A Hypothetical Model of Food Loss Generation from Grocery Store to Customer

Theory Building for Future Data Collection

Master thesis

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I have had the privilege to be surround by amazing, knowledgeable people who helped me realize what I was capable when I was not prepared to.

And a special thanks to my family back in the US, I never could have undertaken such a task without your love and support.

Nathan Cole

Abstract

Food loss is a massive problem that does not get the attention that it should. Estimates suggest that 30-40% of food produced is wasted or lost before it can be consumed. With an ever-growing population and increasingly heating and changing environment, agriculture cannot continue to produce as they have been without more problems cropping up. Unfortunately, data on how, where and why food loss occurs is sparse, and data surrounding reduction efforts are disjointed and complicated through multi-pronged efforts. The data that is available indicates that the bulk of food loss in the western and developed world occurs between retail and the end customer. Given the scale of the problem, and the lack of data available this model and analysis have been constructed to create a hypothetical framework with which to determine what data needs to be collected in order to produce more data driven, policy minded models in the future.

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Introduction

This thesis is formulated to establish the problem faced and the scale on which it is found. Research objectives and questions will be presented to provide the basis for which the model was built, followed by an in-depth analysis and break down of each of the model components. Concluding with an analysis of the results and potential next steps for further food loss systems analysis.

Problem Description and Problem Definition

Access to food is poor in many parts of the world, estimates from 2017 say 821 million people face chronic food deprivation, an increase from 804 million the year before (The Economist Intelligence Unit, 2018). Access to good, nutritious food is worse still, due to poor farming practices, insufficient infrastructure or wasteful decisions. Food production and distribution are economically and environmentally costly. Current estimates site agriculture as responsible for 70% of freshwater withdrawals, 20% of global land use and 32% of worldwide energy consumption, as well as substantial contributions to solid waste, GHGs and other pollutants (Spang, et al., 2019). The costs extend beyond fuel, labor and environmental impacts, and eat into the food supply itself via food loss and food waste. Most estimates state that food loss and food waste account for 30 to 40% of total food production (Nelleman, et al., 2009). With world population expected to reach 9 billion by 2050, current production methods would need to grow 70% to feed such a large population (The Economist Intelligence Unit, 2018). It is clear that wide spread, systemic change is needed. Changes that go beyond customer behavior at home, and address how food is produced, distributed and marketed.

While food loss and food waste can occur everywhere throughout the food supply chain, the bulk of loss in the western and developed world occurs between

retail and the end customer, which will take the focus of the model. Customer waste estimates vary from around 40% of total food waste in the US occurring at the home, to 53% in parts of Europe (Spang, et al., 2019). When combined with retail, it is estimated that 31% of the food supply is lost to food loss and waste (US Department of Agriculture). Retail stores generally generate food loss through overstocking food in order to maintain appearances of abundance, or inadequate treatment by employees or customers (Burgos, et al., 2017). Losses at home are usually centered around poor habits, ability or understanding of food preparation and preservation (Burgos, et al., 2017).

Focusing on these sectors of the food supply chain are not without their problems. The two main issues being a lack of data, and insufficient motivation to change. Both sectors have poor information about the amount of waste that they generate (Jackson, 2019), and further data about previous efforts to reduce waste is scattered, difficult or impossible to translate between environments or just missing (Goosens, Wegner & Schmidt, 2019). And if the data is collected, it can be difficult to disentangle effects of different interventions as multiple policies are often simultaneously enacted (Stöckli, et al., 2018). Given that data availability on waste and the effect of waste reduction is poor, it becomes a bit clearer why motivation might be low. For individual consumers, the issue that is being faced can both seem simultaneously smaller than it is, as people underestimate their personal waste, but also too big and unscalable that they no longer feel responsible. While grocery stores, and producers further up the chain, continue to make substantial profits, representing to them that there is little problem with the status quo.

In order to properly proceed with the problem, it is important to make clear how the words will be used within the context of this model and analysis, which is

especially important as there are some discrepancies and disagreements about their use inside and outside of the food loss and waste community. In this model and analysis, food loss refers to edible food that is discarded at any step in the process, and food waste is food discarded due to appearance or other undesirable traits towards the end of life. Food loss is loss at any point of the chain, while food waste is a subset of food loss and generally will occur within retail, restaurants or residences. For the sake of the model and discussion all food that is not consumed or sold will be referred to as food loss.

The problem that this thesis aims to address is food loss, but as described before, data on the topic is scarce. As such, the problem is more precisely to develop a hypothetical framework of the system with which focuses can be developed to build a more data driven model in the future, which can be used to more precisely model this system. With a more data driven and oriented model points of intervention and specific policies can be tested and analyzed prior to real world implementation.

Research Questions and Objectives

The primary goal of this research is to develop a hypothetical food loss model which illustrates what data needs to be gathered to build a more complete, fully realized model which can be used to more holistically and systematically combat food loss. A model which will make potential intervention points clearer, allowing for policies to be tested and implemented that fully appreciate and utilize the complexity of the system and the loops that make it up.

This future model and analysis would aim to address, how can food loss and food waste be better prevented? And, where are the most effective points of

intervention? But given that the data is not presently available, the goal of this research is to establish what data needs to be collected in order for the model to get to that state. Particularly important data will center around the two following questions

1. Which loops appear to present potential points of intervention?

2. Which loops might present problems or prove reluctant to change?

Model Explanation

The model has been constructed to recreate the life of commercial fruit from when it enters a grocery store to when it leaves the customer's home. It runs as a series of goal gap loops with the goals established mostly endogenously, except for some exogenously, artificially imposed attempts to influence customer demand.

A number of assumptions needed to be made in order to build the model. Primarily among them, the representative grocery store is in charge of its own decisions, and that it is not influenced by external judgments. Further, due to a lack of data on many of the parameters within the model best estimates needed to be formed from available data.

The goal is to establish an explanatory model for this small section of the fruit supply chain, between this single representative grocery store and the customers who shop there. And through this construction, better understand the structures that lead to food waste and food loss in order to develop more reliable strategies to mitigate them going forward.

Stocks

There are four stocks which make up the bulk of the model; the Grocery Fruit (GF), the Target GF, the Customer Fruit (CF) and the Target CF. The

Grocery Fruit stock represents the fruit that is currently on display at the representative grocery store. The Target GF stock is the amount of fruit that the grocery store aims to have stocked on their shelves every day. Whenever the store is ordering more fruit, it is trying to return the Grocery Fruit stock to the level of the Target GF stock. The Customer Fruit stock represents the fruit that is currently at the customers' homes after being purchased at the grocery store. The Target CF is the amount of fruit that the customers of the store would like to keep in their homes. The Target CF is an aggregate of all of the fruit between the different customers, and does not represent a single home or buyer.

The Grocery Fruit (GF) stock and the Customer Fruit (CF) stock are material stocks, while the Target GF and Target CF stocks are information stocks. Both of the material stocks have one inflow and two outflows with similar structures driving them. The inflow of the Grocery Fruit stock is GF Restock and represents the flow of fruit into the store. This inflow is comprised of two main parts, a goal gap function as Grocery Fruit works to reach Target GF and an outflow cancelling structure that anticipates the amount of waste and sales generated by the store. By accounting for the goal gap and the outflow, the inflow of GF Restock is able to keep Grocery Fruit near the desired level.

The Customer Fruit stock is similarly regulated by its inflow GF Sales. GF Sales is driven by the goal gap function between Customer Fruit and Target CF, along with an average outflow from the Customer Fruit Stock. While GF Sales is influenced by the outflows like GF Restock is, there is a minor difference that is important in understanding the construction of the model and the system. The grocery store monitors its inventory, its sales and its workers at a level that no customer would ever have reason to do. The grocery store has a financial incentive to ensure that fruit is being sold, and to mitigate waste to the point that it doesn't

hurt their profits. While the customer does face their own economic pressures, they are generally not treated as existential threats in the way that the grocery store treats them. The customer may shy away from an expensive product in the store, but once the food has come home, the money and volume of food has largely left their mind. For this reason, the outflows of customer fruit are referred to as average instead of expected, to reflect their diminished awareness.

Flows

The outflows of Grocery Fruit are GF Loss and GF Sales. GF Loss is largely a function of the short shelf life of fruit and the large quantity of fruit that is stocked at the grocery store. GF Sales was largely covered above as a Customer Fruit inflow.

