Smart Lockers: A Shortest Path-Finding System to Maximize Locker Accessibility for Secondary Schools

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1. Introduction

In modern secondary schools, students are burdened with heavy backpacks (*Heavy Backpacks Give Kids Back Trouble*). Students routinely carry many items including textbooks, binders, instruments, coats, and sports and club paraphernalia. Moreover, research has further highlighted the prevalence of heavy backpacks and how they commonly lead to back pain. A study conducted by Avantika Rai and Shalini Agarawal in 2013, published in the *IOSR Journal of Humanities and Social Science*, concluded “Carrying backpacks increases the risk of back pain and possibly the risk of back pathology. The prevalence of school children carrying heavy backpacks is extremely high” (22). It is thus apparent that lockers, a large asset for decreasing the weight of students’ backpacks by offering a personal storage space, are a very important entity.

It is also relevant to consider how locker assignment systems are developed and employed in terms of providing students with ready access to their lockers. The greater the locker accessibility, the more opportunities students will have to lighten their backpacks during the school day. However, secondary school administrators tend to focus primarily on issues related to student safety and security, visibility, and maintenance of the lockers (*Guidelines for School Facilities in Virginia’s Public Schools* 20, 38; *North Carolina Public Schools Facilities Guidelines* 32, 43; *Planning Guide for Maintaining School Facilities* 161). Consequently, there are no major efforts to maximize student locker accessibility. It is in this context that the “Smart Locker” system of locker assignment was conceived. The system aims to provide an easy method for schools to assign student lockers that maximizes locker accessibility through minimizing the distance students need for a midday locker visit based on their schedules. In assigning lockers, the system utilizes a shortest path-finding algorithm to minimize the distance students need to travel for a midday locker visit between classes. The system can assign lockers for any school, with the only two input requirements being student schedules and a connected, undirected graph diagram of the walkable school that is split into segments. The following study tests the “Smart Locker” system’s effectiveness - when employed for several common secondary school designs - in assigning lockers that are more easily accessible than lockers that are assigned randomly. The hypothesis is that the “Smart Locker” system will assign lockers that are significantly more accessible than lockers assigned randomly in common secondary school designs. In the following research, I hope to affirm this hypothesis.

2. Experiment

First, secondary school designs were analyzed in order to create composite diagrams that reflected the schools’ most predominant characteristics. In this process, 100 secondary school designs were randomly selected from a pool (consisting of over 1000 schools) of all secondary schools whose designs were made publicly available. Three primary design types were identified.

Table 2.1. Secondary School Design Types

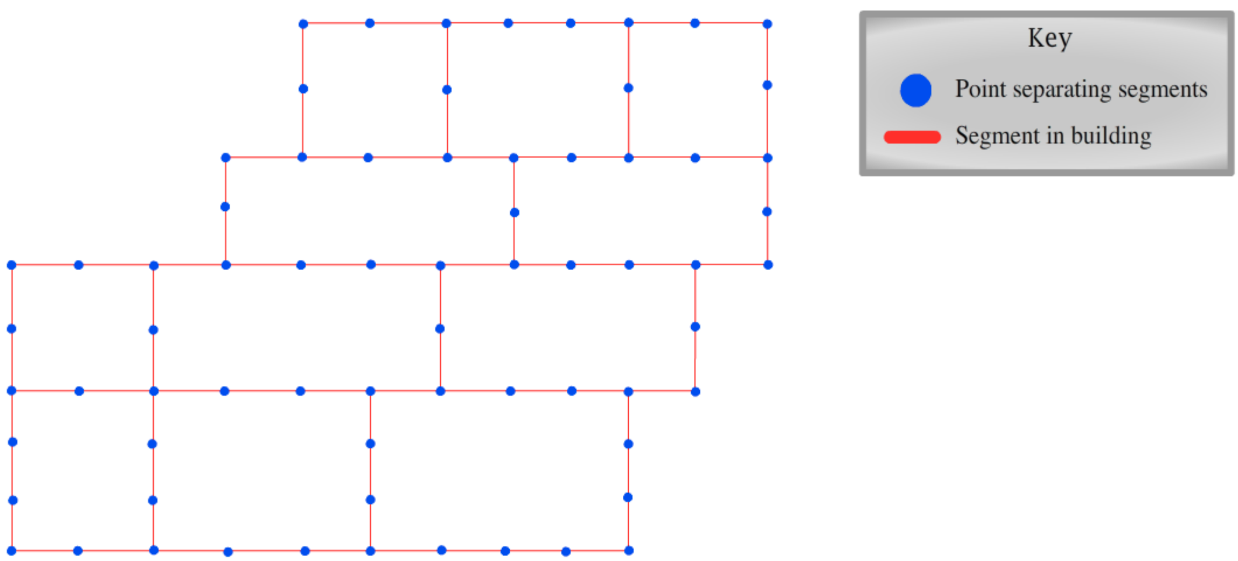
Type	Characteristics	Number Found in Selection
Rectangular	● One building ● Interconnecting rectangles	41
Branching	● One long, branching building	26
Campus	● 5-8 buildings with 1-5 exit/entry points each ● Ability to walk from almost any exit/entry point of a building to any other ● Intersecting paths	35

