Mismanagement of Compostable and Recyclable Materials at Carleton College

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Math 245: Applied Regression Final Project

Abstract:

To contribute to the campus wide reduction of waste contamination at Carleton College, we used data collected over the 2013-2014 school year by the Student Waste Monitors on contaminated waste bins in Carleton College dorms. We used a Quasi-Poisson regression to model the contamination of landfill-bound garbage bins containing recyclable or compostable materials on dormitory floors. Our explanatory variables included total number of bins, number of compost bins, number of recycling bins, number of resident students, weekday of data collection, academic term, and whether the floor in question was a first floor. Collinearity between the numbers of bins and number of students make their effects difficult to interpret, but we find that first floor status is associated with significantly greater bin contamination, as is winter term and data collection on Saturday.

Introduction and Background

The Climate Action Plan (CAP) is a multifaceted framework for fulfilling Carleton's pledge to achieve carbon neutrality by 2050 as articulated by the President's Climate Commitment. CAP lays out a strategy to reduce greenhouse gas emissions by setting goals within five focus areas: energy supply and demand, land management, transportation, procurement, and waste management (Carleton CAP, 2011). Some examples of Carleton's success in improving campus sustainability include the reduction of campus energy consumption, the construction of LEED certified buildings, prairie conservation efforts in the Cowling Arboretum, construction of a commercial-sized wind turbine, and institutional support for student and staff led sustainability projects (Carleton CAP, 2011).

Success in improving waste management has been the most elusive of the five focus areas. Custodial services have taken action to improve the systemic and structural aspects of waste collection and management at Carleton. Carleton's recycling program was launched in the mid-1980's, followed by its composting program in 2005, which have expanded the number of recycling and composting resources in academic and residential buildings. Waste Busters, a community of concerned custodians, has worked to monitor and centralize waste collection sites to reduce the cost of waste hauling. Custodial services is currently negotiating a monthly recycling and compost reporting system with the campus waste hauler (Carleton CAP, 2011). Despite these efforts, unquantified loads of compostable and recyclable materials are sent to unknown landfills while the college's investment in compost and recycling pickup subscriptions is underutilized.

The current obstacle for optimizing campus waste sustainability is the issue of student waste handling. Custodial services and the office of sustainability have witnessed the under-utilization of recycling and composting resources across campus over the years (Carleton CAP, 2011). On any given weekend during the school year, one can enter a campus dorm and see an array of compostable and recyclable content placed in waste bins destined for landfills. Student waste handling is a persistent problem despite the establishment of Carleton's community waste program, which has installed standardized waste stations in academic buildings and has proliferated signage and media on proper waste disposal methods. Custodial services is currently considering further standardization of waste stations in student dorms. However, differences in dorm-floor layout and population demographics may call for a more nuanced, site specific approach to accommodating student waste disposal needs.

This study models the count of contaminant types tallied on individual dorm floors on Saturday and Sunday mornings in the 2013-2014 school year (Fall, Winter, and Spring term). Analysis was limited to Myers, Goodhue, Watson, Cassat, James, and Nourse dormitories. Explanatory and indicator variables were selected and assessed in order to answer the following research questions.