The outflows of Customer Fruit are CF Consumption and CF Loss. CF Loss is identical to GF Loss except for two important distinctions. Primarily, the fruit shelf life is shorter than it was in the grocery store, as some of the shelf life of the fruit was eaten up there. Secondly, as discussed before CF Loss does not have the same weight on the Customer Fruit stock as GF Loss does on the Grocery Fruit stock, and as such the feedback loops from it are fewer and weaker. CF Consumption is a function of Customer Fruit with diminishing consumption as the stock shrinks. CF Consumption could be further developed, but it does not seem to play a very important part in the driving the system or its loops so this minimalist structure will work for now.

Variables

Where Target GF and Target CF reflected information stocks for their respective, material fruit stocks. Indicated Grocery Fruit and Indicated Customer Fruit reflect moving goals for these targets to reach. They are represented by

converters instead of stocks to reflect their more nebulous, immaterial nature. They don't have the same inflows and outflows like stocks but can jump around to reflect changes in their environment much more rapidly. Indicated GF is a function of many variables defined as table functions. These variables and how their respective values were found will be further explained in the section dedicated to them. Suffice to say in this section, Indicated GF is driven up by the desire for greater profit, and driven down by reductions in profit. Indicated CF has similarly convoluted influences, which will be explained later, but it is driven by anything which would increase customer demand.

The drivers of Indicated GF are the Effect of GF Cost, the effect of Sales and the effect of GF Loss Cost. The Effect of GF Cost represents the extent to which the store is more likely to stock fruits which cost them less to stock. This is not wholly representative of the grocery store's specific fruit volume decision, but is sufficient for the purposes of this model. The Effect of Sales is largely a reflection of the volume that the store expects they will need to stock based on previous GF Sales. If sales are high, they will keep the grocery store well stocked, if they are low, they might cut down on their fruit. The Effect of GF Loss Cost is a measure of how much the grocery store will change the indicated GF based on the monetary cost they accrue from losing fruit. Small costs from fruit loss will result in no to negligible changes in Indicated GF, whereas larger costs may make the grocery store reconsider the volume they keep on stock. If the cost felt here could be amplified, grocery stores would have greater incentive to reduce their direct waste.

The drivers of Indicated CF are the Effect of GF Price, the Effect of Marketing, the Effect of Discount, the Effect of CF Loss and the Effect of CF Consumption. The Effect of GF Price works similarly to the Effect of GF Cost,

customers are similarly limited by their funds and will be less inclined to purchase large quantities of expensive fruit than cheap fruit. This trend does not hold forever, as lower costs can give indications of low quality which can drive down their demand. The Effect of Marketing and the Effect of Discount work in tandem with each other, as frequently they will be posted within the same documents or advertisements. Generally, as more ads are consumed, or more discounts offered, customer demand as represented by Indicated CF will grow. People view a more familiar brand or fruit as higher quality, and thus will be more interested. The Effect of Discounts will induce some increased demand, but similar to the issues faced by very cheap fruit in the Effect of GF Price, if discounts are too large or frequent, then customers may lose trust in the product and demand can drop. The Effect of CF Loss is the impact that food loss at the customers' homes have on their demand for fruit. At the moment, the correlation is not very strong, through a combination of a poor understanding of the volume of waste generated and cultural habits. The Effect of CF Consumption represents the impact the consumers' consumption has on future demand. Customers that appreciate and consume higher volumes of fruit will seek out more fruit up to a point, customers that do not eat much fruit will only purchase limited quantities.

Beyond the previously covered components, there are a few more miscellaneous variables to cover, the Effect of Sales on Marketing, the Effect of Sales on Discount, the Effect of GF Loss on Discount and the Discount Calendar Switch. The Effect of Sales on Marketing and Discount work similarly, and will be covered more in depth in the discussion about loops in the model, but suffice it to say that Marketing and Discounts are vehicles to drive up sales, and as sales increase, they reinforce their case for their future use. The effect of GF Loss on Discount represents the extent to which the grocery store will discount their goods

as they see that they have expired or will soon. This effect is not very strong, as only a small portion of the store is dedicated to such a discount section, and the discounts provided are trying harder to recover costs than to reduce waste. The Calendar Switch is unique in comparison to the rest of the model, but it is a key part in understanding the hypothesis. The Switch allows for a variable discount and marketing campaign to appear every 80 days and run for 20 days. The appearance of the discounts and advertisements will result in spikes in customer demand through the Indicated CF. The increased Indicated CF will result in growth in the stock Target CF, which takes longer to update. This increased Target CF will produce peak sales during the campaign, with the lingering effects of increased demand resulting in above equilibrium sales in the gap between campaigns.

Causal Loop Diagram Explanation

The variables that have been explained so far are useful in developing a foundational understanding of the hypothesis of the system, but they are limited as the linkages and loops have not been developed. In this section, the loops that drive the behavior will be established.

There are six main loops, most of which interact via Grocery Fruit Sales. From these six they can be broken down into two more distinct groups, Grocery Fruit Loops and Customer Fruit Loops. For the sake of readability, I have broken the loops into the Grocery Fruit and Customer Fruit sections at GF Sales, with a second analysis of Customer Driven and Grocery Store driven loops, and a more complete CLD to follow at the end.

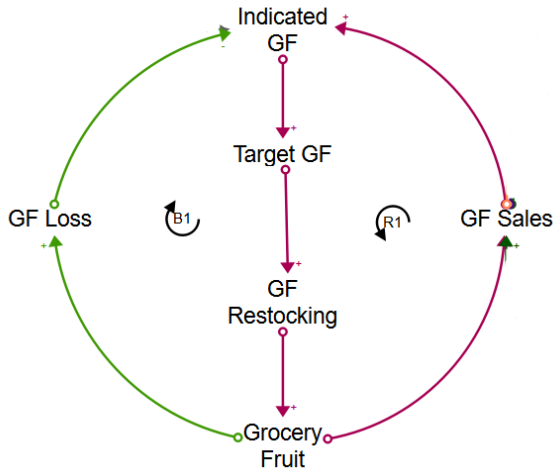


Figure 1: Grocery Fruit Loops

Grocery Fruit Loops

The Grocery Fruit Loops consist of the Grocery Loss Loop and the Fruit Sales Loop. The Grocery Loss Loop (B1) is a balancing loop with a single negative polarity between GF Loss and Indicated GF. This negative polarity is

representative of the grocery stores interest in reducing their own loss, which drives them to keep their Target GF close to what they can sell. This link is not very strong as the food loss they pay for is largely just seen as a cost of business. This link could be strengthened via external intervention, taxes for example, but, due to the hypothetical nature of this model and poor data availability, this potentiality was not developed here. With proper data in the future, an economic intervention at the point of grocery waste should be analyzed further.

The Fruit Sales Loop (R1) is a reinforcing loop that reflects the desire to constantly increase sales. The key interesting linkage that could be further analyzed is between the Grocery Fruit stock and Grocery Fruit Sales. The waste that is generated is based on the amount of Grocery Fruit, but so too are the sales. If there was a way to disentangle the cultural desire for well stocked, high volume fruit displays while not sacrificing sales, the grocery store would have greater incentive to lower the amount of fruit they have on stock.

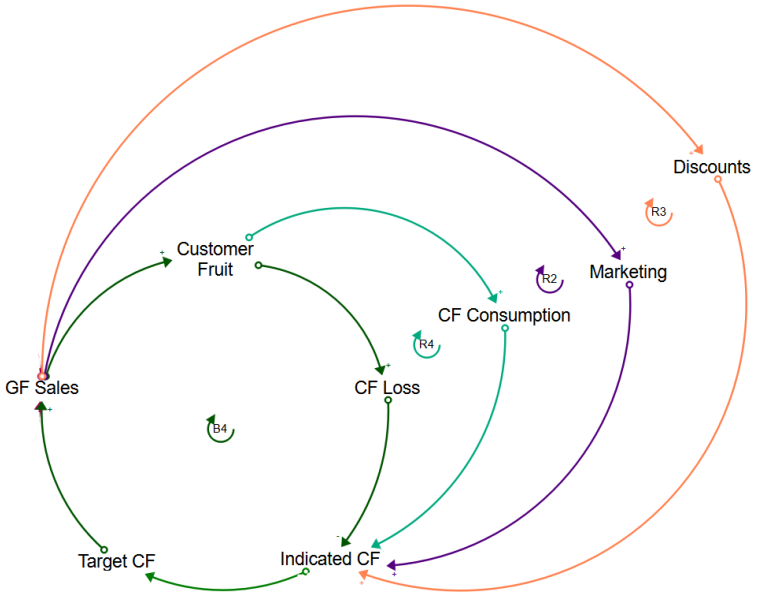


Figure 2: Customer Fruit Loops

Customer Fruit Loops

The Customer Fruit Loops consist of the Customer Loss Loop, the Customer Consumption Loop, the Marketing Loop and the Discount Loop. The Customer Loss Loop (B4) is a balancing loop with a single negative polarity between CF Loss and Indicated CF. This negative linkage is representative of the desire of the customer to reduce their own fruit loss by reducing the amount of fruit that they purchase. (citation) But as the bulk of food loss occurs at the end user, home, restaurant or institution, it is clear that this link is not sufficiently strong to drive behavior towards food loss reduction. Presently the incentives are not in place for customers to worry about, or monitor their food loss to the extent grocery stores, distributors or farmers do. (citation) Interventions to reduce customer fruit loss at this point through economic disincentives have produced some promising results, but specific strategies need to be further developed and expanded.