**Two designs in the random sample were each identified as being two different design types.

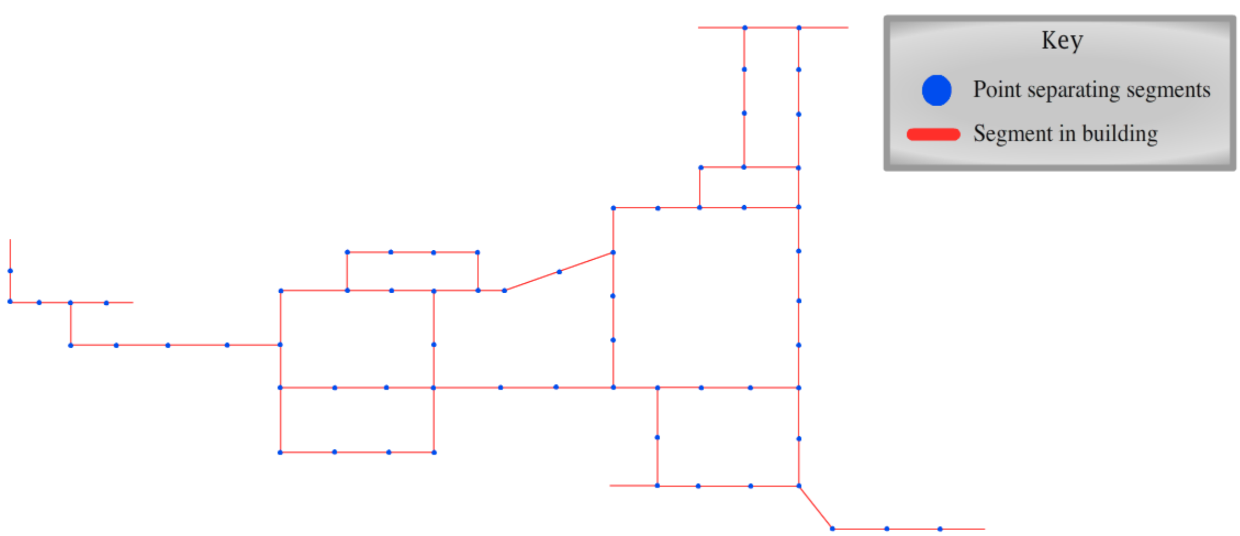
One composite diagram was constructed for each of the three most commonly appearing secondary school design types: Rectangular, Branching, and Campus. Each diagram was broken up into a connected, undirected graph with 79 segments mapping out the walkable school.

The following diagrams are drawn to scale.

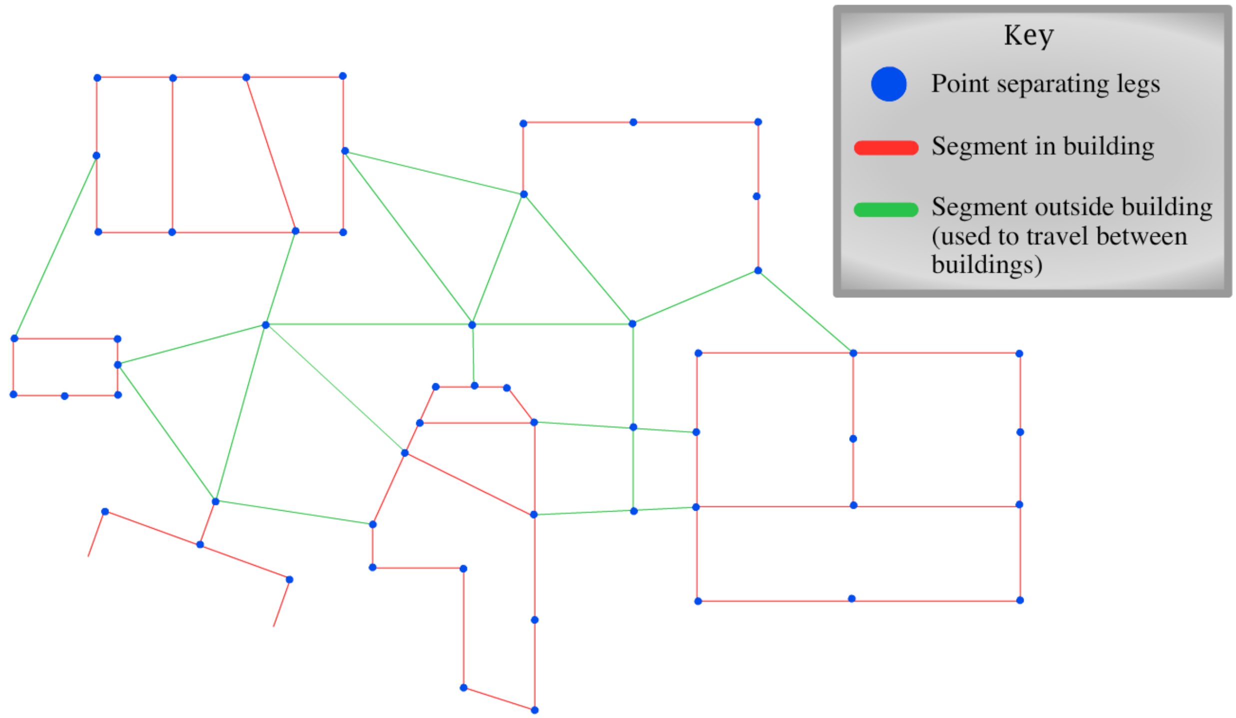
Type 1: Rectangular



Type 2: Branching



Type 3: Campus



The diagrams were then prepared for locker assignment. For the first two diagrams, 10 lockers were logged for each segment, and for the third diagram, 14 lockers were logged for each building segment except for the smallest, for which only 6 lockers were logged. This resulted in each of the three diagrams having 790 lockers. Then, 60 sets of student schedules were generated for each diagram that contained 790 students, the average student enrollment in a regular American secondary school (according to the most recent census on this data by the National Center for Education Statistics in the 2010-2011 school year).

A program (one that was specifically designed to automate data collection) was then run that went through each set of student schedules for each diagram. For each set, the program assigned lockers to every student using a random system of locker assignment and then using the "Smart Locker" system of locker assignment. After both locker assignments were completed for all students in a student set, the program compared the "Smart Locker" system locker assignments to the random locker assignments, and provided the average midday locker visit distance the "Smart Locker" system saved each student over the random system of locker assignment. This whole process resulted in 60 such saved distance values for each diagram.

