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ANALYSIS OF THE MAINTENANCE WORK ORDER DATA IN EDUCATIONAL INSTITUTIONS

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The growing number of aging buildings is of critical importance to the economic and social well-being of a country. For institutional organizations, particularly those with large building portfolios, an effective facility management approach is required to ensure these buildings function properly for their missions. As a part of facilities management, building maintenance activities occupy a significant role in reaching the goal of delivering an acceptable level of performance while minimizing costs and failures. Historical work order data may potentially include a substantial value for assessing the condition of building systems by helping to identify frequent and common building maintenance activities. As an exploratory study on building maintenance activities in educational institutions, this paper conducts an analysis of historical work order data collected from six educational institutions in the State of Colorado and Connecticut in the United States between 2008 and 2018. Within this context, a total of 877,668 work orders have been analyzed to identify possible trends of the maintenance activities with building age and building type. The results of this study provide a preliminary understanding of the frequent maintenance activities in the data sets with their relations of building age and building type. The need for the comprehensive statistical analysis is apparent to better understand any possible trends in the maintenance activities and their correlations between building age and building type.

Keywords: Facilities management, Building maintenance, Condition assessment, Educational facilities.

1 INTRODUCTION

Educational facilities are a fundamental part of educational institutions, providing the necessary environment and services for the institutions to meet their objectives. As the average age of educational institutions increases, facilities management practices and their effectiveness become important to sustain their educational missions. The Sightlines Report (2017) states that the average age of buildings in higher educational facilities as of 2007 was 34.2 years; and with no new building additions, the average age would have been 44.7 years. The database of the Sightlines Report (2017) tracks 52,200 buildings over 400 campuses in 44 U.S. states and four Canadian provinces for a total of 1.5 billion gross square feet (GSF) of space. The spaces for educational facilities grow and their ages increase faster than the resources allocated to maintain the spaces. Subsequently, limited budgets and resources highlight the need for effective maintenance management.

The main purpose of this study is to identify possible trends in maintenance activities such as the relation between the maintenance activity and building age as well as the maintenance activity and building type. The findings of this paper provide a basis for a resource efficient condition assessment framework in educational institutions. The operation and maintenance of the facilities include many different daily activities. Work order management systems provide a significant amount of data including activity types, crew/trade types, building ages, building types, dates, and etc. This paper conducts an analysis of work orders collected from six educational institutions in the State of Colorado and Connecticut in the United States between 2008 and 2018. The preliminary analysis of 877,668 work orders suggests that electrical, heating, ventilation and air conditioning (HVAC), and plumbing activities are the most frequent and common building maintenance activities. Therefore, this study mainly focuses on electrical, HVAC, and plumbing work orders.

2 BACKGROUND

Cost constraints, budget cuts, and the lack of proper management are the main reasons of lower performance of facilities, which result in the need for effective facilities management approaches (Eweda *et al.* 2013). Kaiser (2016) states that almost 75 percent of the higher educational facilities are in the range of 30 to 40 years old and they are facing the challenge of deferred maintenance backlog and inadequate funding for their maintenance needs. The same study mentioned that the deferral of major maintenance activities causes significant issues for system and infrastructure reliability, health and safety, and functional use of space (Kaiser 2016).

The aging buildings and insufficient funding of maintenance needs highlight the importance of the condition assessment process, which is a fundamental step of maintenance decisions. The limited resources have a negative impact on the condition assessment practices of the higher educational institutions. Therefore, most of the higher educational institutions are not able to perform the visual inspection part of the condition assessment process.

The historical work orders include comprehensive information related to the maintenance activities. Over the life of the facilities, the analysis of work orders may provide a preliminary feedback about the buildings' current conditions. There are some studies in the literature using the work order analysis for fault detection and maintenance budget calculations. Bossmann and Lennerts (2013) studied the maintenance data sets of 140 federal buildings in Germany to identify the key influencing factors of accurate and reliable budget calculations for the building maintenance. Their study emphasizes the influence of the age of facilities, the type of use, the size of the building and the number of stories on the budget calculations. Additionally, Yang *et al.* (2018) proposed a failure mode and effect analysis method for HVAC issues in the building maintenance. Their method uses a data mining approach for the analysis of work orders, though, it is limited to a specific type of maintenance activity. A more comprehensive approach is needed to analyze the historical work order data for obtaining meaningful information that will help better understand the condition of the building systems.

3 DATA COLLECTION AND METHODOLOGY

The work order data sets used in this study are collected from six educational institutions in the state of Colorado and Connecticut in the United States between 2008 and 2018. Among six educational institutions, three are state universities, two are private universities and one is a school district. The GSF of these six institutions is 34,964,771 square footage (SF) with a total of 1,671 buildings. The characteristics of the institutions with the average age of their buildings are shown in Table 1.

