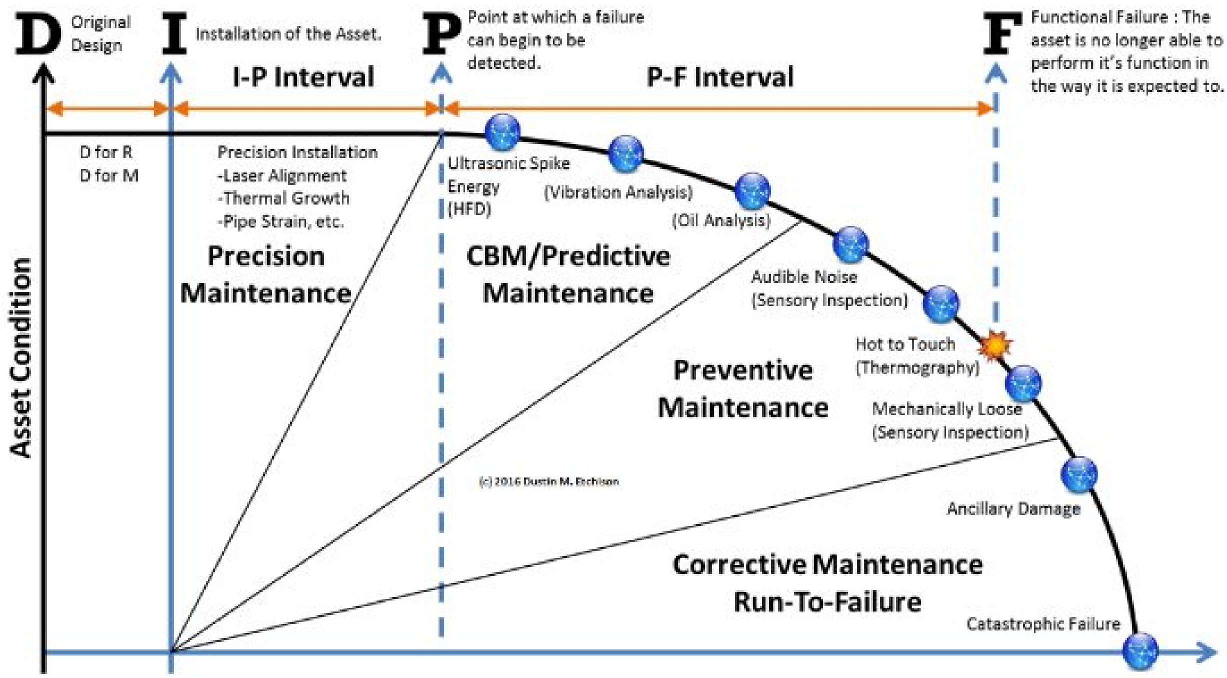

Figure 3. P-F Curve describing the condition of building assets as a function of time (Etchison, 2017)

This type of preventative maintenance, which offers saving in both energy efficiency and time as a result of preventing unforeseen failures, is one major benefit of implementing data analysis in conjunction with the existing abilities of machine learning algorithms within BAS softwares. Beyond this, the current front of innovation for entities within this category is developing the ability to take the vast amounts of data received from each individual building's BAS and then analyze all of this data as a collective unit (T. Pryor, personal communication, April 9th, 2019). However, at the scale of a Category Three entity, instead of only being able to address each building as an individual circumstance, an entire campus or portfolio of buildings can be analyzed. The expanse of data generated ranges across countless metrics from elevator capacity data on a per-ride basis over the course of two years to HVAC efficiency data in specific external temperature instances for specific occupancy type buildings over the past five years. The data is already generated for all of these points, yet storage is only possible for very limited amounts of time, approximately 90 days for Penn State, a similar limitation to the 30-day limitation within Category Two (T. Pryor, personal communication, April 9th, 2019). In order to address the inability to properly store data on the required scale, the main focus of innovative efforts is to find and implement data storage via a cloud "data lake" system in order to permanently record and analyze the hundreds of millions data points available for each machine annually (T. Pryor, personal communication, April 9th, 2019). As discussed in the second category section, 262 million data points will be generated by one mechanical component in a year. At Penn State, within the large classroom Willard Building alone, approximately 1100 data generating components are present and monitored. Overall, 289 billion data points will be recorded for the Willard Building alone each year, which is just one of over 600 buildings in Penn State's portfolio (T. Pryor, personal communication, April 9th, 2019). This highlights the need for innovative development in terms of storing and making logical sense of essentially limitless amount of building data. By storing this data in a data lake setting, all information uploaded can be found and referenced at a later date or tracked indefinitely on a scale previously unimaginable. This is currently only possible within the Category Three scale operations, as entities like Penn State's Office of Physical Plant have entire subdivisions that work to manage and integrate automated building control solutions and operate data analytic software.