The Customer Consumption Loop (R4) represents the reinforcing behavior exhibited by customers who regularly eat fruit, or those who do not. Customers that regularly eat will maintain and potentially grow their diet of fruit, whereas customers who consume less will purchase fruit less frequently. Customer Consumption behaves similarly to Grocery Fruit Sales in the Fruit Sales Loop seen in the previous section. Grocery Fruit has two outflows, a productive one via GF Sales, and a wasteful one via GF Loss, whereas Customer Fruit has CF Consumption and CF Loss. The similarities between the flows extend to the desire for abundance as well, as a poorly stocked cupboard can leave a bad taste in the customer's mouth. Beyond this cultural desire for volume, customers on average lack sufficient skills to properly prepare and preserve the all fruit they purchase. This inability can manifest as tossing food that has not yet expired, poorly packaging food leading to earlier spoilage, or trimming away of edible and nutritious parts of foods. This loss is eating into potential customer consumption and making the Indicated CF artificially high. Through cultural changes, as well as improved skills and habits, food that is currently lost could be consumed.

The Marketing Loop (R2) and the Discount Loop (R3) represent how awareness of products and discounts can induce customer demand, as well as the lingering effect they have on demand. These loops, while separate and with different implementation strategies from the grocery store, act very similarly. They both aim to produce familiarity with a brand, product or fruit, and they both are the result of a higher level, more systems-based analysis of the system. In the short term, they both will result in costs to the store, costs that are not and cannot be directly recouped with sales like with the apples or oranges, but which are known to produce better results in the long term.

Marketing will develop more familiarity and name recognition through visuals, whereas discounts will provide a sense of value to the customer and develop a new or increased desire for a product. This familiarity boosts demand and can develop into loyalty to a new good. This increase in demand manifests in Indicated CF where it then drives longer term demand in the Target CF. Target CF does not react as quickly to the pulses in Discounts and Marketing, but it also will not deteriorate as fast when they go away. The boosts seen there will have lingering effects which help keep GF sales above equilibrium levels. This increase in Target CF and GF sales results in a Customer Fruit level higher than necessary for customer consumption, which leads to food loss.

Loop Interactions

The loops were separated due to their impact on the respective Indicated Grocery Fruit or Customer Fruit variable, but similarly they could have also been divided between Customer driven and Grocery Store driven loops. Dividing the loops in this fashion helps further paint a picture of how the loops function and where the strength behind the driving forces emanates.

Customer Driven Loops

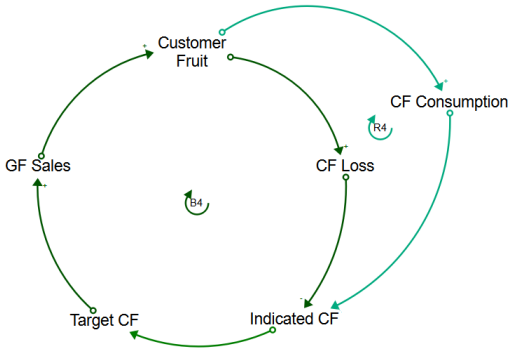


Figure 3: Customer Driven Loops

The Customer Driven loops, Customer Loss (B4) and Customer Consumption (R4) are ones driven by the consumer, the intended end user of the fruit. These loops have a relatively small impact on the behavior of the system as a whole. While they both will help contribute to building a gap between Target CF and Customer Fruit by depleting Customer Fruit, there impact does little beyond this point.

The Customer Loss Loop (B4) could help reduce the amount of fruit that a customer wants to buy, but it does not presently have this result for a few reasons. High among them is the fact that many customers do not have any idea of the amount of food they are wasting. According to a Natural Resources Defense Council study 76% of Americans surveyed think that they throw out less food than the average American (Jackson, 2019). When customers are not aware of the amount of food they are wasting, how can they be concerned about the environmental impact of their waste, or even the cost from their own pockets. An additional complicating factor are the plethora of cultural and habitual behaviors that drive customers towards abundance, wasteful preparation and poor preservation habits (The Economist Intelligence Unit, 2018). Further, reductions in healthy purchases can make people feel as if they are sacrificing taking good care of their family (Jackson, 2019). If these habits and behaviors could be changed, this loop could be strengthened to help customer's purchases better reflect their need. Until then, this loop will have little impact on the behavior of the system.

The Customer Consumption Loop (R1) helps the customer's purchases reflect their need by increasing Indicated CF when they consume a lot of fruit and reducing it when they do not. This largely behavioral and habit driven loop similarly is not very strong, and can and is overwhelmed by other loops which will drive GF Sales higher than what the customers will consume. Any steps made to

change Customer Loss should have an opposite, but encouraging impact here, as any food that makes it to the customer that is not wasted, needs to be eaten. Additionally, this loop should be low in the focus for potential interventions, as strengthening the desire for more fruit while failing to address wasteful behaviors will lead to more waste.

Grocery Store Driven Loops

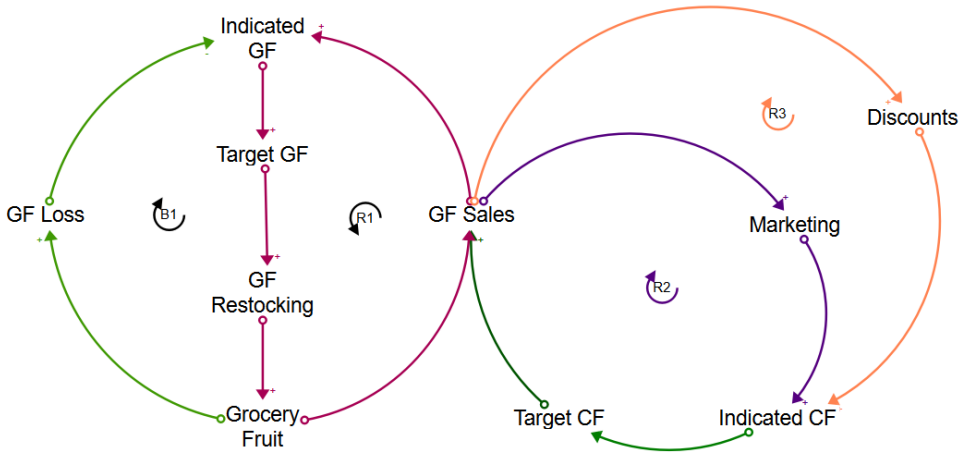


Figure 4: Grocery Driven Loops

The Grocery Store Driven loops, GF Loss (B1), Fruit Sales (R1), Marketing (R2) and Discount (R3) are the loops driven by the grocery store for the sake of the model, or the loops in which the grocery store is directly acting with the system. The GF Loss Loop and the GF Sales Loop will behave similarly to the Customer Loss and Customer Consumption loops, respectively. They are important in restocking and as a potential place for intervention, but at the moment produce very little interesting behavior. The driving forces for the model lie in the Marketing and Discount Loops.