1. Are there significant differences in waste contamination across the six specified dorms?

2. Do the first floors of any given dorm have higher contamination counts than other floors?

3. Are sub-free floors associated with greater or lesser levels of contamination?

4. Are the number of recycling and compost bins present on a given floor associated with contamination count?

5. Are the number of students living on a floor and class year demographics associated with contamination counts?

6. Are contaminant counts different on Saturdays vs. Sundays?

7. Are fall, winter, and spring terms associated with different levels of contamination?

Data

Individual floors of a given dorm were the unit of analysis in this study. This is an observational study, as floors were not randomly sampled. Every floor in Myers, Goodhue, Watson, Cassat, James, and Nourse was assessed between 9 AM and 12 PM on every Saturday and Sunday morning of the fall and winter terms. The dataset includes only 3 weeks worth of data from spring term due to changes in the data collection protocol. Data from these dorms speak for themselves, but could arguably be used to describe general student waste handling habits. On each floor, a student waste monitor recorded the total number of waste bins (not recycling or compost, only waste to be sent to a landfill), the total number of cross-contaminated bins, the total number of empty bins, and the average bin fullness of all waste bins present. Relevant to this analysis, student waste monitors tallied incidents of cross-contamination by cross-contaminant type in all waste bins. Student waste monitors examined the entire volume of each waste bin and marked the presence of the following contaminant types: organic waste, paper towels, pizza boxes, coffee cups, Sayles take-away boxes, recyclable plastic, cardboard, paper, aluminum, glass, and solo-cups.

The Carleton online directory was used to collect data on floor populations and class demographics. Floor plans and waste bin audits were used to determine the number of recyclable and compostable waste bins present on each floor.

Results

Exploratory data analysis investigated how first floor status, academic term, weekend day, number of recycling and compost bins, and student population are associated with contamination count. Graphics suggest that variation in contamination count may be associated with first floor status (Figure 1), academic term (Figure 2), and student population (Figure 6). Graphical EDA did not suggest an obvious trend in contamination count with weekend day (Figure 3), compost bin count (Figure 4), and recycling bin count (Figure 5).

Due to the nature of contamination count as our response variable, a Poisson model was fit with all explanatory variables. A goodness of fit test indicated over-dispersion in the initial Poisson model (GOF p-value <0.001 in favor of saturated model). Quasi-Poisson models were then used for model refinement.

We find that there are no significant differences across the six specified dorms under study, so dorm is not included in the final model. First floors do have significantly more contamination than non-first floors (p=0.0158). Sub-Free floors are not significantly different from non-sub-free floors in terms of contamination so this distinction is not included in the final model. Number of recycling bins is significantly associated with contamination (p<0.001), and number of compost bins is also significantly associated with contamination (p<0.001). Number of students living on a floor does significantly impact contamination (p<0.001), but class year demographics have no significant association with contamination. Contamination counts are significantly lower on Sundays, (p<0.001) and are also significantly higher in winter compared to fall (p=0.00334).

Collinearity was tested for using a variance inflation factor test. The test results indicated likely collinearity between number of students, recycling bins, compost bins, and the interaction of recycling bins and student numbers. Drop in deviance tests were used to investigate whether some of these variables could be removed, but in no circumstance were the removal of any of these variables justified by the test results. (Table 3).

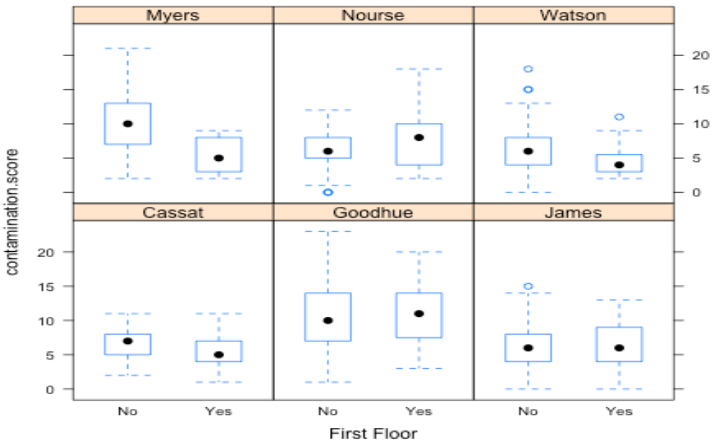


Figure 1: Contamination by first floor status grouped by dorm.