Chapter 4: Analysis and Findings

Considering the level of effort taken by entities such as the Borough of State College and Penn State's vastly interconnected Office of Physical Plant into developing robust energy-saving building automation systems, the presented proposal allows for these same tactics or techniques to be adapted in various other organizations - with a focus on small enterprises. With all that in mind, however, there are a few scenarios in which the implementation of these systems may not be the best option.

4.1 Counter Arguments

First, consider the example of campuses, potentially governmental or collegiate, that are primarily composed of old buildings with little to no self-monitoring software within them. Retrofitting these old buildings with new technology may not be the most financially viable option, especially for buildings whose lifespan is short and is slowly coming to an end. On the flip side, retrofitting a building may be a much better time-dependent solution, should the need for the building be in high demand. In some scenarios, it can likely be a better option to opt for partial or complete demolition and construction of a new building already fitted with the desired technology, rather than working backwards into implementing complex technologies into archaic frameworks that may be close to the end of their operation lifetime. Prior research in cost-benefit analysis has shown that the economic viability of retrofit projects is most dependent on energy price in the region, followed by initial retrofit project cost (Liu et al., 2018). An example of this is the aforementioned redevelopment of the Borough of State College Maintenance Building, originally built in the 1970's, which is implementing a smart HVAC system despite the building itself being old. In its case, the use-case of the building clearly outweighed the cost of its renovation (T. Brown, personal communication, April 16th, 2019). Based on these findings, it is clear that retrofitting of old buildings is a sensitive measure to take, and thus should involve careful, measured cost-benefit analysis before a decision is made.

Another set of parameters to consider for decision-making with regards to large-scale building automation system implementation is the need for short-term vs. long-term gain. Once again returning to the concept of building life-expectancy, buildings which are only a short time away from demolition do not warrant the installation of a retrofitted system for that short time period. Conversely, for a newly constructed building, long-term energy-savings is likely the goal, and so appropriate building automation systems should be built-in. This idea of long- vs. short-term gains does, as a result, also tie into the level of financial capital an entity can place into building monitoring technology. If only a small amount of money can be put forward towards these types of improvements, then it makes much more sense to invest in a small-scale solution, such as a smart-learning thermostat. Larger campuses such as Penn State's have the liberty of allocating a larger portion of its budget towards improving its building automation initiatives, and thus should be used as a prime example of the positive effects this policy proposal can have in a large enough setting. Working towards energy savings, similar to the overall goals of sustainability, all require some sort of short-term loss to achieve a long-term gain - it is up to each individual group or organization to identify the time-intensive needs of their facilities.

Finally, it is worth considering the number of facilities for which each organization is looking to implement new building automation systems. The number of buildings can have a large impact on the number of individual systems required to be installed, as well as the general connectedness of these systems across all facilities. For example, a small city government comprised of only two or three buildings with a low number of staff, or another group classified as a Category One set of facilities, will likely not require the advantages a vast, interconnected automation system can offer - rather, a Category One group should be looking to invest in smaller-scale solutions on the individual scale for each of its facilities. Obviously, a local government like that of State College, which is comprised of 13 facilities and has a need for a unified system (T. Brown, personal communication, April 16th, 2019), is much more likely to pursue the implementation of smart monitoring systems for its facilities. Then taking into consideration a campus like Penn State, which itself is comprised of over 600 buildings over several campuses (T. Pryor, personal communication, April 9th, 2019), a set of facilities which might be geographically separated has a high use case for an interconnected system that can facilitate communication across all systems.

This paper's proposed policy looks to create a set of standardized set of operations that entities can utilize to achieve a long-term goal of sustainability and energy efficiency. However, as the above counter arguments outlined, there are various scenarios where more thought should be placed into the action taken. Careful cost-, time-, and scope-based analyses can result in proper implementation of "smart" automation systems in facilities based on their individual characteristics.

4.2 Additional Initiatives

While implementation of his paper's policy is one way to pursue a sustainable energy-saving solution for entities or organizations seeking a controlled method for building automation, additional steps can be taken outside of this policy to further learn more about sustainable facilities, as well as implement innovative technologies that are already being used by building automation leaders. With sustainability being such a collaborative effort, resources for system development are abundant.

Conferences serve as a fantastic means to gain knowledge about building automation initiatives around the country. One such example is the Big Ten and Friends Facilities Management Directors Conference, which last took place in 2017 (“Big 10 + Friends”, 2017). This conference in specific brings together directors of facility management at Big Ten schools to discuss and collaborate on special initiatives that a school may be taking. The most recent conference not only covered topics such as facility data analytics and energy consumption techniques, but also held workshops in interesting areas such as resource management, recruitment to the industry, and classroom outreach through experiential learning.

