UNIVERSITY OF BERGEN

A system dynamics approach to study the sustainable reduction of a restaurant food waste

By

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Durga Devi Giri

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Abstract

Food is essential for living creatures. Food wastage is a serious problem in a restaurant. Similarly, food waste comes along with the food demand, food preparation and food consumption. Food waste is mostly found in every sector such as households (43%), restaurants (40%), food production (2%), and farms (6%). Restaurant service sector is the third largest source of food waste covering almost 40% according to the Food Waste in America in 2022. The problem of managing food waste in a restaurant is a complex process and includes various factors. The purpose of this study is to examine the food waste produced by a restaurant and overview the research strategy which can be used for making policies to reduce the food waste in a restaurant. The restaurant that this thesis study is considering has zero historical data, therefore the system dynamist has estimated 10 kg of food waste per day as initial food waste. The study has been conducted with three phases: supply phase, production, distribution and consumption phase and waste management which rules the total food waste model. During the simulation, the problem statement was determined as per day basis. The model structure was made as respective to their relevance as one is related to next step. After the problem was found the implication of two kind of policies were introduced. The restaurant implements Policy 2 decision- making as findings which is responsible for solving the problem of the food waste in long run.

Keywords

Food waste, Restaurant, System Dynamics

Chapter 1: Introduction

Food is necessary for all human beings to live. One part of the world doesn't have enough food to eat while the other part of the world is throwing away food. In restaurants we order food, we do not finish food, if we don't like it, we throw it away. According to the Food and Agriculture Organisation of the United Nations, more than 1 billion tons, more than a third of the total of food produced, are wasted every year while 800 hundred and 15 million people still suffer from chronic hunger. The problem has been huge, and the solution is possible.

There are two different ways to describe wasted food. First, food waste and food loss are the second ways to describe. Food loss and waste undermine the sustainability of our food systems. When food is lost or wasted, all the resources that were used to produce this food - including water, land, energy, labour, and capital - go to waste.

Food waste and food loss has been one of the topmost problems especially in restaurants. It is because the food service sector is unable to manage the daily food waste in their restaurant. Annual global food waste is estimated to be around 1.3 billion tons, which is equivalent to about 30% of total food products intended for human consumption (global analysis). The food service sector (restaurant) is the third-largest food waste source (covering 18% of the total) after households (Betz et al. 2015).

According to a recent report generated by US restaurants (Gunders, Dana, 2017), half a pound of food is wasted per meal in restaurants, whether it's from what is left on a customer's plate, or in the kitchen itself. Approximately 85% of the food that isn't used in a typical American restaurant is thrown out while only a small percentage is recycled or donated.

Food is lost or wasted for various reasons: bad weathers, processing problems, overproduction, and unstable market cause. Food loss is the main problem for the restaurants with all these reasons such as storage houses with expiration rate. Different sectors are doing the best to solve or prevent food waste and loss such as the Hong Kong Government is has adopted Organic Waste Treatment Facility (C. K.M.lee, C. K. Kwong). However, there is always something missing which increases the problem.

1.1 Brief history of restaurants food waste

Food waste is a global problem which receives attention from government, non-government organisations, firms, and society. Each year, there are around 30- 50% of edible parts of food produced for human beings globally (Gustavsson, Cederberg, Sonesson, Van, &

Meybeck, 2013). Food waste and food loss by its very nature, is extremely inefficient and has a negative impact on the environment, economic and social sector (Lipinski et al., 2013).

Food waste occurs at different stages of the food value added chain. All around the world approximately 1.3 billion tons of food designated for human consumption is either lost or waste (FAO, 2013). Restaurant food waste is approximately 40%. All government and private sector have been slow to encourage restaurants to implement food waste prevention strategies and measures. The Food and Agriculture Organization of United Nations (UNFAO) study on food waste did not specifically estimate the amount of food waste produced globally by the restaurant sector; however, other studies indicate that, this sector is very related and significant because the hospitality and catering sector of Europe is contributing 14 percent in the whole food wastage of Europe (Gustavsson et al., 2011). This problem should be a major concern for individual restaurants as well as high level. It is because, in accordance with consumer interest, consumer visit restaurant, they taste food if they like it, they will eat it and if not, it is counted as food waste. But consumer is not responsible of the total loss. It is restaurant problem. However, restaurants are gradually moving towards preventing loss and implementing preventive approaches to reducing food waste.