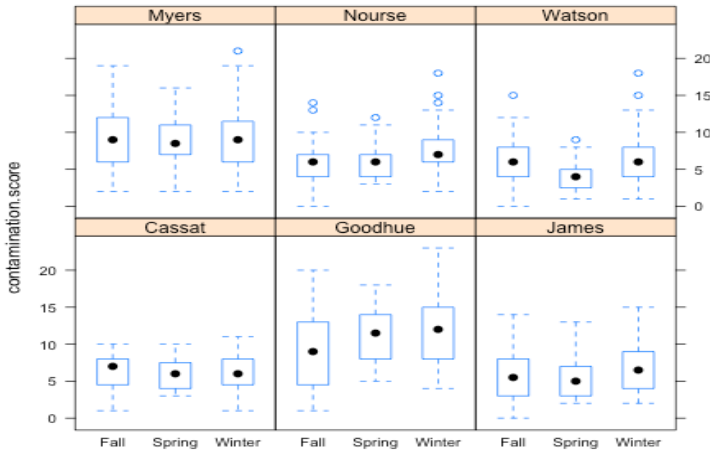


Figure 2: Contamination by academic term grouped by dorm.

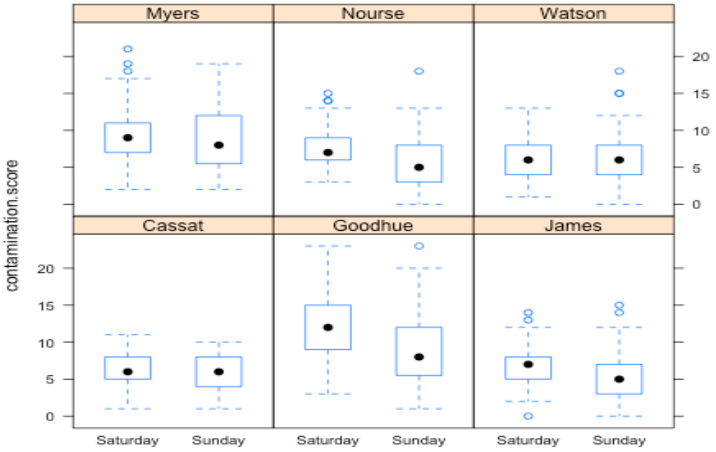


Figure 3: Contamination by weekend day grouped by dorm.

Quasi-Poisson Model Coefficient Table

Table 1:

	Dependent variable:
	contamination.score
total.bins	0.195***
	(0.014)
DaySunday	−0.089***
	(0.027)
TermSpring	−0.027
	(0.046)
TermWinter	0.082***
	(0.028)
X.students	0.034***
	(0.004)
X.recycle	0.224***
	(0.040)
First	0.109**
	(0.045)
X.compost	−0.045***
	(0.010)
X.students:X.recycle	−0.005***
	(0.001)
Constant	0.131
	(0.172)
Observations	938
Note:	*p<0.1; **p<0.05; ***p<0.01

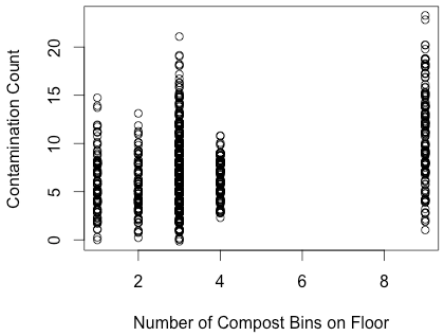


Figure 4: Contamination by number of compost bins.

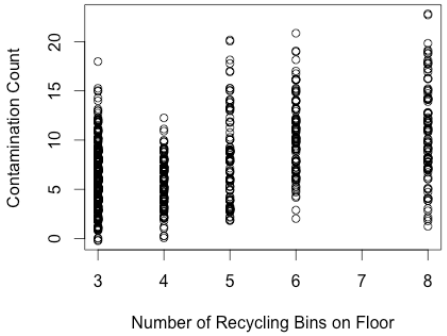


Figure 5: Contamination by number of recycling bins.