The GF Loss Loop (B1) does not presently have the strength that it could. Most grocery stores do not properly track the food that they have wasted (Helmer, 2021). Failing to keep track of these losses, just like with the customer, will

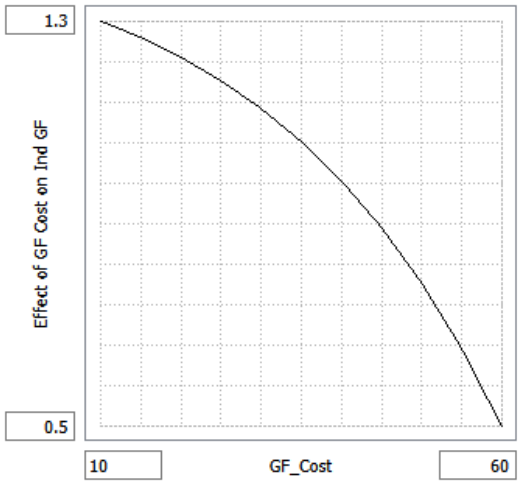
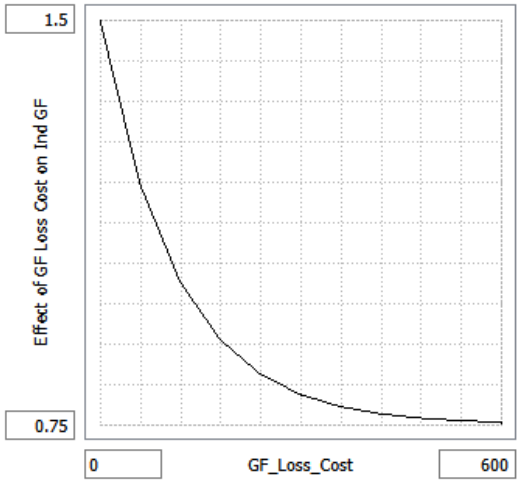
produce poor results when attempting to battle food loss. Further, the food myself and others saw while dumpster diving indicated, if they were aware of the loss, it had very little impact on the amount of food they had on display. We would regularly find a few kilograms of bananas, and loose odds and ends of other fruits and vegetables. But on the "worst days" for food loss, and the "best days" for us, we found 20 kilograms of blueberries, or 40 mangos. The grocery store is not feeling any impact from their waste, and as such is not adjusting their stocking behavior. The strength of this loop could be bolstered through additional charges for such waste or environmental media pressure, but until there is greater incentive it will produce relatively small results.

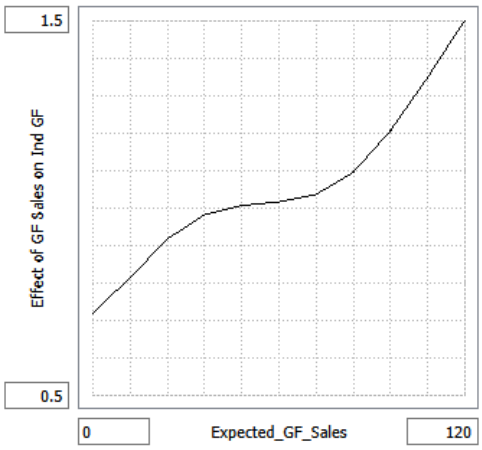
The Fruit Sales Loop (R1) behaves similarly to the Customer Consumption loop, as well as representing the ideal purpose of the fruit. Ideally the fruit is eaten, and in order to get this step in the process it must be sold. The strength of this loop is enough that the Fruit Loss Loop is largely ignored. As long as sales are sufficiently high, then the grocery stores feel little need to worry about any costs accrued from food loss. This loop is further bolstered by the Marketing and Discount Loop which raise the Indicated GF in order to prepare for the spike in demand that discounts and ads will produce. This disturbance in demand and Indicated GF produces a turbulent Target GF, which can then mask a level of sales and stocking that more closely align with the goal of reducing food loss. Or more succinctly, if sales are fluctuating, it is harder to properly stock the grocery store with food loss as a priority.

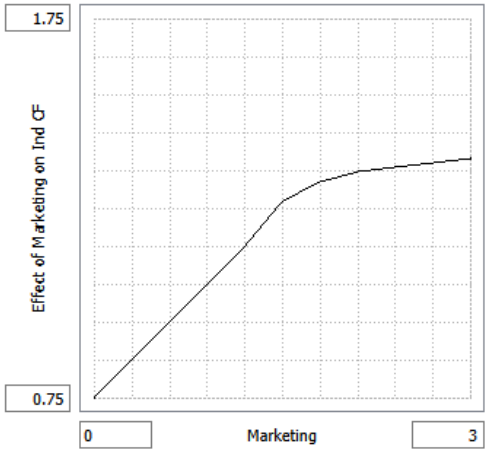
The Marketing Loop (R2) and the Discount Loop (R3) drive the bulk of the behavior seen in the model, especially when the calendar switch is on. If customers were left to their own devices, their natural state, there would be relatively little disruption to their purchasing and eating patterns. The Marketing Loop and

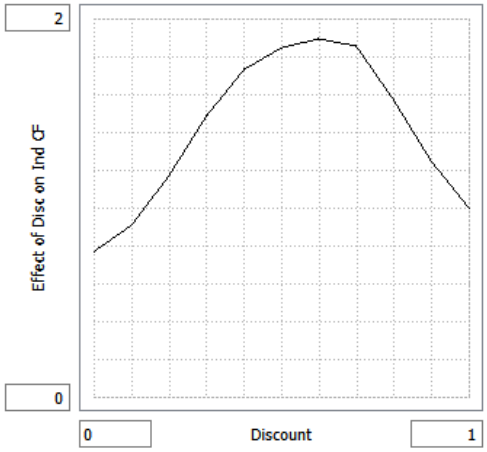
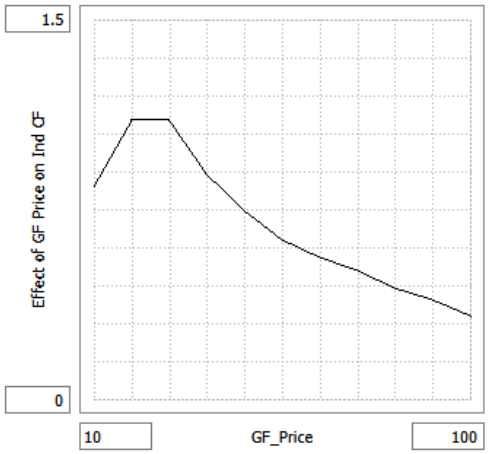
Discount Loop appear to disturb that natural state of sales. They aim to induce higher demand, which leads to higher sales. While higher sales are the top priority for the grocery store, they result in customers purchasing beyond their need, resulting in more customer food loss. These loops lead to the greatest gap between sales and consumption, and as such present a good point of intervention to reduce food loss.

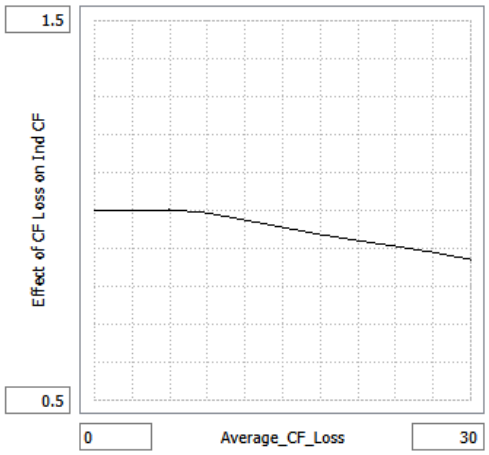
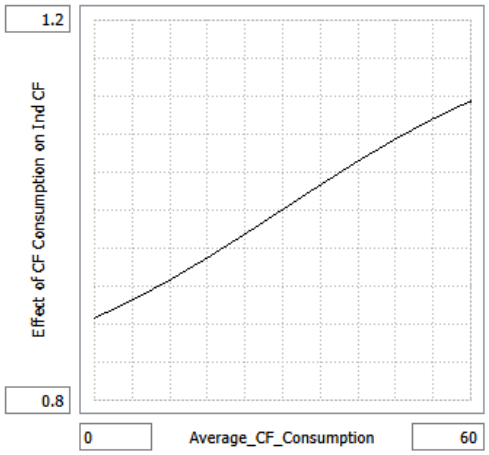
Effects