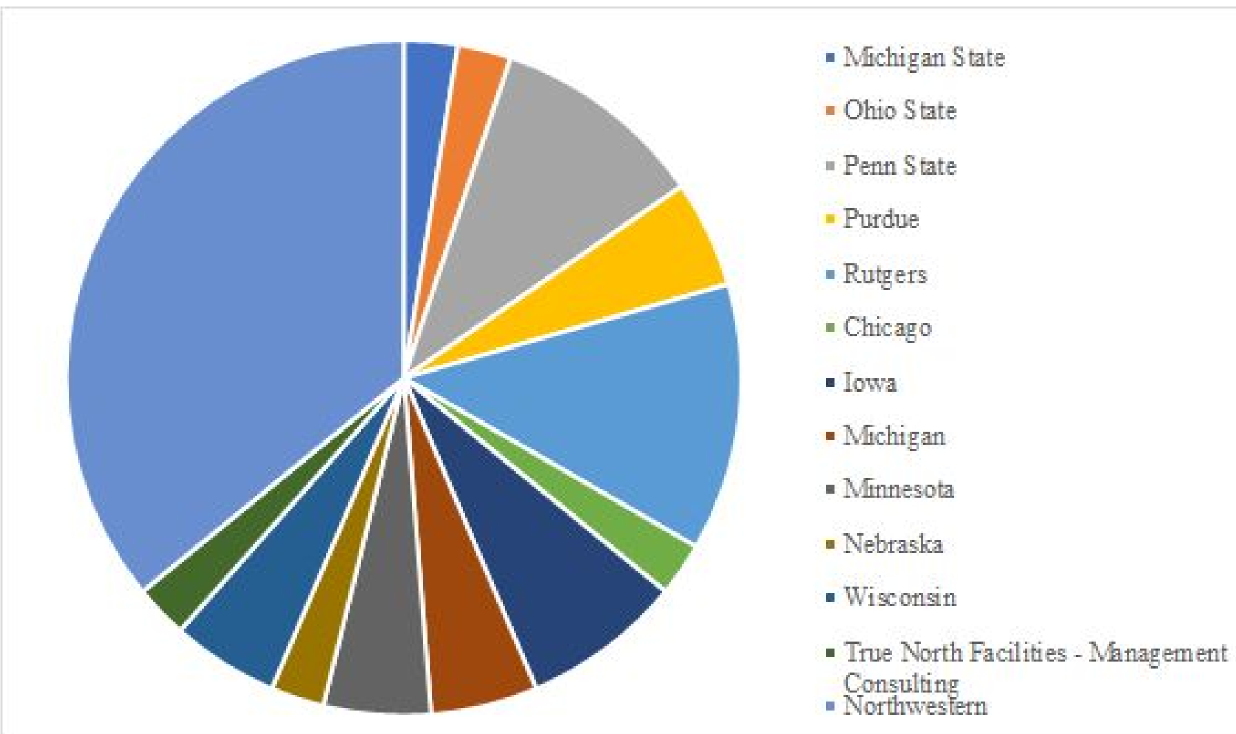

Figure 4. Pie chart displaying diversity of attendees to Northwestern’s Facilities Management Directors Conference

Additional conferences which run similarly and have parallel goals are (Saha, 2018):

- IFMA (International Facility Management Association) - SFP Part I of III Strategy & Alignment for Sustainable Facility Management

- Facilities Management Ireland - Exhibition and Conference
- Northeast Sustainable Energy Association (NESEA) - BuildingEnergy Boston

Conferences like these not only serve to build a group of industry leaders in facility automation, but to advance the overarching goals of sustainability. Additionally, conferences bring forth innovation in facilities automation, and supplement this policy well. In fact, a further iteration of this policy could mandate the attendance of a facility management conference by an entity, especially if this entity is governmental or an institution of higher education.

Another means through which automation system networks can be furthered is through direct collaboration with other entities and eventual centralization - specifically, this strategy can especially work when the entities themselves share some sort of "mother-daughter" relationship. As noted during an in-person informational interview (T. Pryor, personal communication, April 9th, 2019), Penn State has exhibited this exact type of collaboration by pledging to take over facilities automation initiatives for Penn State's commonwealth campuses. In doing so, the Office of Physical Plant at University Park is not only clearly displaying leadership in being a "parent" entity, but is also facilitating the saving of costs and time for Penn State employees as a whole. Centralization has shown to provide immensely useful monitoring capabilities for a given system ("Centralized Control System", 2001), as well as the ability to implement various scheduling features no matter the geographical distance. This has allowed the Office of Physical Plant's specialized Facility Automation Services group to highlight large-scale trends in student and faculty activity in campus buildings, and is a much more efficient system when compared to delegating automation responsibilities across the campuses. Translating this strategy to the use-case of government buildings, centralization could take place on the county level - in the case of the State College area, the Borough Facilities Division could look to coalesce with municipality buildings in nearby areas such as Bellefonte and Boalsburg, potentially spanning out to the major areas in Centre County. In this case, county-level centralized systems enhance collaboration between local governments and create an interconnected network that, when built with the guidelines proposed in this paper, can collectively serve to lead energy-saving sustainability efforts.