1.2 Problem Description and Problem Definition

Food waste is a relevant problem all over the world. Number of researchers such as (Rehman, 2020), (Gunders, Dana 2019) are observing the process of food waste generation that occurs during food raw materials supplies of restaurants and the wastage during preparation of food and consumption. This study explains all the supply chain factors that lead to the food waste generation. The study considers the real-world process of food waste in a restaurant. This is the view of an employee who studies restaurant food waste per day and tries to provide solutions to reduce food waste. Everyday restaurant food waste increases with the increasing number of customers. The ordered food by the customer leads to the demand for food raw materials in a restaurant. Everyday transaction of food raw materials and the food ordered by the customer leads to the actual gap which is the cause of maximum food waste in a restaurant. It is because the factor that leads to the maximum food waste in a restaurant is the great number of customers and their demand. A restaurant service is prepared for the estimated customer of 30 people which varies and every day the flow of customers fluctuates with other exogenous variables. The preparation of food in the kitchen also varies with the flow of customers. Similarly, the more the customer, the more the demand of food, the more the storage and the more the food waste. The reinforcing loop increases the food waste behaviour in the simulation.

Focusing on these sectors of the food supply chain, kitchen culture and staff behaviour such as over- preparation of food, improper ingredient storage and failure to use or not sold food scraps and trimmings can also contribute to food waste (Gunders, Dana 2019). The food consumed by customers and leftovers cannot legally be reused and donated due to health code restrictions.

To properly proceed with the problem definition, it is important to have clarity on how the indicators will be used within the context of this model and analysis. It is most especially as there is real data of restaurants, the protocol and confidentiality. According to the model development, all the food waste from preparation, storage to expiration and consumption referred to the total food waste and the model documents will discuss the reasons throughout.

The problem this thesis study aims to address is food waste, but due to the ethical perspective of a restaurant, data on the topic is scarce. As such, the problem is more precisely to develop a hypothetical framework of the system but also with real experienced data which would help to build a more data driven model in future and can be used by other viewers. The study is tested and analysed with the specific policies if needed in the real-world implementation.

1.3 Research Objectives and Research Questions

The main objective of this master thesis is to understand and find out, what are the reasons behind the food wastage in a restaurant and making strategies and finding out the practices through which the restaurants can reduce the food waste if the restaurant manager implements those strategies. The model will make clear that all variables are relevant, allowing for policies to be tested and implemented in future in a restaurant that fully value and utilize complexity of the system and the loops that are established through the model development.

This model and analysis would aim to address i.e.,

1. **What is the main cause of restaurant food waste?**
2. **How can a restaurant food waste can be reduced sustainably?**
3. **And what effective policies would be used by restaurant managers to minimise food waste?**

With the aim to analyse restaurant waste there is less availability of data, historical data is not presently available, however the study will show the clear vision of restaurant food waste and helps to find out the best policy or provides insight to reduce daily food waste. It could be from any one such as chef, manager, supplier, and staff.

1.4 Key Performance Indicator

To answer this research- question a closer look should be given to one of the most important key performance indicators, namely total food waste.

As we can see in Figure 1, initially there is a linear growth of food waste in a restaurant (green line= without policy). The present situation of food waste in a restaurant is growing day by day. The study lacks the historical problem behaviour and creates a hypothetical reference mode to evaluate and carry out the thesis study. The effect of food waste is clearly affecting the economy of a restaurant. It is because most of the waste were from storage house and food expiration. The restaurant owner is buying food raw materials without having proper information from the responsible person, which leads to over supply and increase more waste. Therefore, to prevent the restaurant from the loss, the study has been taken. The challenge of food waste reduction includes food waste prevention, preservation, and awareness. The study examines the major reasons for increasing food waste in a restaurant and finds out the policy and implements those policies to prevent restaurants from food waste. The red line= with policy shows the reduction of food waste over time. The problem has been described in previous paragraph 1.2, and now the overall model would work according to problem description, research objectives.