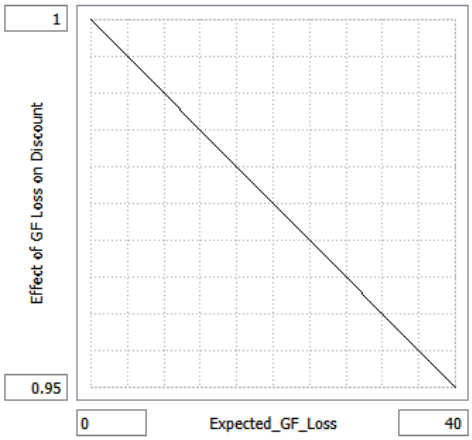
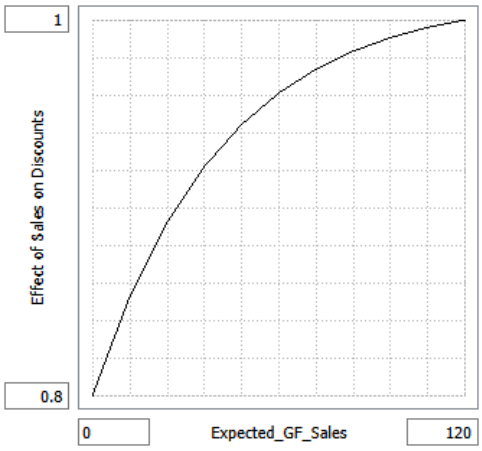
Effects on Indicated Grocery Fruit (Indicated GF)			
Effect of GF Cost on Ind GF 	[(10,1.3)-(60,0.5)], (10,1.3), (15,1.2673), (20,1.2284), (25,1.1822), (30,1.1273), (35,1.0621), (40,0.9847), (45,0.8928), (50,0.7836), (55,0.654), (60,0.5)	DMNL	This effect's impact is small as it is not part of a loop. The GF Cost is largely reflected in GF Price, where price can reflect quality, but also result in low sales and high waste (Burgos, et al.). Higher costs are bigger gambles for the store.
Effect of GF Loss Cost on Ind GF 	[(0,0.75)-(600,1.5)] (0,1.5), (60,1.1952), (120,1.0143), (180,0.9069), (240,0.8431), (300,0.8053), (360,0.7828), (420,0.7695), (480,0.7616), (540,0.7569), (600,0.7541)	DMNL	Derived from my experience and discussion with fellow "dumpster divers". Roughly 6 to 10 kilograms was found every visit, or a GF Cost of 180-300. The store tolerated this cost, and more with little impact on the GF stock.

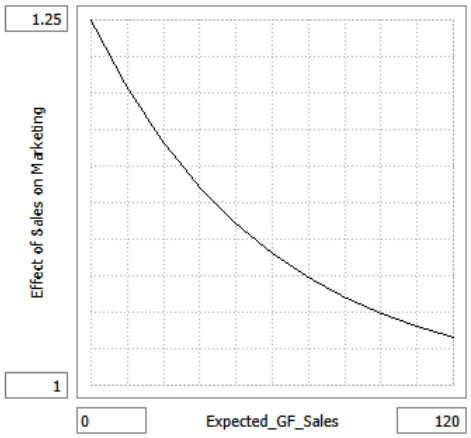
Effect of GF Sales on Ind GF 	[(0,0.5)-(120,1.5)], (0.0,0.719), (12.0,0.8126), (24.0,0.9159), (36.0,0.9804), (48.0,1.0055), (60.0,1.0149), (72.0,1.0350), (84.0,1.0940), (96.0,1.2050), (108.0,1.3468), (120.0,1.500)	DMNL	Well stocked displays lead to more sales, more sales lead to more stocked displays. Based on desire of grocery store to produce more sales, and the ability of grocery stores to reallocate funds to more profitable products. (Burgos, et al.)

Effects on Indicated Customer Fruit (Indicated CF)			
Effect of Marketing on Ind CF 	[(0,0.75)-(3,1.75)], (0,0.75), (0.3,0.85), (0.6,0.95), (0.9,1.05), (1.2,1.15), (1.5,1.269), (1.8,1.319), (2.1,1.346), (2.4,1.358), (2.7,1.369), (3,1.381)	DMNL	Marketing will prove most effective at the beginning, but they will reach a saturation point where efficacy drops. Marketing needs to be targeted and fit the customer needs, not exhaust or frustrate them. (Charm et al.)

Effect of Disc on Ind CF 	[(0,0)-(1,2)], (0,0.769), (0.1,0.908), (0.2,1.169), (0.3,1.485), (0.4,1.731), (0.5,1.846), (0.6,1.892), (0.7,1.854), (0.8,1.569), (0.9,1.246), (1,1)	DMNL	Customers will seek out discounts, but the effect is not always positive. If they think they are getting good value the effect can be quite strong, but if they perceive the product as poor quality sales will drop. (Elberg, et al.)
Effect of GF Price on Ind CF 	[(10,0)-(100,1.5)], (10,0.842), (19,1.102), (28,1.102), (37,0.888), (46,0.744), (55,0.629), (64,0.56), (73,0.508), (82,0.438), (91,0.392), (100,0.329)	DMNL	Customers are sensitive to the price of goods. Too low prices can reflect poorly on the quality of the product, too high and they will find substitute goods and food will be wasted. (Burgos, et al.)

Effect of CF Loss on Ind CF 	[(0,0.5)-(30,1.5)], (0,1), (3,1), (6,1), (9,0.992), (12,0.973), (15,0.954), (18,0.935), (21,0.919), (24,0.904), (27,0.888), (30,0.869)	DMNL	While end users and residences account for a lot of waste, they do not know how much they are wasting. If they do not have a good idea of their waste it cannot produce much impact on their decisions. (Jackson)
Effect of CF Consumption on Ind CF 	[(0,0.7)-(60,1.2)], (0,0.8857), (6,0.9045), (12,0.9257), (18,0.9491), (24,0.9741), (30,1), (36,1.0259), (42,1.0509), (48,1.0743), (54,1.0955), (60,1.1143)	DMNL	Customer habits can be shaped, but for the most part they are their own. Those who eat a lot of fruit will be motivated to eat more, where as those who eat less may have their desire piqued with discounts or ad campaigns. (Charm, et al.)

Miscellaneous Effects			
Effect of GF Loss on Discount 	[(0,0.95)-(40,1)], (0,1), (4,0.995), (8,0.99), (12,0.985), (16,0.98), (20,0.975), (24,0.97), (28,0.965), (32,0.96), (36,0.955), (40,0.95)	DMNL	Grocery stores are not properly incentivized to reduce waste. Despite high expected loss, still only small portions of fruit will be discounted. Furthermore, the impact of these discounts on sales is unclear, which lowers motivation.
Effect of Sales on Discounts 	[(0,0.8)-(120,1)], (0,0.8), (12,0.8525), (24,0.892), (36,0.9218), (48,0.9442), (60,0.9611), (72,0.9738), (84,0.9833), (96,0.9905), (108,0.9959), (120,1)	DMNL	Grocery stores are businesses which exist to sell food. They are much more incentivized to provide discounts when they need to drive sales than prevent waste. If sales are high, their incentive drops off.

Effect of Sales on Marketing  	[(0,1)-(120,1.25)], (0,1.25), (12,1.2039), (24,1.1663), (36,1.1356), (48,1.1106), (60,1.0902), (72,1.0735), (84,1.06), (96,1.0489), (108,1.0399), (120,1.0325)	DMNL	In order to keep sales at a desirable level, the grocery store will increase their marketing campaigns to establish or develop new shopping habits. If their audience becomes saturated and they begin to see less return, they will reduce spending on marketing.

Calibration

The effects and variables were based on a combination of available aggregate data, personal experiences with grocery stores and dumpster diving as well economics courses and many articles discussing the effects of prices, discounts and ads on customers. Any variable calibrations that have not yet been covered in the document will be explained with what they represent and their formulations in the model documentation following at the end of the document.

Results and Conclusions

Research Findings

The core question of this research is, what data needs to be collected to improve future food loss models? This can be best addressed by viewing the research through the lens of its follow up questions. The data that needs to be collected would be that which helps flesh out the loops which produce interesting behavior or drive the results, as well as the loops which could be strengthened to improve good behavior or balance out bad behavior.

1. Which loops appear to present potential points of intervention?

With the focus of this thesis being food loss reduction, a good place to focus would be on the loops which directly interact with food loss, the Grocery Loss Loop and the Customer Loss Loop. Presently they are both very weak, due to a bad combination of lack of data for the actors, the grocery store and the customer, and lack of motivation. But both of these problems have seen attempts to address them everywhere around the world, whether that is customers paying additional charges for disposal of food (Lee & Jung, 2017), or charities and some private businesses stepping into distribute aging produce (The Economist Intelligence Unit, 2018). With better data about the efficacy of these efforts the model could move forward producing results that more closely reflect reality.

