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Abstract

Traditional food pantry models give customers pre-arranged boxes of food that offer no or limited choice of the items received. Recent research indicates that the client-choice model, in which customers get to choose items in a grocery store-like setting, is a much less wasteful and more dignifying method of running a food pantry (Remley, et al. 2006). However, there has not been scholarly research into the best practices for organizing and restocking items at client-choice pantries, which can significantly affect the quality and amount of food a customer has the opportunity to shop for. This research outlines a method of using common probability and statistics techniques to quantify the expected equity and risk of products expiring to find an optimal restocking method.

Keywords

mathematics, inventory management, client-choice food pantry, food pantry

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Traditional food pantry models give customers pre-arranged boxes of food that offer no or limited choice of the items received. Recent research indicates that the client-choice model, in which customers get to choose items in a grocery store-like setting, is a much less wasteful and more dignifying method of running a food pantry (Remley, et al. 2006). However, there has not been scholarly research into the best practices for organizing and restocking items at client-choice pantries, which can significantly affect the quality and amount of food a customer has the opportunity to shop for. This research outlines a method of using common probability and statistics techniques to quantify the expected equity and risk of products expiring to find an optimal restocking method.

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1. INTRODUCTION

During the Covid-19 pandemic, millions of people became newly food insecure. Food pantries are an essential lifeline to provide these people with free access to food. The Western Oregon University Food Pantry is a student-run organization whose services are open to anyone, including non-students. As one of the coordinators at the Pantry, it is my responsibility to innovate and improve upon the services we offer. My work led me to research inventory management, which is well-studied in commercial settings but not non-profit settings. Noticing the lack of research in this area of food pantry operations, I sought to create an inventory management system that would minimize food waste and maximize equitable food distribution among customers.

2. TRADITIONAL FOOD PANTRY VS. CLIENT-CHOICE FOOD PANTRY

The terms *food pantry* and *food bank* are often used interchangeably, but they are actually quite different. Generally speaking: a food bank is a supplier that gives food to food pantries, and a food pantry distributes food to people. The job of the WOU Food Pantry is to provide food directly to customers.

When people think of a food pantry, they typically imagine the *traditional food pantry model*, in which one must fill out an application to receive a box of food. Typically, a customer gets no or limited choice of what food is in the box, and the quantity of food received is based on the client's "need" as determined from the application.

Current research indicates that this is an ineffective way to run a food pantry based on observed flaws by pantry coordinators as well as customer feedback and evaluations

(Remley, et al. 2006). In contrast, the research-supported best model is the *client- choice food pantry* (Remley, et al. 2006), which emulates a grocery store in that pantry customers can "shop" for items by selecting them directly from the shelves, fridges, and freezers.

3. THE RESTOCKING PROBLEM

Both traditional and client-choice food pantries must deal with *inventory management* in different ways. Inventory management means specific guidelines, rules, and practices for allocating resources.

In a traditional pantry, inventory management is the assembly and distribution of food boxes to customers. The specific guidelines are how a pantry determines the type and amount of food to give to each customer. On the other hand, the inventory management at a client-choice pantry is often less explicit.

In a client-choice pantry, food is stored in two areas: the *storefront* and *back storage*. This is just like any retail grocery store where customers can shop from the store- front and extra items are held in a staff-only back storage area. Here, restocking means moving products from the back storage to the storefront. Therefore, inventory management is the process of determining when, which, and how much food to restock.

Restocking is at the discretion of volunteers and pantry staff members. At the WOU Food Pantry, items are restocked as they are depleted from the storefront, but there are no guidelines on how frequently, or how much, to restock. This can lead to two major problems. First, items can expire if they are not properly managed; the sooner an item is put into the storefront, the less likely it is to expire. Second, customers can experience inequity if items are not restocked fairly; e.g., customers on one day of the week may have access to a higher quantity or quality of food than customers on another day of the week.

This creates an interesting problem because restocking quickly can reduce waste from expiration but also decrease equity, and vice versa. Further study indicates that there are actually no research-supported best practices for restocking at client-choice food pantries. The natural hypothesis from this problem is that there is some optimal point between reducing waste and increasing equity, which led to the choice of using applied mathematics to solve this issue.

4. CREATING THE INVENTORY MANAGEMENT SYSTEM

To create an inventory system, we must first define its structure, inputs, outputs, and goals. The proposed inventory system is a computer algorithm that takes in data about customer shopping preferences, and outputs an *item schedule* that minimizes waste and maximizes equity. An item schedule is a list of every item unit and its restock date; i.e., the date when the item unit will be moved from the back storage to the storefront.

For example:

Item Unit	Restock Date
Milk Unit 1	1/4/2021
Milk Unit 2	1/4/2021
Milk Unit 3	1/5/2021
Milk Unit 4	1/6/2021

Table 1: Example Output Item Schedule from Inventory Management System

4.1 DESIRABILITY

To determine the best item schedule, we must be able to quantify waste and equity. Quantifying waste is simple because it is easy to count the number of item units that have expired. For this to be useful, we want to be able to look at a particular item schedule, and then predict the likelihood that a certain number of items expire. We do this using the concept of *desirability*.