3. Results

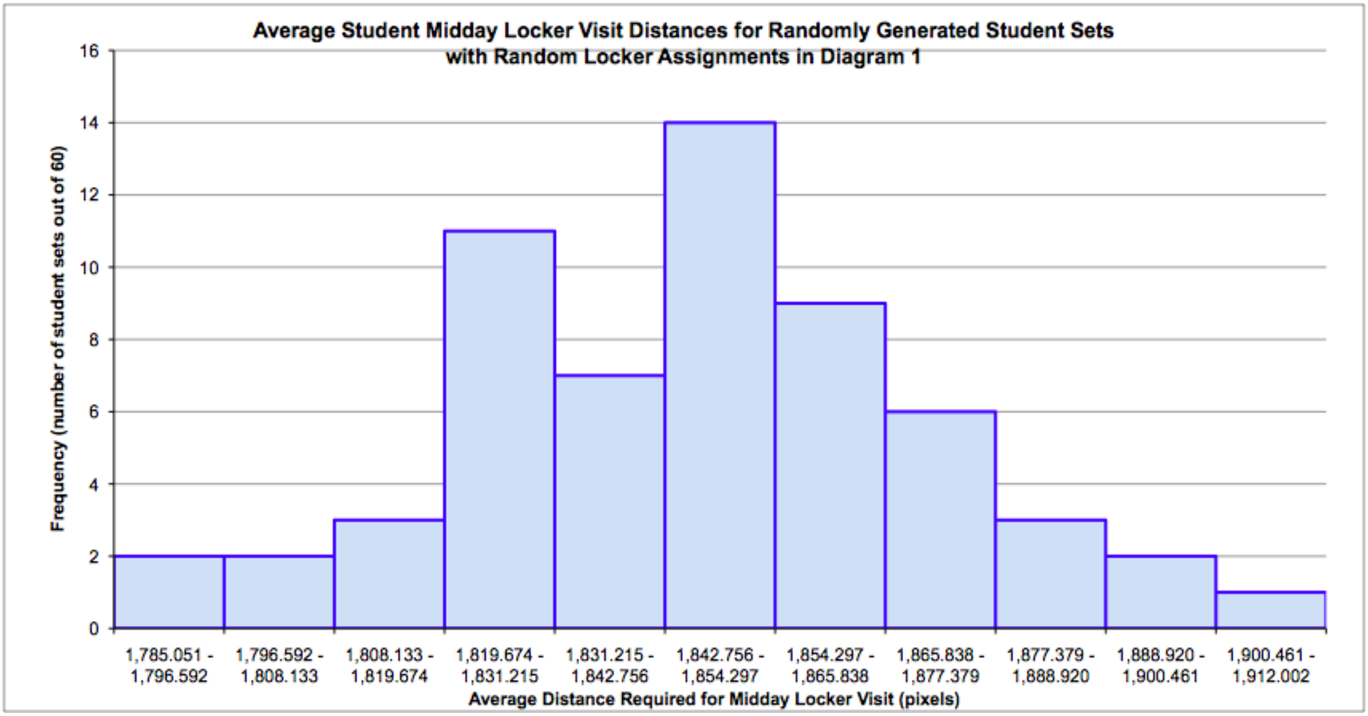
Test of Whether the "Smart Locker" System of Locker Assignment Significantly Decreased the Distance Required for a Locker Visit as Compared to a Random System of Locker Assignment for Three Secondary School Designs

Summary Statistics and Accompanying Histograms:

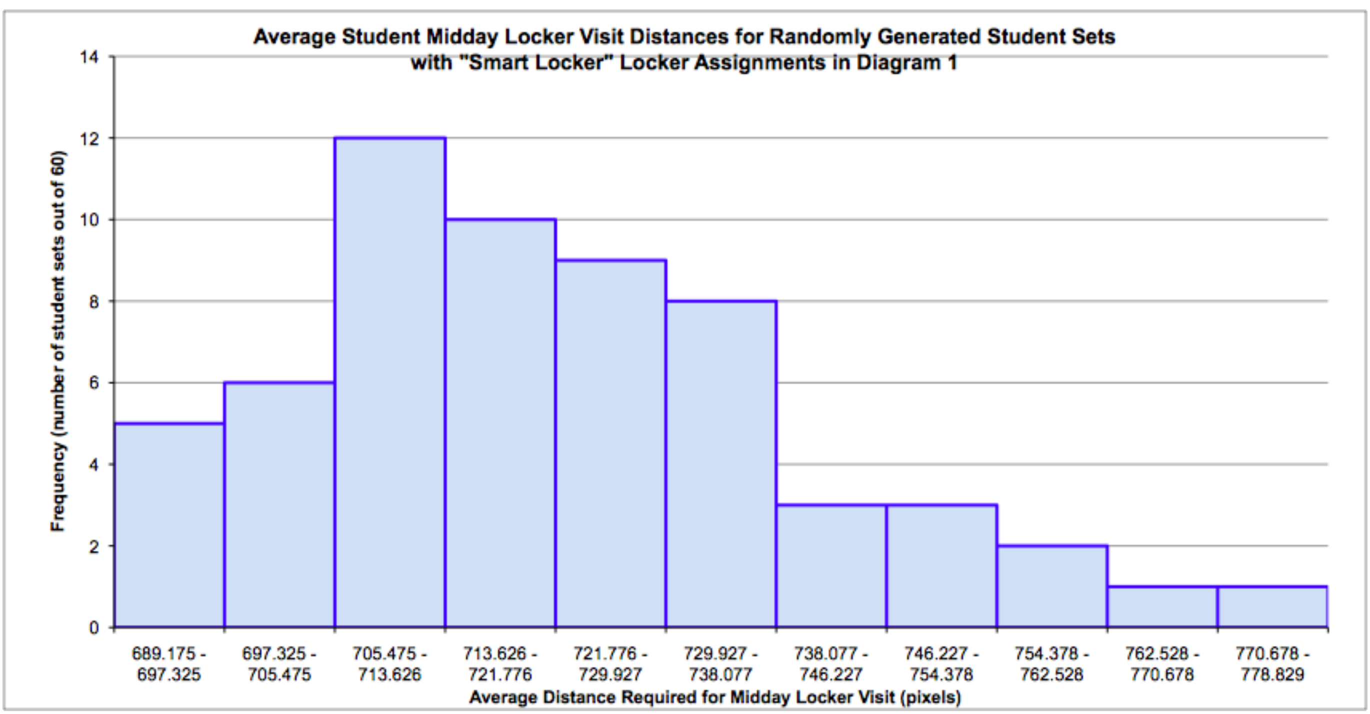
**The unit of pixels is a hypothetical unit that the data-collection program used to measure the distance a student had to travel to visit his/her locker.