As the discount loop and marketing loop have been found to be the major drivers of behavior in the model, they are a good place to look for potential intervention. Recalling the scale of the agricultural industry, as well as the multifaceted efforts that groceries stores take to induce sales, some loss prevention could be found here, not by adding some additional taxes or levies, but rather by reducing the number of discounts and ads that customers face. Looking to the

model, these discounts and ads disturb what could otherwise be normal purchasing habits and incentivize them to purchase additional food that they do not need or otherwise would not have wanted. The best way to reduce food loss and waste is not to create it in the first place (US Department of Agriculture). If customer demand (Indicated CF) was not artificially raised for more sales, loss could be reduced. Data about the efficacy of ads and marketing campaigns could help establish the extent to which reducing them could help reduce food loss.

2. Which loops might present problems or prove reluctant to change?

Interestingly enough, it appears that the same loops that would prove useful intervention points also may produce some of the most reluctance to change. The Grocery Loss Loop, Discount Loop and Marketing Loop are all working under the premise that they need to increase sales. Any efforts to reduce their efficacy is going against their established goal, so moving up food loss reduction in priority would be difficult. Data would need to be collected which reflects the point at which sales are hurt, as well as data around policies that were able to walk the line between these two seemingly diametric priorities.

The Customer Loss Loop is mired in cultural, identity and behavioral problems. People around the world do not just eat for sustenance, but to show love to others, to entertain, to respect their traditions (The Economist Intelligence Unit, 2018). These habits are deeply rooted, and to change them will take no small feat. More reliable data around the effect of food preparation classes and food loss prevention ad campaigns would need to be collected.

Reflection

Food loss reduction is a lofty goal with many hurdles to overcome in order to combat it. The effects and drivers seem so inextricably intertwined, but they must be in order to improve the increasingly dire situation the world finds itself in. Further, seemingly invisible systems that drive our behavior need to be see the light of day. Similar to how plastic reduction and oil consumption reduction strategies, the blame and responsibility can not be solely placed on the end consumer. The scale of the industries and the weight that they carry must be appreciated to really understand the burden the individual consumer is under.

Improving representation of these systems, and their explanatory, as well as policy shaping power, will help remove the weight of the world that has been placed on the end users' shoulders. What had once felt like an unbearable, unscalable task as one makes the small, individual decision to eat that single over ripened banana, can start to feel manageable through cooperative, comprehensive efforts.

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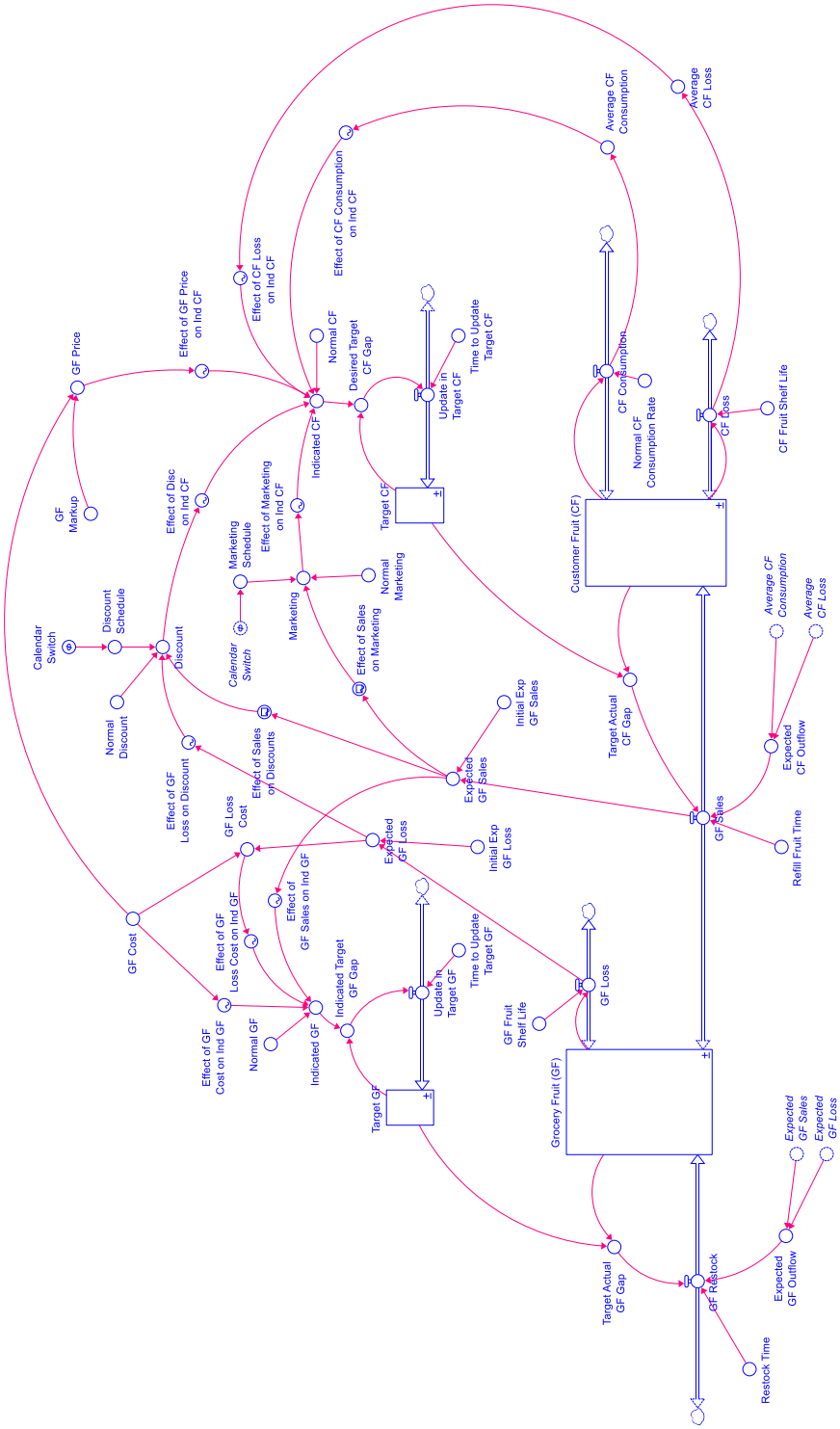
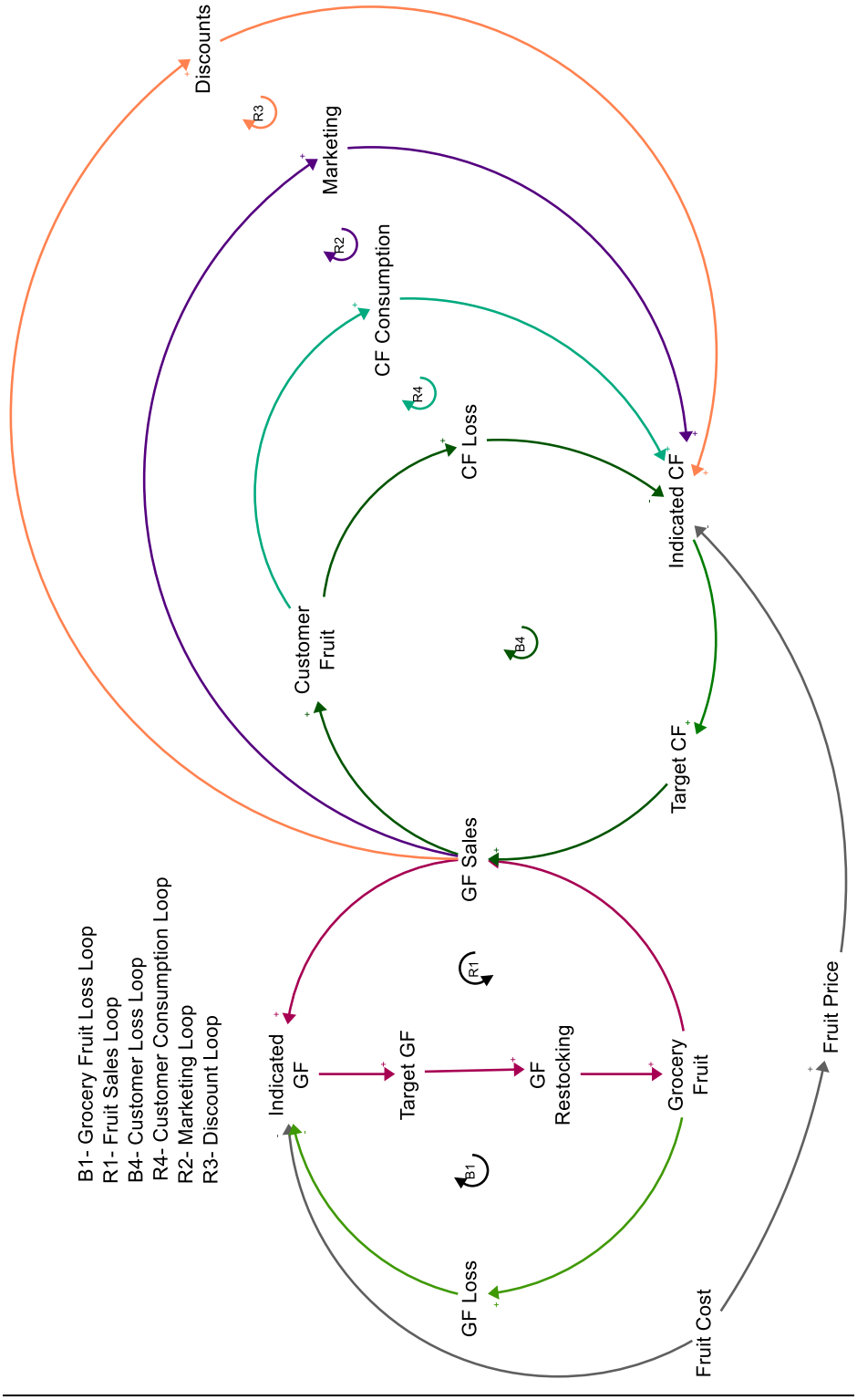
Simulation Model