Desirability is a way to quantify how much people want a particular product. This is similar to the idea of demand, except it is for free products. The desirability of a product is the chance that a customer will want that product. For instance, if we determined that the desirability of milk is 70%, then there is a 70% chance that each customer will want milk when they visit the Food Pantry. Notice that desirability is a product-specific property; different products, such as milk, canned green beans, and sliced bread all have their own desirabilities.

Measuring the desirability of a product is straightforward. For example: if, over the course of a few months, 431 out of 697 customers took canned peaches when they were available, then the desirability of canned peaches is $\frac{431}{697}$ = 61.8%. In simple cases, desirability and the binomial distribution can predict the likely waste of an item schedule, which is useful in providing insight for complex cases.

To use the binomial distribution, the required assumptions are that customers will only take one unit of a product they want, and all item units start in the storefront and expire on the same day. Let n be the total number of customers expected before the item units expire, d be the desirability of the product, and $f(X)$ be the probability that X customers out of n will want the product. Then this is a binomial process $b(n, d)$with probability mass function

$$f(X) = \binom{n}{X} d^X (1 - d)^{n-X}$$

This gives the probability that X customers out of n will want a product, but the goal is a function $g(Y)$ that gives the probability that *Y* out of the supply, *s*, of item units will expire. We will specify that $s < n$; i.e., the supply of items is less than the number of customers. If $s \geq n$, then the supply of items meets or exceeds the quantity of items demanded, so special inventory management is unnecessary. We use $f(X)$ to define $g(Y)$ in the following way: when X customers want the product, then $s - X$items expire, so we set $g(Y) = f(s - X)$. There is a special case for $g(0)$, where zero items expire, because this occurs whenever $X \geq s$; that is, the number of customers who want the product is greater than or equal to the supply of items. Therefore, $g(0)$ is equal to the sum of all$f(X)$ where $X \geq s$, yielding the piecewise function:

$$g(Y) = \begin{cases} \Sigma_{X=s}^{n} f(X), & \text{if } y = 0 \\ f(s - X), & \text{if } y \neq 0 \end{cases}$$

As a concrete example, suppose the Food Pantry has s = 11 units of milk in stock, the desirability of milk is d = 70%, and n = 13 customers are expected to visit before the milk expires. Substituting in the variables and applying the definition of $f(X)$ gives the function

$$g(Y) = \begin{cases} \Sigma_{X=11}^{13} \binom{13}{X} (0.70)^X (1 - 0.70)^{11-X}, & \text{if } y = 0 \\ \binom{13}{11-X} (0.70)^{(} 11 - X)(1 - 0.70)^{13-(11-X)}, & \text{if } y \neq 0 \end{cases}$$

which results in the following graph of $g(Y)$:

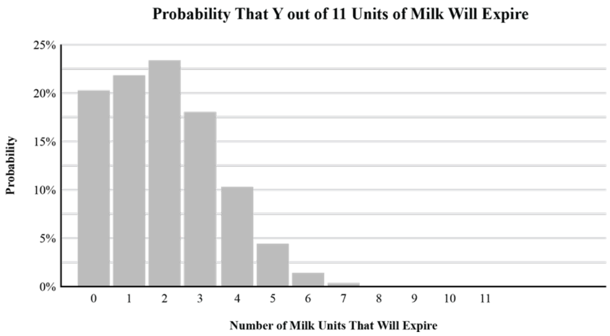

Figure 1: Graph of the Function g(Y): Risk of Expiration

4.2 SATISFACTION

To understand how to quantify equity, it will be easier to work backwards from the outcome we want to achieve. Suppose we restock items according to some item schedule, and we want to measure how fairly the items were distributed. To do this, we introduce another concept: *satisfaction*. A customer is *satisfied* if they want a product and they CAN get it. In contrast, a customer is *dissatisfied* if they want a product and they CANNOT get it. Notice there is also a neutral case where a customer doesn't want a product at all, and that satisfaction is product-specific just like desirability. Over the course of a week, we could count the number of satisfied and dissatisfied customers to see what percentage of customers were satisfied on each weekday. For example:

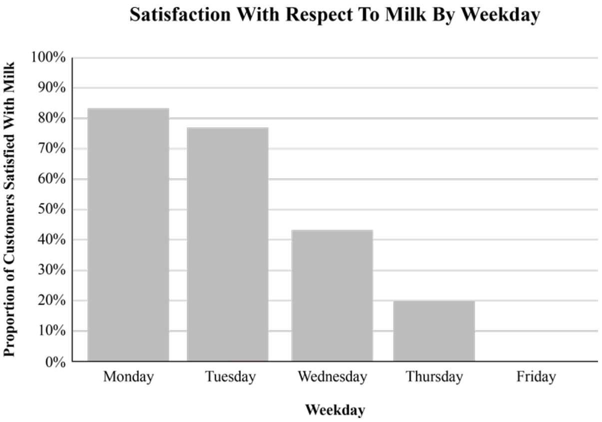

Figure 2: Example Graph of Satisfaction Distribution for Milk

Once again, there is more work to mathematically justify this (Salsbury 2021), but we may think of the percentage of satisfied customers as one's probability of being satisfied. If 83% of Monday customers were satisfied with finding milk, then customers who come in on Monday have an 83% chance to find what they want. Since inequity occurs when certain customers are at an advantage, it becomes clear the definition of equity is that every customer should have an equal probability of finding the products they want; i.e., the heights of the bars on the satisfaction graph should be equal.