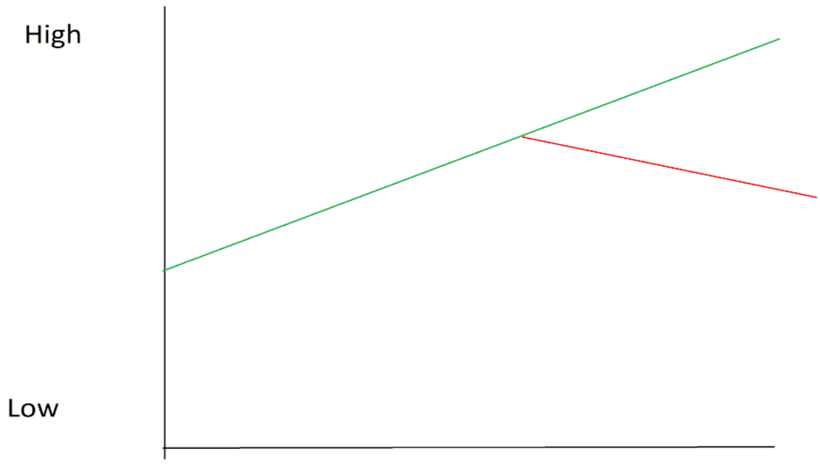

Figure 1: Reference mode of total food waste

The figures show the expected behaviour when no policy is there and when there is a policy implemented. The historical trend is derived from hypothetical daily activities of a restaurant. This figure has no source and is purely hypothetical.

1.5 Research Strategy

This is a model-based study which uses quantitative system dynamics modelling and simulation- based analysis. Simulation models allow us to represent explicitly, coherently, and consistently also theoretically. In that way, it is possible to develop the model, facilitate a variety of formal analyses, review various literature on the same topic and enhance the knowledge on food waste as a serious problem and try to solve the problem by assessing the impacts of strategies and policies intended to improve the restaurant profit.

1.6 Literature Review and Research

The backbone of the qualitative and quantitative data for the constructed system dynamics model is obtained from the extensive analysis of the literature related to the defined problem. As mentioned in paragraph 1.3, the model uses the quantitative data analysis strategy. This paragraph provides an overview of the literature used throughout the study. This thesis study provides a clear overview of daily restaurant activities that lead to food waste from demand of food raw materials to preparation of food and service and consumption. The main influence of having this study is the real work experience. This study draws reference from System Dynamic Model for Restaurant’s Food Waste in Surabaya (Sakura Ayu Oktaviasari, Iwan Vanany and Diesta Iva Maftuhah, 2021) to understand the overall framework of restaurant food waste and implementation of policy to reduce waste. The literature talks about the three scenarios developed in the study to reduce the food waste that includes increasing the frequency of purchases, implementing a fine system for customers who leave scraps and cooperating with the food bank. In addition, the research shows that restaurants should start to consider collaborating with food banks to donate their serving losses to those who need it.

During the period of literature review, it was found that the food waste is generated in each sector such as supply sector (demand of food raw material, available raw material for preparation of food), preparation sector, consumption sector. It is impossible for a restaurant not to produce any food waste at any costs. Food waste generation does not indicate individual faults since it occurs due to different comprehensible and inevitable reasons. As food waste is categorised in two groups such as pre- consumer and post- consumer food waste, the causes of them are different. Pre- consumer food waste is often caused by undefined demand, overstocking, inefficient production, poor communication, staff behaviour, unskilled trimming, over merchandising, food safety., and postconsumer includes last portion sizes, inefficient service model and customers menu acceptance which is mentioned in the book name as Green Food & Beverage Services written by (Baldwin & Shakman, 2012).

1.7 Model Hypothesis

The dynamic hypothesis is based on literature reviews, interviews with restaurant owners and other information sources. The findings are represented in the down below simplified causal loop diagram.