Stock and Flow Diagram



Causal Loop Diagram



Documentation of Simulation Model

"Customer_Fruit_(CF)"(t) = "Customer_Fruit_(CF)"(t - dt) + (GF_Sales - CF_Consumption - CF_Loss) * dt

INIT "Customer_Fruit_(CF)" = Normal_CF

Unit = kg

Customer Fruit is the total fruit that was purchased from the Grocery Store by customers, with the intention of personal consumption. It is spread evenly through the Customers of this store. It is replenished via GF Sales and depleted via CF Consumption (Customer Fruit Consumption) and CF Waste.

"Grocery_Fruit_(GF)"(t) = "Grocery_Fruit_(GF)"(t - dt) + (GF_Restock - GF_Sales - GF_Loss) * dt

INIT "Grocery_Fruit_(GF)" = Normal_GF

Unit = kg

Grocery Fruit is the total fruit in this single specific grocery store in kilograms. It is replenished via GF Restock (Grocery Fruit Restock) and depleted through GF Waste and GF Sales.

Target_CF(t) = Target_CF(t - dt) + (Update_in_Target_CF) * dt

INIT Target_CF = Normal_CF

Unit = kg

This represents the aggregate target amount of fruit of all of the customers of our grocery store. When the Customer Fruit is restocked it is moving towards this as the target. This grows based on a number of factors that can increase the demand for fruit.

Target_GF(t) = Target_GF(t - dt) + (Update_in_Target_GF) * dt

INIT Target_GF = Normal_GF

Unit = kg

The Target GF represents the level to which the store is presently trying to stock the fruit. It is related to physical capacity and store planning. For example, the grocery store may only have 15 bunches of bananas, but they have designed space to allow for 40 bunches. The Target GF is the 40 bunches that they are working to maintain.

CF_Consumption = "Customer_Fruit_(CF)"*Normal_CF_Consumption_Rate

Unit = kg/day

CF Consumption reflects the rate at which the customers are eating fruit and depleting the Customer Fruit (CF) Stock.

CF_Loss = "Customer_Fruit_(CF)"/CF_Fruit_Shelf_Life

Unit = kg/day

This reflects the amount of waste generated by all of the customers of the grocery store.

GF_Loss = "Grocery_Fruit_(GF)"/GF_Fruit_Shelf_Life

Unit = kg/day

GF Waste is the amount of waste generated from the grocery store. It is driven mostly by the short shelf life of fruit.

GF_Restock = Target_Actual_GF_Gap/Restock_Time+Expected_GF_Outflow

Unit = kg/day

GF Restock (Grocery Fruit Restock) is how Grocery Fruit is replenished. It is a function based on the gap between the Target GF and the actual GF as well as the expected values of the flows depleting Grocery Fruit, Expected GF Outflow.

GF_Sales = Target_Actual_CF_Gap/Refill_Fruit_Time+Expected_CF_Outflow

Unit = kg/day

GF Sales is the amount of Grocery Fruit that is sold to customers per day and becomes Customer Fruit. This flow is a function of the Target CF (Target Customer Fruit Level) and the actual Customer Fruit and the expected outflow.

Update_in_Target_CF = Desired_Target_CF_Gap/Time_to_Update_Target_CF

Unit = kg/day

This reflects the rate at which the Target CF is updated to match the Indicated CF.

Update_in_Target_GF = Indicated_Target_GF_Gap/Time_to_Update_Target_GF

Unit = kg/day

This represents building up or removing additional capacity to reflect changes in expected GF sales.

Approximate_CF_Loss = CF_to_GF_Loss_Ratio*GF_Loss

Unit = kg/day

CF Waste is roughly 1.5 - 2 times greater than GF Waste. This value was used to roughly calibrate CF Loss with respect to GF Loss.

Average_CF_Consumption = SMTH1(CF_Consumption, 25, CF_Consumption)

Unit = kg/day

This reflects the average fruit consumption by all of the customers of the store per day. Unlike the store these numbers aren't as well monitored, after purchase customers don't monitor their fruit with the same economic incentives.

Average_CF_Loss = SMTH1(CF_Loss, 25, CF_Loss)

Unit = kg/day

Average CF Waste is the average waste generated by customers. This is not closely monitored by Customers or other bodies. Because customers aren't very aware of their waste, it is hard to use it as a value with which to adjust their behavior.

Calendar_Switch = 0 OR Calendar_Switch = 1

Unit = dmnl

This turns off and on a discount and marketing calendar. Otherwise, the discounts are only based on GF Loss and Sales.

CF_Fruit_Shelf_Life = 4

Unit = day

The expected life before spoilage at the customer's home. This is further down the supply chain than the GF Fruit Shelf Life, and as such the time is shorter. This time can be further reduced if the grocery store places old produce on discount.

CF_to_GF_Loss_Ratio = 1.75

Unit = dmnl

CF Waste is roughly 1.75 times greater than GF Waste.

Desired_Target_CF_Gap = Indicated_CF-Target_CF

Unit = kg

This is the gap between the indicated CF and the Target CF. As the gap grows, based on discounts, marketing or the like, the Target CF will grow.

Discount =
Normal_Discount*Discount_Schedule*Effect_of_GF_Loss_on_Discount*
Effect_of_Sales_on_Discounts

Unit = dmnl

This reflects the relative price of the item based on increases in discount. As the discount grows so does demand, when the discount goes away it remains relatively static, only slowly depreciating.

Discount_Schedule

(1-Calendar_Switch)+Calendar_Switch*(1-STEP(0.2, 80)+STEP(0.2, 100)-STEP(0.2, 180)+STEP(0.2, 200)-STEP(0.2, 280)+STEP(0.2, 300)-STEP(0.2, 380)+STEP(0.2, 400)-STEP(0.2, 480)+STEP(0.2, 500))

Unit = dmnl

This represents the discount schedule imposed by the grocery store it is turned off and on by the calendar switch.

(Numerical Values of Effects are portrayed within the document)

Effect_of_CF_Consumption_on_Ind_CF

This is the effect of CF Consumption on Indicated CF. As customers eat more fruit their interest in more fruit increases, if they have low consumption their interest in fruit drops off.

Effect_of_CF_Loss_on_Ind_CF

This is the effect of CF Waste on Ind CF. As customer waste increases customers can lower their demand for additional fruit. This effect is not presently that strong, but may be strengthened through better monitoring of CF Waste, or a tax similar to that seen in GF Waste Cost.

Effect_of_Disc_on_Ind_CF

This is the effect of the discount on customer demand. Greater discounts will increase customer demand.

Effect_of_GF_Cost_on_Ind_GF

The cost of fruit influences the amount of fruit that the grocery store will have on stock. As the cost goes up, they will stock less, and as the cost goes down, they will stock more.

Effect_of_GF_Loss_Cost_on_Ind_GF

This represents the effect that the GF Waste Cost will have on the Indicated GF. If the GF Waste Cost is higher than tolerable for the Grocery Store it will drive down the Indicated GF, which will in turn drive down the Target GF in an effort to drive down GF Waste Cost.