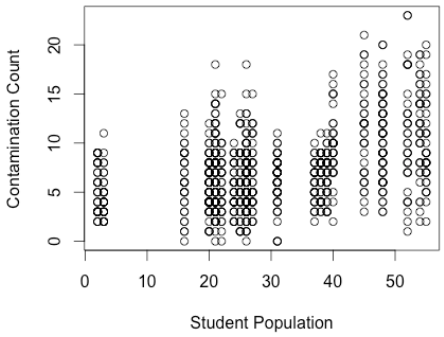


Figure 6: Contamination by student population

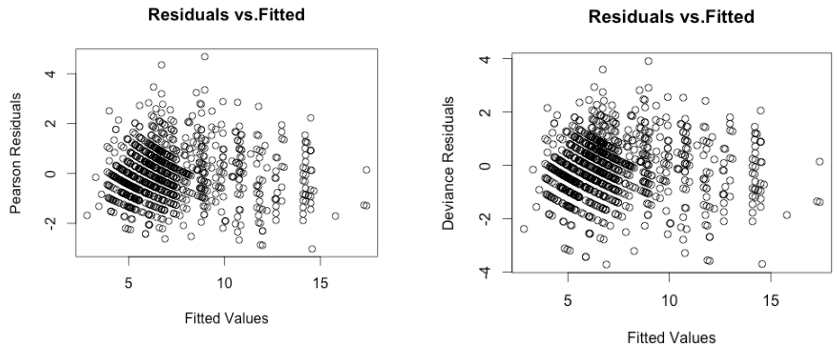
Table 2:Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
waste.contamination.score	938	7.316	3.872	0	23
waste.total.bins	938	3.851	1.531	0	9
waste.X.students	938	30.465	13.817	2	55
waste.X.compost	938	3.689	2.357	1	9
waste.X.recycle	938	4.264	1.674	3	8

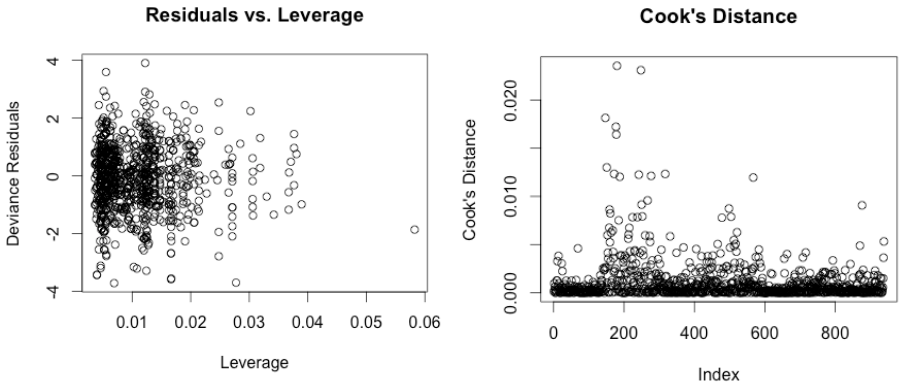
Table 3: Collinearity

	GVIF	Df	GVIF^(1/(2*Df))
total.bins	3.540	1	1.881
Day	1.057	1	1.028
Term	1.038	2	1.009
X.students	19.994	1	4.471
X.recycle	31.451	1	5.608
First	1.937	1	1.392
X.compost	4.323	1	2.079
X.students:X.recycle	98.266	1	9.913

We plot both the deviance residuals and Pearson residuals against the fitted values and find a fairly even scattering of points around the zero line with relatively few extreme points, indicating that the model is adequate.



Below are plots of leverage and Cook's distance that we use to check for influential observations. We find one case with a high leverage and relatively high Cook's distance, that corresponds to the Sunday of first weekend of fall term in first Goodhue. This observation was from the second day when data was collected and may not have been collected properly, making it an outlier. However, removing the point does not greatly change the model, so we do not omit the point. Otherwise there do not appear to be problems with influential observations in the model.