5. SIMULATIONS AND DETERMINING THE BEST ITEM SCHEDULE

Now we have mathematical definitions to quantify waste and equity. But how do we actually take an arbitrary item schedule, determine these quantities, and find the optimal item schedule? In probability and statistics, one method is to map the likelihood of outcomes (as seen in Figure 1). These are models that represent a real-world process. Essentially, a computer can repeat this simulation thousands of times to measure how often certain outcomes occur.

Building the model of the WOU Food Pantry involves lots of programming, but the basic idea is that the computer receives data about the Pantry including the average num- ber of visits each day, the desirability and quantity of the product, and the expiration date of each individual item unit. The model then takes an input item schedule to simulate. Each day in the simulation, the computer gets rid of expired item units, moves scheduled items from the back storage to the storefront, and has the average number of customers visit. It then uses the desirability of the product to determine whether or not a customer wants the product. If the customer wants the product, the system checks if it is available in the store front. If it is available, then the customer takes it and is satisfied. If it is not available, then the customer leaves and is dissatisfied. This goes on until all item units have expired or gone out to customers. All of that is on individual simulation. This simulation is then repeated a thousand times, and the frequency of items expiring and how frequently customers are satisfied each day is recorded.

This code snippet shows the algorithm to simulate visits:

```
# Simulate customer visits for the day
num_visits = visits_key[weekday]
satisfied = 0
dissatisfied = 0

for customer in range(num_visits):

# If the customer wants an item
if random.uniform(0,1) <= desirability:

# Check if an item is available for the customer
if store_front:

# Remove the item
store_front.pop(0)
satisfied += 1

else:
dissatisfied += 1
```

The end result of this is the ability to take any arbitrary item schedule and predict the likely waste and equity resulting from it. To find the best schedule, we may test many possible item schedules and rank them with a scoring system. Then, the schedule with the highest score will be the one the minimizes waste and maximizes equity, which means it is the optimal restocking schedule for that product and achieves the goal of this project.

6. A NOTE ABOUT EXPERIMENTAL V. TRUE PROBABILITIES

In the previous sections, we will relied on the concept of using past data to estimate probabilities. Note that we must mathematically define an experiment and justify why we may use it to estimate certain probabilities. The exact definitions, justifications, and assumptions for each of the previous sections are explicitly stated in the full thesis (Salsbury 2021).

As an aside, it is important to make it clear that desirability, satisfaction, and the results of the simulations are all experimental probabilities. By way of analogy, we are flipping a coin thousands of times to determine the probabilities of it landing on heads or tails. We might find that 51% of trials yielded heads and 49% of trials yielded tails. We then use the results of our trials to infer that subsequent flips have a 51% chance of being heads and a 49% chance of being tails, within some margin of error. On the other hand, we know that under ideal conditions with a fair coin, the true probabilities are 50% for heads and 50% for tails. There is no margin of error; these are the exact odds for each outcome.

That may seem like a trivial example for an introductory statistics concept, but it is necessary to reset our perspective. Desirability, satisfactions, and the simulation results are all experimental probabilities, which means that we are attempting to estimate some true probability. For example, we can estimate that the desirability of milk is 70%, but we cannot assert that the exact chance of a random customer taking milk is 70%.

As one final note, I used simulations to predict the results of item schedules because it was not within the scope of this project to find or determine a formula that could produce the results of an item schedule. If such a formula exists, it will take in the same inputs as the simulations, but it will output the true probabilities of items expiring, instead of experimental probabilities. The use of simulations is having an experimental probability (the results) on top of another experimental probability (desirability). Having a formula to predict the results means that we would be able to remove one layer of experimental probability, which would increase the accuracy of predictions.

7. CONCLUSION

This research is novel in both its deep examination of inventory management at client-choice food pantries as well as its mathematical approach to the subject. By defining the concepts of desirability and satisfaction, it is possible to quantify the likely outcomes for waste and equity of any arbitrary restocking item schedule. While item-level inventory management is not currently the standard practice of food pantries, affordable technology makes the data collection piece of this feasible for many small- and medium-sized pantries if they have sufficient volunteer time. Future work includes implementation of the algorithm with actual food pantry data. The ability to predict the results of item schedules allows them to be calculated and ranked ahead of time in order to determine the optimal schedule that minimizes waste and maximizes equity. Pantries that use this inventory management system can be more confident they are maximizing the utility of their resources, instead of leaving it up to random chance at the somewhat arbitrary decisions of volunteers and coordinators.

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