Effect_of_GF_Loss_on_Discount

Expected waste drives some discounts on fruit. More stores are presenting fruit further along in their life cycles at lower prices for the customer. These fruits will have age spots, and may have some inedible parts, and the customer is compensated with a lower price. Lower price for the customer, and reduced food waste at the grocery store.

Effect_of_GF_Price_on_Ind_CF

This is the effect of the normal price on the Indicated CF. Low prices generally increase demand, there is some level of increased demand as price goes up, but the effect is not as strong. Additionally changes here are not as strong as changes in discount levels.

Effect_of_GF_Sales_on_Ind_GF

Expected GF Sales can drive up the Indicated GF as the grocery store sees potential money in the market. If they are selling a lot of fruit, they can continue to increase their indicated GF to match these higher sales. Similarly, if sales go down they can shrink their fruit section and repurpose it for other more profitable wares.

Effect_of_Marketing_on_Ind_CF

This is the effect of Marketing on Customer Demand. As the marketing increases the customers' interest in the product will grow.

Effect_of_Sales_on_Discounts

If Sales are low, or not where the store would like them, they can introduce new discounts, weekly discounts or coupons, to increase customer demand. They will see some drop in money related to those individual items momentarily, but they will usually reclaim this loss via accompanying purchases, bulk purchases of these items, or by maintaining higher appetite for the product.

Effect_of_Sales_on_Marketing

If sales are not where the store wants them to be they will increase the amount of marketing campaigns that they will run. These marketing campaigns will often run in tandem with other attempts to increase sales.

Expected_CF_Outflow = Average_CF_Consumption+Average_CF_Loss

Unit = kg/day

Expected CF Outflow (Expected Customer Fruit Outflow) is a function of Expected CF Consumption and Average CF Waste. In order for GF Sales to properly refill the Customer Fruit stock the outflows need to be taken into account.

Expected_GF_Loss = SMTH1(GF_Loss, 7, Initial_Exp_GF_Loss)

Unit = kg/day

This represents the average expected loss generated by the grocery store per day. The average is taken over a 7 day time frame to represent that the grocery store is concerned with the average loss, and not any natural peaks or valley that could otherwise throw off their system.

Expected_GF_Outflow = Expected_GF_Sales+Expected_GF_Loss

Unit = kg/day

Expected GF Outflow is a function of the Expected GF Waste and Expected GF Sales. Grocery Stores keep data about the amount of waste and sales that they generate so they can use these metrics to approximate the outflow. This combined with the Gap mechanism will help the Grocery Fruit stock stay at the desired level.

Expected_GF_Sales = SMTH1(GF_Sales, 7, Initial_Exp_GF_Sales)

Unit = kg/day

This represents the average expected sales of fruit from the grocery store per day. The average is taken over a span of 7 days so the grocery store won't respond to strongly to passing peaks or valleys.

GF_Cost = 30

Unit = kroner/kg

A rough reflection of the price of fruit. It is mostly used to reflect how much fruit either the grocery store or the customers want to purchase.

GF_Fruit_Shelf_Life = 7

Unit = day

The average shelf life of fruit while it is at the grocery store. This shelf life is longer than the customer fruit shelf life because it is earlier in the life cycle of the fruit so there is more time before it spoils.

Additionally, discounts applied due to expected grocery fruit waste levels will allow the grocery fruit shelf life to eat into the customer fruit shelf life.

For example, bananas that have begun to spot or turn brown, will be discounted to sell to the customer. This banana will have spent much of it's edible life at the grocery store, resulting in a shorter shelf life at the customer and potentially inedible parts upon purchase.

GF_Loss_Cost = Expected_GF_Loss*GF_Cost

Unit = kroner/day

This represents the monetary cost of the fruit that was lost. It is the cost of the fruit times expected waste amount. This could be a point of intervention to cut back on GF loss.

GF_Markup = 1.5

Unit = dmnl

This is the markup in cost of fruit for the customer. The grocery store will rarely sell goods at the cost they purchased it at. They need to recoup the cost of the food as well as pay for overhead costs.

GF_Price = GF_Cost*GF_Markup

Unit = kroner/kg

This is the price that the Customers normally pay for their fruit.

Indicated_CF =
Normal_CF*Effect_of_GF_Price_on_Ind_CF*Effect_of_CF_Consumption_on_Ind_CF*Effect_of_CF_Loss_on_Ind_CF*
Effect_of_Marketing_on_Ind_CF*Effect_of_Disc_on_Ind_CF

Unit = kg

This represents the change in Demand in Fruit across all the customers of this grocery store. This drives up the Target CF which provides a target for the actual fruit stock in Customer Fruit (CF).

Indicated_GF = Normal_GF*Effect_of_GF_Cost_on_Ind_GF*
Effect_of_GF_Loss_Cost_on_Ind_GF*Effect_of_GF_Sales_on_Ind_GF

Unit = kg

Indicated GF is the direction the Grocery Store is planning to move the Target GF.

For example, if costs are low, demand is high, then they will have a desired stock level that is higher than the present Target GF and this value will reflect that.

Alternatively, if waste is too high that it results in unbearably high costs, the indicated GF will drop driving down the Target GF and thereby the Grocery Fruit (GF).

Indicated_Target_GF_Gap = Indicated_GF-Target_GF

Unit = kg

This is the gap between the present Target GF and the Indicated GF. When greater sales are expected this gap will grow, when sales are not growing this gap will be small.

Initial_Exp_GF_Loss = 6.5

Unit = kg/day

This represents the initial amount of loss expected from the grocery store daily.

Initial_Exp_GF_Sales = 42

Unit = kg/day

This represents the initial expected sales of Grocery Fruit.

Marketing =
Normal_Marketing*Marketing_Schedule*Effect_of_Sales_on_Marketing

Unit = ad/day

This represents the current level of marketing being used. It is a function of the normal marketing level and the effect of expected sales on marketing.

Marketing_Schedule = (1-Calendar_Switch)+Calendar_Switch*(1+STEP(0.2, 80)-STEP(0.2, 100)+STEP(0.2, 180)-STEP(0.2, 200)+STEP(0.2, 280)-STEP(0.2, 300)+STEP(0.2, 380)-STEP(0.2, 400)+STEP(0.2, 480)-STEP(0.2, 500))

Unit = dmnl

This represents the normal level of marketing used by the grocery store.

Normal_CF = 40

Unit = kg

This is the Normal Indicated CF, the effects all work as multipliers on this base level of Ind CF.

Normal_CF_Consumption_Rate = 0.8

Unit = 1/day

This reflects the normal rate of consumption by customers. If consumption rate goes up it is a reflection of a larger customer stock due to increased demand.

Normal_Discount = 1

Unit = dmnl

This represents the normal discounts that are applied. The normal cost is 100% of the GF Price, so the discount is 1* GF Price or 100% * GF Price. This value will be modified by the Effect of GF Loss on Discount and Effect of Sales on Discounts in the Discount variable.

Normal_GF = 45

Unit = kg

This represents a base level Indicated GF. If all of the effects on Indicated GF are equal to 1, then the Indicated GF will be equal to Normal GF.

Normal_Marketing = 1

Unit = ad/day

This represents the normal marketing scheme that is applied. The normal marketing plan is 1 ad/day, but can it can be modified by other variables. The exact value is not as important as the understanding of how the impact develops when ads are added or removed.

Refill_Fruit_Time = 1

Unit = day

The amount of time between visits to the grocery store to refill Customer Fruit. Because Customer Fruit represents all Customers of the store these visits will occur daily, as there will always be some customers purchasing fruit.

Restock_Time = 1

Unit = day

The amount of time required for new stock to arrive at the Grocery Store to restock it towards the Target GF level.

Target_Actual_CF_Gap = Target_CF-"Customer_Fruit_(CF)"

Unit = kg

This is the gap between the Target CF and the actual stock Customer Fruit (CF). This gap can grow as the Customer Fruit stock gets depleted via eating or wasting fruit, or it can grow as the Target CF increases.

Target_Actual_GF_Gap = Target_GF-"Grocery_Fruit_(GF)"

Unit = kg

Target Actual GF Gap is the gap between a fully stocked grocery and the actual stock present at the grocery store. This gap can grow as the actual stock gets depleted daily, or as the Target GF grows to reflect greater expected GF sales

Time_to_Update_Target_CF = 10

Unit = day

This is the amount of time required to update the Target CF to match the Indicated CF.

Time_to_Update_Target_GF = 15

Unit = day

This reflects the amount of time required to update the Target GF to the new Indicated GF. These changes are more complicated than simply restocking bananas or grapes, and therefore the time to update is greater.