Discussion

After controlling for other variables, we are 95% confident that being on the first floor is associated with between 2.10% and 21.80% greater estimated contamination score compared to other floors. We are also 95% confident a one-unit increase in number of compost bins is associated with a decrease in contamination score of between 2.51% and 6.26%. Interpreting the effect of recycling bins is complicated by the significant interaction term between recycling bins and number of students. We are 95% confident that one additional recycling

bin on a floor is associated with between 15.67% and 35.31% higher contamination, with that effect being reduced by between 0.304% and 0.694% for every student who lives on that floor. We are 95% confident that contamination counts observed on Sundays are associated with being between 3.60% and 13.6% lower than Saturday counts. We are 95% confident that contamination counts from winter term 2014 are between 2.78% and 14.68% higher than counts measured in the fall term 2013 and spring term 2014.

Since collinearity was flagged as a limitation of our model (Table 3), the inferences made in the previous paragraph cannot be trusted for the variables: number of students, number of recycling bins, number of compost bins, and total bins. Drop in deviance tests did not support the removal of any of these collinear variables; therefore these variables are still included in our model.

This model reliably indicates that first floors are associated with higher contamination counts, contamination is greater in the winter than spring and fall, and that Sunday patrols are associated with lower contamination counts. One explanation for why first floors are associated with higher contamination counts could be that dorm residents from all floors and general traffic likely contribute to contamination while passing through first floors. One explanation for why winter term is associated with higher contamination counts may be that students spend more time consuming and generating waste within dorms due to cold weather. Custodial services do not regularly collect waste from dorms during the week, but send student patrols to collect waste on Saturday and Sunday mornings. Contamination is likely higher on Saturday mornings due to a longer period of waste accumulation.

It is important for the reader to understand the significance and the limitations of the contamination count and our model. Contamination count on the bin level signifies the number of contaminant types, not the mass or quantity of contaminants. On the floor level, which is the unit of analysis, contamination count is the sum of all the counts for each bin. Therefore there is a range of error and deviation on the bin level that is not accounted for by our model. A proper model would be somewhat of a binomial within a binomial model. We used a Quasi-Poisson model since the response variable contamination count has high mean and max values (mean = 7.316, max =23) and because the number of trials – number of bins on each floor, is not uniform (ranging from 0 to 9)(Table 2).

Future statistical analysis could experiment with a mixed effects model that addresses potential variation in contamination count throughout the course of a term. Data from more dorms beyond the six analyzed in this study could resolve some of the collinearity issues between student population and bin numbers. A more complex model could analyze how the explanatory variables used in this model affect the contamination counts of individual waste type (e.g. how the number of available compost bins is associated with the contamination count of compostable pizza boxes).

The data collection method allows one small apple core in a waste bin to increase contamination count for the floor by one, the same outcome as 50 apple cores would in one waste bin. While this method for quantifying contamination may not seem useful for reducing total contamination mass, this data does reflect the

student community's understanding of proper waste disposal. Although individual students have the potential to misrepresent the waste habits of an entire floor, these individual actions have costly impacts on the sorting and handling of waste after it is hauled away from campus. As it has been measured during the 2013-2014 school year, contamination count may be thought of as measure of a floor community's potential to improve floor awareness and waste disposal habits. Our model indicates that Custodial Services may strategically reduce contamination on a campus level by expanding recycling and composting resources on first floors, during winter term, and by continuing to support the outreach measures of the Carleton Student Waste Monitors.

Conclusion

This study sought to model contamination count in student dorms at Carleton College. A Quasi-Poisson regression model was used to fit contamination count by total number of bins, number of compost bins, number of recycling bins, number of resident students, weekday of data collection, academic term and first floor status. Collinearity proved to be an issue for number of bins and number of students, which made the interpretation of these coefficients not trustworthy. However, first floor status, term, and collection day were found to be significant explanatory variables of contamination count.