Conclusion

The overall conclusion that can be drawn from much of the information and research provided is that facility management with the use building automation systems provides a framework for sustainable management. However, while these systems should exist in any facility to the applicable degree to advance environmentally-friendly operations, the feasibility of implementation varies depending on the scale of industry.

Category One of facility management is within a small industry scale. Similar to Category Two, this group would operate under limited resources and spaces. There are a number of ways to go about facility management that consider both the size, cost, and existing systems. The first question that should be asked is what systems exists within these buildings? If the institution is performing management manually via excel sheets, it would be worth considering introducing individual automated control systems for the areas that they would like to see greater efficiency and can afford. If a BAS system already exists, within a building this group can incorporate the integration of occupancy schedules and a calendar system if applicable. Another great step includes booking and real-time confirmations for spaces that are reserved but not occupied in order to avoid wasted energy. Lastly, if there is management under both a calendar and BAS system, if it is cost effective, there is incentive for motion detection software that further reduces energy use. Many of the issues of facility management in this group are linked to limited funds and limited staff that can update and manage these building at the same rigor as larger institutions. However, the largest possible gains from automated controls and BAS are offered to these small entities. Therefore, this group has the largest incentive and rewards for implementing these changes. Ideally, any advancement in facility management for this scale should align with their capabilities and the economic viability of investment.

Many of the theories behind the practices of facility automation in Category Two do not differ from much from Category Three. Much of the difference between the two categories boils down to resources. A group in this tier simply does not have the ability to scale up in the same way as a large institution with a large dedicated staff. Because of this, there is likely to be fewer integrated building automation systems, missing links between softwares, and variation between facilities and operations. While it might not be feasible to have a CMMS software or have integrated BAS software in all facilities, there are still opportunities to incorporate sustainable facility management. Outsourcing data analysis, implementing automated work order maintenance systems, and collaborating with other Category Two entities are the most viable paths of innovation for this group. Further, opportunities for Category Two (and Category One) include rebates, collaborative work, and the use of the calendar systems within existing systems. Rebates allow an organization to receive the funding and help from companies to better improve their energy efficiency. To reiterate, collaboration with other institutions can help provide investment, innovation, and additional resources. Lastly, the use of integrated operational calendars can allow energy use to be controlled within a time frame so that is it not being wasted. The most important consideration for entities in Category Two is to incorporate building automation system as feasible and to maximize their resource usage for greater sustainable practices.

Category Three of facility management organization are exemplified by institutions with large-scale resources and staff. This group will have the ability to utilize building automation systems throughout their facilities as the economies of scale reduces the marginal cost of incorporating systems into additional spaces and buildings. The use of these systems at such a large scale provides great reductions in energy use, cost, and overall efficiency that is significant in the beginnings of implementation and dwindles over time. BAS softwares are linked within automated CMMS softwares and have vast pools of data for analysis. The development of viable storage methods for this data, currently being explored as a data lake cloud storage initiative by Penn State's OPP will allow for Category Three operations to conduct proper "big data" analysis across an entire portfolio of buildings. Additionally, common practices at this level will previously mentioned initiatives, such as system links to a calendar software, occupancy detection throughout facility spaces, and data analysis and oversight by inhouse personnel staff.

The process in which different industries introduce building automation systems will vary. Yet, building automation systems at all levels provide the data for trend analysis, reports for utility function and failure, and work directly at providing energy efficiency facility management solutions. Implementing this technology and software is great way to create a framework for sustainable planning and management. The most important things to consider when going about the introduction of BAS software and automated controls is the feasibility, the costs, and the viability of installation regarding overall facility management strategy. Feasibility can be analyzed in terms of whether there is enough funds to advance automation, if the ability exists to retrofit projects on a required scale regarding age and state of the building itself, and if there is staff that could adapt and manage these systems properly. Lastly, a group should consider the implications of installment in terms of short-term and long-term gains. Adopting new policy and strategy regarding automated systems is recommended if there is foreseeable long-term gains.

The practice of facility management with the use of building automation systems provides significant incentives and benefits across industries. Although one common solution does not exist for every industry or building, there are multiple strategies and recommendations to follow depending on the scale of operations. We hope to have presented this idea clearly so that institutions can further advance their practices to realize more sustainable operations. If so, the changes that are made in the automation of buildings and facility management, whether large or small, will have great beneficial impacts on both practices within the profession and the environmental impact of building operations.

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