Table 1. The characteristics of the educational institutions of the study.

Institutions	State	GSF of Buildings	Total # of Buildings	Average Age of Buildings	Time Interval of Work Orders	Work Order Management Software
State #1	Colorado	4,076,953	60	63	2009-2018	TMA
State #2	Colorado	12,361,537	748	43	2008-2017	FAMIS
State #3	Colorado	8,186,982	409	67	2013-2017	FAMIS
Private #1	Colorado	3,567,470	74	51	2012-2018	TMA
School District #1	Colorado	3,979,365	70	43	2011-2017	SchoolDude
Private #2	Connecticut	2,792,464	310	105	2013-2017	SchoolDude

The work order data sets were exported to Microsoft Excel from the work order management software of the institutions. Table 1 shows the names of their work order management software. The primary analysis of the work orders focused on identifying the distribution of the maintenance activities for each institution.

The total of 877,668 work orders of six institutions contain all types of maintenance activities. However, the keywords and classification of the work orders were not constant for all institutions the names of crew or trade types were similar, namely architectural, carpentry, electrical, HVAC, mechanical, plumbing, structural, etc. Therefore, the work orders were sorted according to the crew or trade keywords. The content of the keywords was confirmed with the facilities management departments of each institution.

The first step of the analysis is focused on identifying any possible relations between maintenance activity types and building ages. On the second step of the analysis relations between maintenance activity types and building types are revealed. The researchers acknowledge that the analysis of this study provides a preliminary understanding of relations between the maintenance activity types and building age as well as the maintenance activity type and building type.

4 RESULTS

The preliminary data analysis of this study revealed that electrical, HVAC, and plumbing maintenance activities comprise the majority of all work orders as presented in Table 2. The "Others" category of Table 2 includes the variety of maintenance activities namely access control, carpentry, construction, custodial, key and lock services, fire safety, grounds, painting, pest management, operational services, structural, security, telecommunications, utility, welding, and etc. The contribution of these maintenance activities is less than 6% to the "Others" category individually. Subsequently, this analysis confirmed the similar feedback given by the facilities management executives who pointed out the higher frequencies in these three categories. Therefore, further analysis of the study focuses on these three maintenance activities.

The first step of the analysis explored the relationship between the maintenance activity types and building age. The corrective maintenance work orders including electrical, HVAC, and plumbing activities were extracted from the data and used in this analysis. The average age of the buildings was calculated per maintenance activity type for each institution considering only the year of construction, and renovations were not included in the calculations. It is important to note that, some of the buildings' ages were not provided by the facilities management departments. Since the focus of the analysis is exploring the relationship between the maintenance activity types and building age, the data of these buildings could not be included in the analysis, and their

data was disregarded. The percentage of the disregarded data varies between 20% and 3% of the total work orders per each institiution.

Table 2. The distribution of the electrical, HVAC, and plumbing work orders of the institutions.

Institutions	**Electrical**	**HVAC**	**Plumbing**	**Others**
State #1	17.54%	16.76%	11.94%	53.76%
State #2	9.62%	22.58%	10.12%	57.68%
State #3	14.56%	12.96%	9.31%	63.17%
Private #1	7.31%	23.57%	5.15%	63.97%
School District #1	14.55%	7.86%	16.50%	61,09%
Private #2	13.87%	13.39%	14.12%	58.62%

The distribution of work orders for the maintenance activities was relatively estimated for each individual building using Eq. (1).

$$Dwb_i = \frac{1}{Nw} \sum_{i=1}^{n} Nwb_i \tag{1}$$

where:

Dwb **=** The distribution of work orders for each maintenance activity at building *i*;

Nw **=** The total number of work orders for each maintenance activity; and

Nwb **=** The number of work orders for each maintenance activity at building *i.*

These distributions are grouped into three clusters in each maintenance activity for all institutions: higher, lower, and zero work orders. The higher cluster represents five percent and greater of total work orders (>5%). The lower cluster represents the buildings that have the work orders less than one percent of total work orders (< 1%). Lastly, the zero work order cluster represents the buildings that have zero work orders assigned (= 0). The higher and lower clusters point out the two extreme ranges in the data set. Table 3 shows the average age of the buildings of each institution in these clusters per maintenance activity type.

Table 3. The average age of buildings with higher #, lower #, and zero # of work order clusters (% of work orders > 5%, < 1%, = 0).