	Diagram	Sample Size	Mean (pixels)	Standard Deviation (pixels)
Average distance required for a midday locker visit with *lockers assigned randomly* for a random set of student schedules	**Diagram 1**	60	1845.18	24.79
	Diagram 2	60	1775.98	24.23
	Diagram 3	60	2585.73	36.45
Average distance required for a midday locker visit with *lockers assigned by the "Smart Locker" system* for a random set of student schedules	**Diagram 1**	60	721.72	18.74
	Diagram 2	60	722.82	21.06
	Diagram 3	60	1107.6	31.67
Average midday locker visit *distance the "Smart Locker" system saved* each student as compared to the random system of locker assignment for a random set of student schedules (random locker assignment distance - "Smart Locker" assignment distance)	**Diagram 1**	60	1123.46	29.40
	Diagram 2	60	1053.16	33.17
	Diagram 3	60	1478.13	40.55

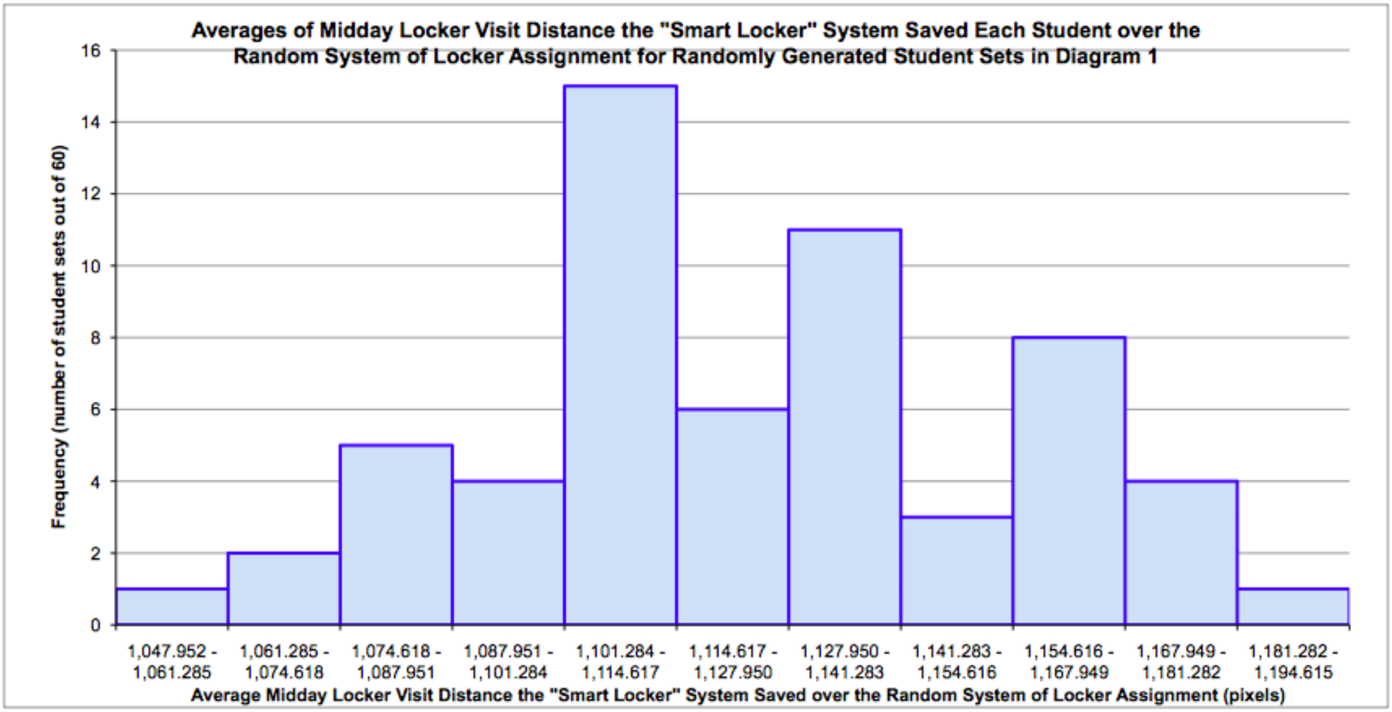
Graph 3.1:



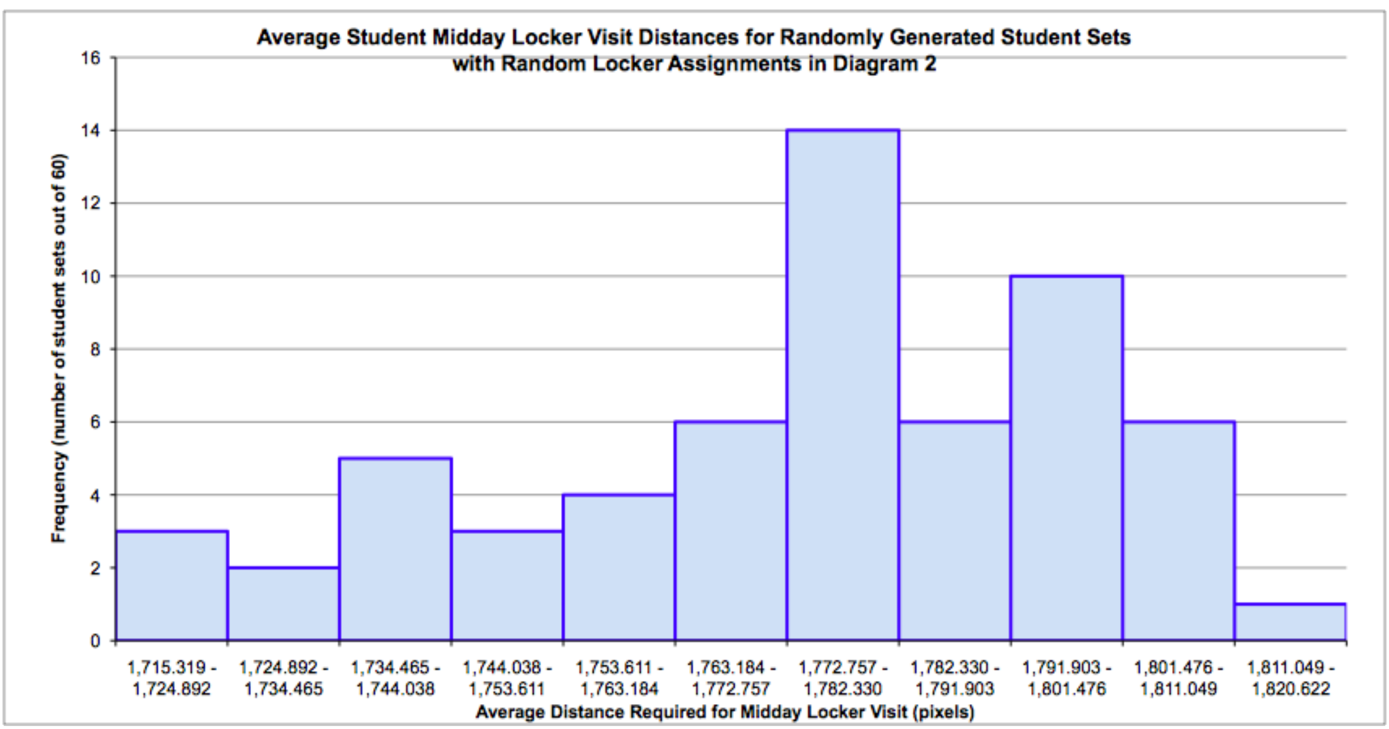
Graph 3.2:



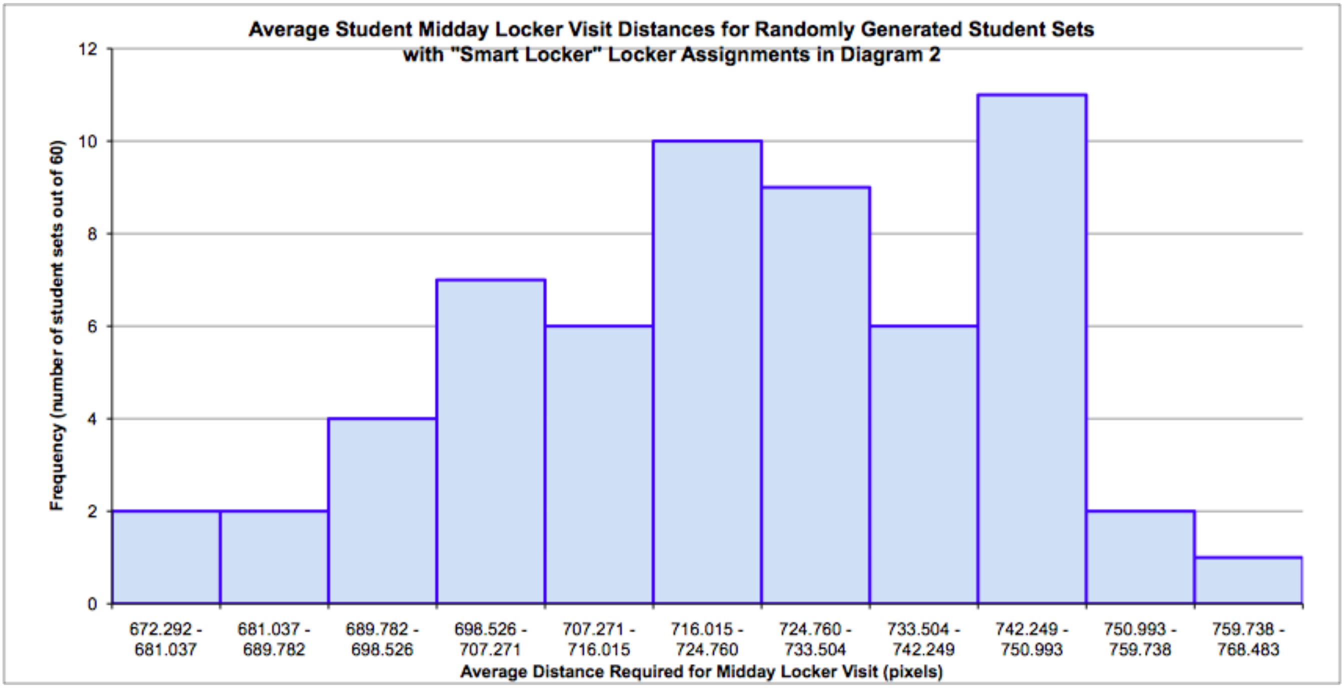
Graph 3.3



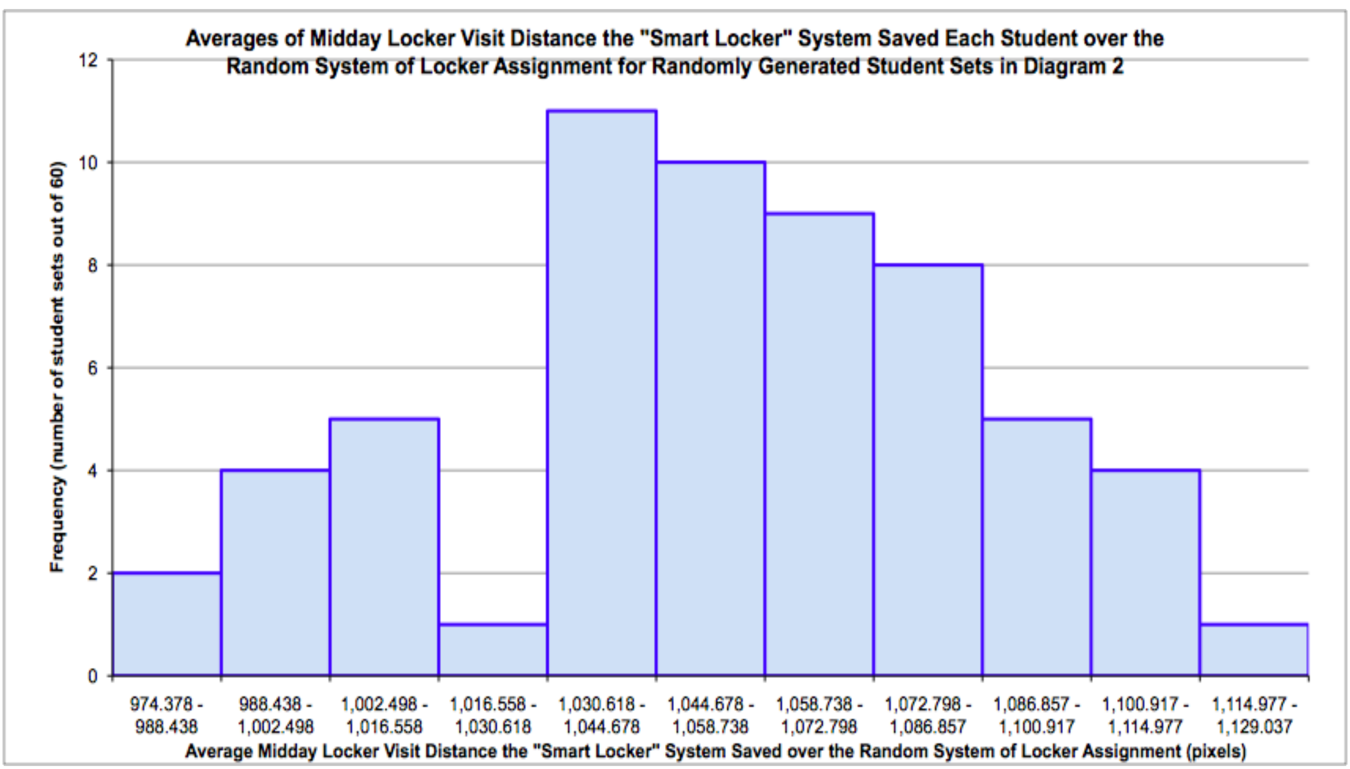
Graph 3.4:



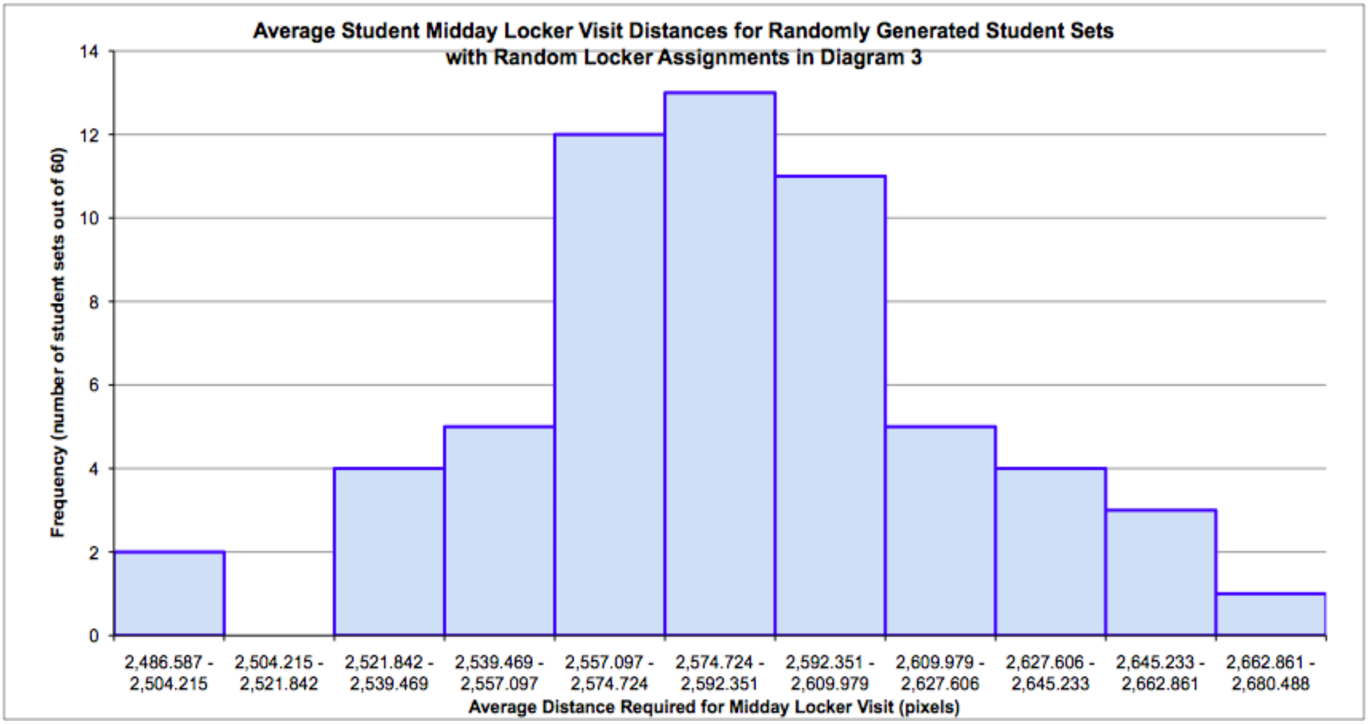
Graph 3.5:



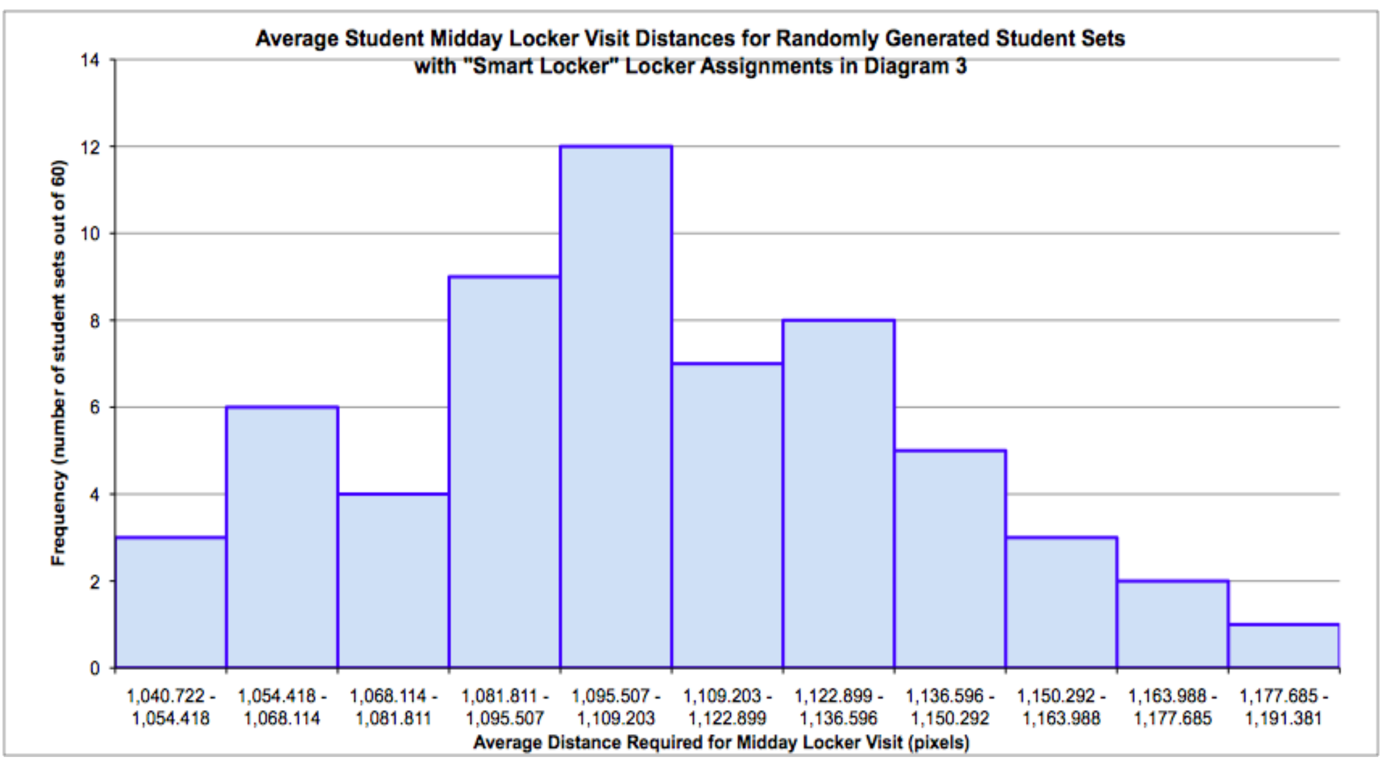
Graph 3.6:



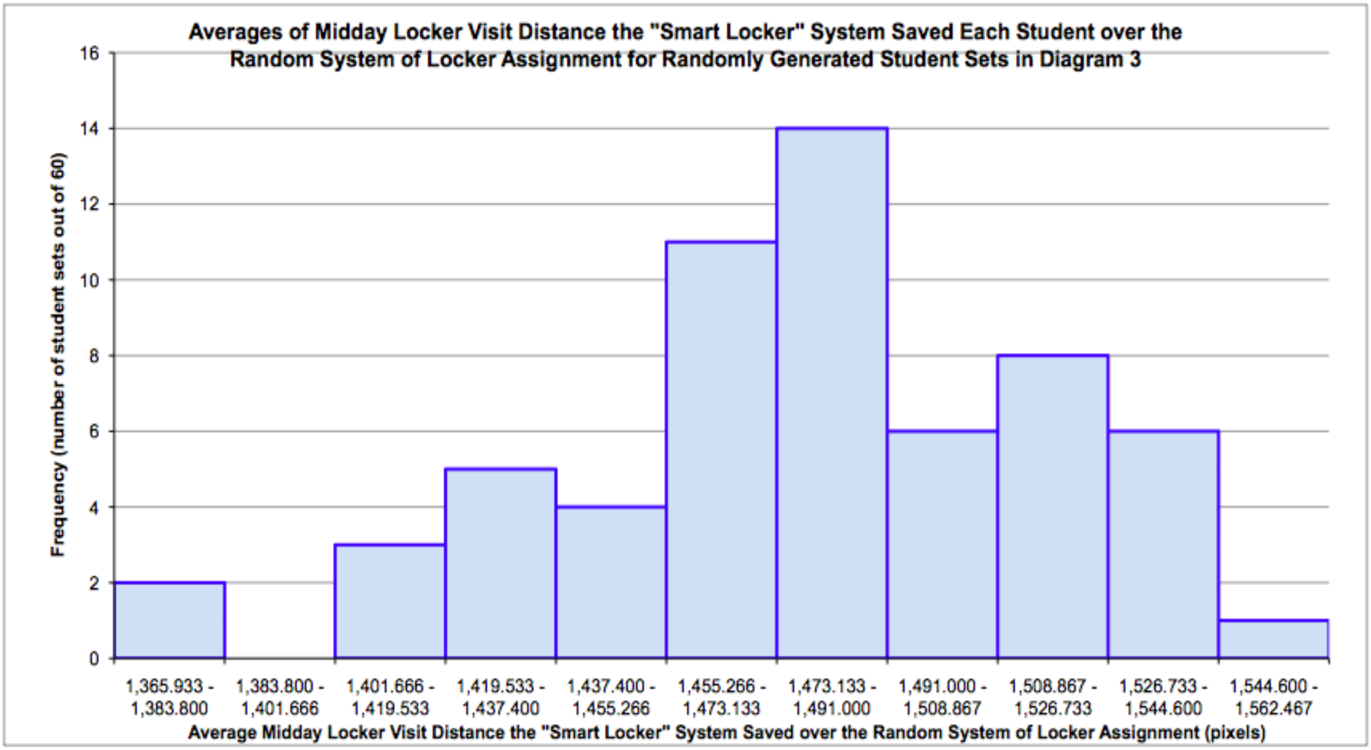
Graph 3.7:



Graph 3.8:



Graph 3.9:


Averages of Midday Locker Visit Distance the "Smart Locker" System Saved Each Student over the Random System of Locker Assignment for Randomly Generated Student Sets in Diagram 3
Frequency (number of student sets out of 60)
0
2
4
6
8
10
12
14
16
1,365.933 - 1,383.800
1,383.800 - 1,401.666
1,401.666 - 1,419.533
1,419.533 - 1,437.400
1,437.400 - 1,455.266
1,455.266 - 1,473.133
1,473.133 - 1,491.000
1,491.000 - 1,508.867
1,508.867 - 1,526.733
1,526.733 - 1,544.600
1,544.600 - 1,562.467
Average Midday Locker Visit Distance the "Smart Locker" System Saved over the Random System of Locker Assignment (pixels)

Significance Test:

For each diagram, we want to test

$$H_0 : \mu_D = 0$$
$$H_a : \mu_D > 0$$

where for each respective diagram, μ_D = The average midday locker visit distance (in pixels) the "Smart Locker" system saves each student as compared to the random system of locker assignment (random locker assignment distance - "Smart Locker" assignment distance) for any set of student schedules.

To do so, for each diagram, a t-test for μ_D was utilized with the third summary statistic.

Test results for Diagram 1: $t = 296.00$, P-value < 0.001

Test results for Diagram 2: $t = 245.94$, P-value < 0.001

Test results for Diagram 3: $t = 282.36$, P-value < 0.001

Interpretation: Assuming that, for each diagram, the "Smart Locker" system of locker assignment does not decrease student locker visit distance as compared to the random system of locker assignment for any set of student schedules, there is a less than 0.1% chance likelihood of observing the "Smart Locker" system respectively saving, on average, 1123.46 pixels for diagram 1, 1053.16 pixels for diagram 2, and 1478.13 pixels for diagram 3 in a sample of 60 random sets of student schedules for each diagram, as was observed in my samples. This gives extremely strong evidence to conclude that assigning lockers in diagrams 1, 2, or 3 with the "Smart Locker" system for any set of student schedules would result in, on average, less required student midday locker visit distance than if the lockers were assigned randomly.

Confidence Interval:

We want to construct a 99% confidence interval to estimate μ_D for each diagram.

To do so, we will estimate μ_D at the 99% confidence level with a t interval based on the third summary statistic.

Interval results for diagram 1: (1113.3, 1133.6)

Interval results for diagram 2: (1041.8, 1064.6)

Interval results for diagram 3: (1464.2, 1492.1)

Interpretation: We are 99% confident that the "Smart Locker" system, for any student set, assigns lockers that require, on average, 1113.3 to 1133.6 fewer pixels for a midday visit over lockers assigned randomly for diagram 1, 1041.8 to 1064.6 fewer pixels for diagram 2, and 1464.2 to 1492.1 fewer pixels for diagram 3. These confidence intervals suggest that the "Smart Locker" system would decrease the distance an average student needs to visit their locker for any student set by approximately 60.3 to 61.4% for diagram 1, 58.7 to 60.0 % for diagram 2, and 56.6 to 57.7 % for diagram 3. This percent decrease is significant, as the "Smart Locker" system, for each diagram, is more than halving the distance that students need to travel to visit their lockers for all three diagrams when compared to the random system of locker assignment. We can thus conclude that the "Smart Locker" system of locker assignment significantly decreases the average distance required for a midday locker visit as compared to a random system of locker assignment for any given set of student schedules in diagrams 1, 2, or 3.

4. Discussion

4.1. The Study

In this research, I sought to affirm the hypothesis that the “Smart Locker” system assigns lockers that are significantly more accessible than lockers assigned randomly for common secondary school designs. Upon creating composite secondary school diagrams mirroring common secondary school designs and pitting the “Smart Locker” system against a random system of locker assigning, I was able to affirm the hypothesis by observing how, for all three diagrams, the “Smart Locker” system’s locker assignments required, on average, over 50% less distance for a midday visit than the lockers that was were assigned randomly.

4.1.1. Weaknesses

One possible weakness of the study is the possibility of the created composite diagrams not being good representations of common secondary school designs. Such a case could happen if the secondary school designs made publically available over the web (the pool in which the composite diagrams were made to represent) do not fully represent the complete variation in secondary school design. However, I do not think this is the case, as this pool of school diagrams was large in magnitude and variation, including over 1000 secondary school designs from all over the country.

Another possible weakness of the study is the use of the unit pixels. The unit of pixels makes it challenging to put the summary statistics into perspective, as pixels have no reference to real-life distance. Despite the use of pixels, the amount by which the “Smart Locker” system decreased locker visit distance over a random system of locker assignment was still meaningfully gauged by calculating the percent decrease in locker visit distance the “Smart Locker” system saved over the random system of locker assignment.

4.1.2. Strengths

Among the data, there was very little variance. The collected statistics on how the locker systems performed over random variations in student schedule sets had standard deviations that were less than 3% the value of the statistic means. This indicates that randomly varying student schedules did not have a great impact on the average performance of the "Smart Locker" system nor the random of locker assignment. Furthermore, the methods of experimentation limited the overall presence of uncontrollable events. The entire experimentation took place in a digital environment, and each student set went through the exact same processes of locker assignment.

4.2. The Significance

Heavy backpacks are a large issue for secondary school students. They are both extremely common and can cause back pain (Agarwal 22). There have been previous methods seeking to fix this issue. One of the most notable developments is the electronic textbook. Electronic textbooks seek to eliminate the traditional heavy printed textbooks that are often required to be carried by students, and have gained momentum in certain school districts (Brown). However, some students have reacted negatively towards this trend (Shepperd, Grace, and Koch 2). Other schools have tried to provide students with an extra textbook in class, allowing students to leave their textbook at home instead of carrying it in their backpacks (Crisp). This method, however, results in exorbitant costs in purchasing double the textbooks. Furthermore, students' backpacks can still be heavy without textbooks, as they can be packed with binders, notebooks, and sports and club paraphernalia.

The “Smart Locker” system offers a novel way of combating this issue of heavy student backpacks by maximizing student locker accessibility. As this study has shown, the “Smart Locker” system significantly decreases the average distance a student needs to travel to visit their locker as compared to a random system of locker assignment for common secondary schools. Moreover, the “Smart Locker” system can offer secondary schools a way to significantly increase student locker accessibility, granting students the ability to more easily access their locker and store items of their choosing to lighten their backpacks. The system poses a cost-effective, low-maintenance, and effectual method for maximizing locker accessibility and decreasing student backpack weight in secondary schools.

4.3. The Future

Further study may include carrying out research similar as this in secondary schools with administrators who may show interest in implementing the system. This way, such schools would be able to receive a personal snapshot of how the system may impact their students’ locker accessibility. Furthermore, such studies will allow the unit of meters to be used instead of pixels, enabling a more meaningful gauge on how much traveling distance the “Smart Locker” could save the students.

Such a study was recently completed for my own high school. The test showed the "Smart Locker" system’s assigned lockers requiring, on average, 68.056 meters less for a midday locker visit than the lockers assigned by the current random system of locker assignment at the high school. This means that the “Smart Locker” system would save an average student at my high school a total walking distance of approximately 6.80 to 8.42 miles over the course of a school year where the student pays a daily midday locker visit. These significant results have helped to prompt the planned implementation of the system in the 2014-2015 school year at my high school.

I am hopeful that the results of this research, showing how the "Smart Locker" system assigns lockers that are significantly more accessible than lockers assigned randomly for common secondary school designs, will aid the process of other schools pursuing such studies and implementing the "Smart Locker" system. With a simple guidebook designed to explain, in detail, all the steps involved in assigning lockers using the "Smart Locker" system, I believe that any school can deploy the system and actualize its benefits.

5. Conclusion

Contemporary research indicates that heavy backpacks are a common contributor to student back pain (Rai and Agarawal 22). One way to address this problem is to ensure that students have easy access to their lockers, a provider of personal space to store items during the school day. The "Smart Locker" project was conceived to do just this by providing an easy method for schools to maximize locker accessibility for students. The system's effectiveness in improving the accessibility of lockers in common secondary school designs was tested in the current study. The test results indicated the "Smart Locker" system's locker assignments requiring, on average, over 50% less distance for midday visits than the lockers that were assigned randomly, leading to the conclusion that the "Smart Locker" system of locker assignment does indeed significantly increase student accessibility to their lockers over a random system of locker assignment. Adding to the strength of the study's findings is the fact that the efficacy of the smart locker system was demonstrated for student locker configurations in three distinct secondary school designs.

6. Acknowledgements

I would like to thank my teacher advisors for providing me with useful feedback, encouragement, and opportunities at every stage of the project. Adding to my motivation to push ahead with the project was they way they took the “Smart Locker” project and me seriously and with open minds. My “support team” included my Learning Enrichment teachers, Statistics teacher, the district’s Educational Records Manager, and my high school’s principal.

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