Maintenance Activity Type	State #1			State #2			State #3			Private #1			School District #1			Private #2		
	H	**L**	**Z**	**H**	**L**	**Z**	**H**	**L**	**Z**	**H**	**L**	**Z**	**H**	**L**	**Z**	**H**	**L**	**Z**
Electrical	36	73	47	53	43	32	49	62	48	51	55	46	38	44	-	53	108	64
HVAC	37	77	44	50	47	34	28	63	52	51	51	53	38	47	-	51	107	104
Plumbing	40	76	45	51	45	32	79	54	44	27	51	55	45	48	-	41	109	141

H = Higher # of Work Orders, **L** = Lower # of Work Orders, **Z** = Zero # of Work Orders

The comparison of the maintenance types and building ages revealed that the average age of the buildings in each cluster is more than the average age of 34.2 years provided on the Sightlines

Report (2017). Table 4 shows the average age distribution of the buildings in this study. The majority of the buildings in all clusters of the analysis are in the range of 40 and 60 years. The comparison of the same institutions in the three clusters revealed that the average age of the buildings in the the lower cluster is larger than the average age of the buildings in the higher cluster. In other words, the analysis does not show that older buildings receive a higher number of work orders as might be expected.

Table 4. The average age distribution of buildings in higher #, lower #, and zero # of work order clusters (% of work orders > 5%, < 1%, = 0).

Average Age	H	L	Z
<40	33%	0%	20%
40 - 60	61%	56%	60%
>60	6%	44%	20%

Classroom, office, and research buildings have the largest square footage among the facilities of this study; thus, only those building types are used for the subsequent analysis. However, based on the data it was only possible to classify the types of buildings of two educational institutions within classroom, office, and research. Therefore, the two educational institutions used for the second step of the analysis are State #2 and Private #1. Table 5 shows the distribution of buildings in classroom, office, and research types of these two institutions.

Table 5. The distribution of classroom, office, and research buildings in State #2 and Private #1.

Institutions	C	O	R	OT
State #2	7%	24%	14%	55%
Private #1	22%	19%	12%	47%

C = Classroom, **O**= Office, **R** = Research, **OT**= Others

The distribution of the building types is grouped into the same clusters of building age distributions namely higher, lower, and zero work orders. Table 6 shows the percentage distribution of building types per maintenance activity and per institution within each cluster. The comparison of the maintenance activity types and building types revealed that classroom, office and research types receive a higher number of work orders. This finding needs further analysis to better understand the correlation between the maintenance activity type and building type.

Table 6. The percentage distribution of building types with higher #, lower # and zero # of work orders. (% of work orders > 5%, < 1%, = 0).

Maintenance Activity Type	H								L								Z							
	State #2 (%)				Private #1 (%)				State #2 (%)				Private #1 (%)				State #2 (%)				Private #1 (%)			
	C	O	R	OT	C	O	R	OT	C	O	R	OT	C	O	R	OT	C	O	R	OT	C	O	R	OT
Electrical	0	33	33	34	100	0	0	0	7	21	12	60	7	9	1	83	0	14	5	81	0	1	0	99
HVAC	33	33	0	34	100	0	0	0	12	30	15	43	4	15	3	78	1	9	6	84	0	0	0	100
Plumbing	25	0	25	50	0	0	100	0	8	26	11	55	8	9	3	80	1	7	10	82	0	0	0	100

Additionally, the data analysis performed for this study helped to identify some common issues in the work order management practices faced by the higher educational institutions. One issue is that the general trend of identifying the maintenance activity depends on the crew or trade type in the work order management systems. None of the data sets used in this study include a category of the maintenance activity type. For that reason, the maintenance issues need to be identified with some additional information. The data sets include task descriptions that may provide useful information to better identify the maintenance issues. However, there is no consistency on the keywords of those descriptions and the variety of the keywords make the descriptions complicated to be analyzed.

5 CONCLUSIONS

The facilities management executives of the educational institutions in this study advised the higher frequency of electrical, HVAC, and plumbing maintenance activities throughout the data collecting process. Subsequently, the findings of the study confirm the opinion of these executives.

The analysis of the study does not reveal a specific relation between the maintenance activity and building age as well as the maintenance activity and building type. The results of this study provide a preliminary understanding of the frequent maintenance activities in the data sets with their relations of building age and building type. Consequently, the need for the comprehensive statistical analysis is apparent to better understand any possible trends in the maintenance activities and their correlations between building age and building type.

Although the data sets include the maintenance types (corrective, preventive, predictive, etc.) and crew/trade types, they do not represent the maintenance activity types properly. The maintenance activities need a subcategory that includes the basic definitions of the frequent failures. For instance, the electrical maintenance activity category requires subcategories such as light bulb changing, electrical panel issues, outlet/switch issues, etc. The subcategory of the maintenance activities may increase the effective use of work order data in the condition assessment process.

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