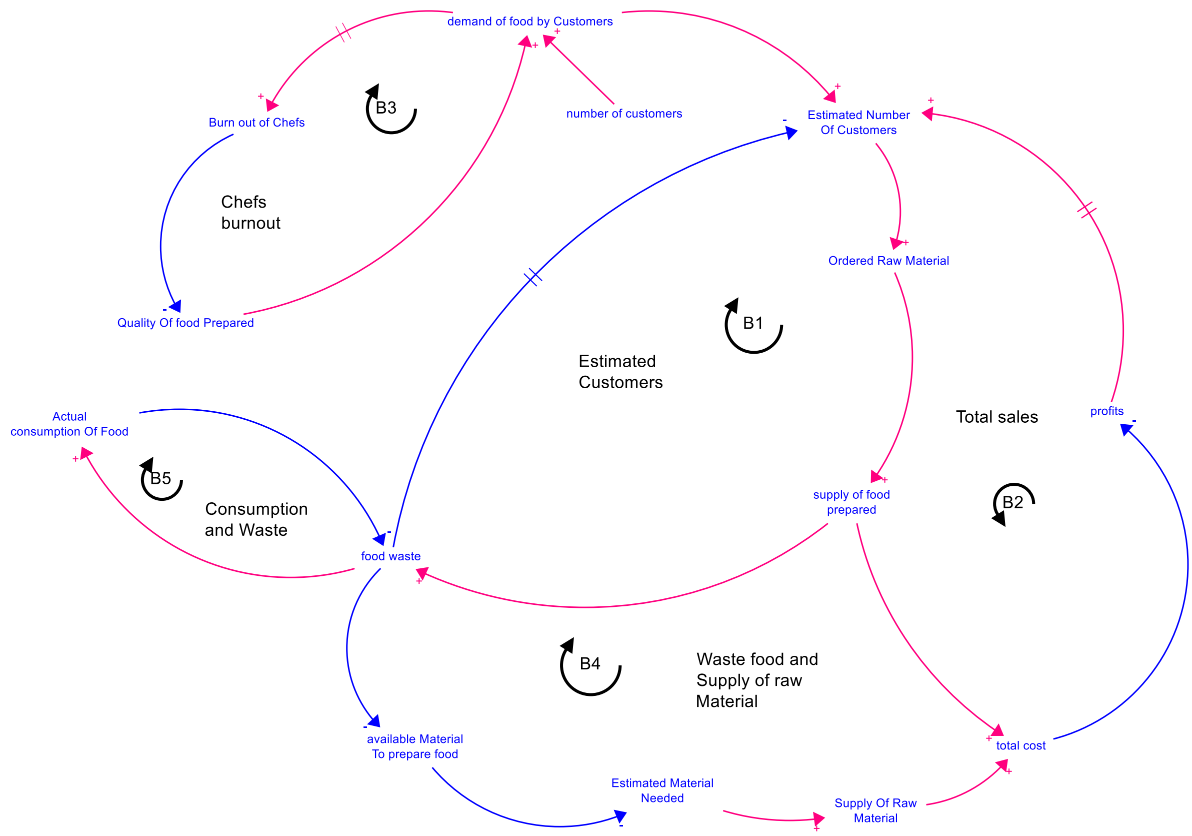

Figure 2: Simplified Causal Loop Diagram

The relationship between the variables that have been identified is illustrated in the causal loop diagram. Causal loop diagrams represent the way in which the system works. Therefore, the relationship of all variables is explained in a causal loop diagram. In the CLD the variables are connected by an arrow which shows the variables influence each other. Each arrow is given a polarity, either positive (+) or negative (-) depending on the interaction between them. The CLDs shows the flow of food raw materials from supplier to the consumption phase and finally shows the food waste generation. The number of customers leads to the total food waste in a restaurant measured per day. However, the total food waste measured in this thesis includes multiple factors, such as expiration of food raw materials during storage, expired prepared food and customers' food waste rate.

The feedback loops are described in below figures:

Estimated Customers *B1: Estimated number of customers Ordered raw materials→ supply of food prepared→ Food waste*

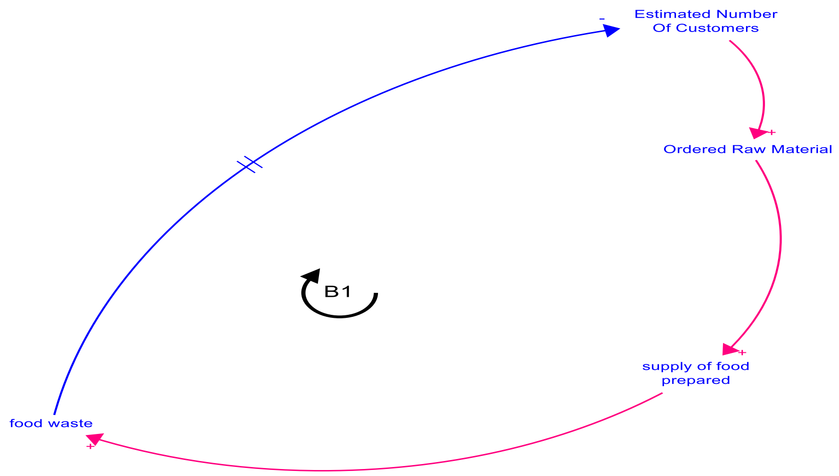

Figure 3: Estimated customers balancing loop

B1: When managers estimate an increased number of customers that will cause an increase in ordered raw materials, then there will be an increase in the supply of prepared food and eventually that will cause more wastage of food.

Total sales *B2: Estimated number of customers Ordered raw materials→ supply of food prepared total cost → profits*

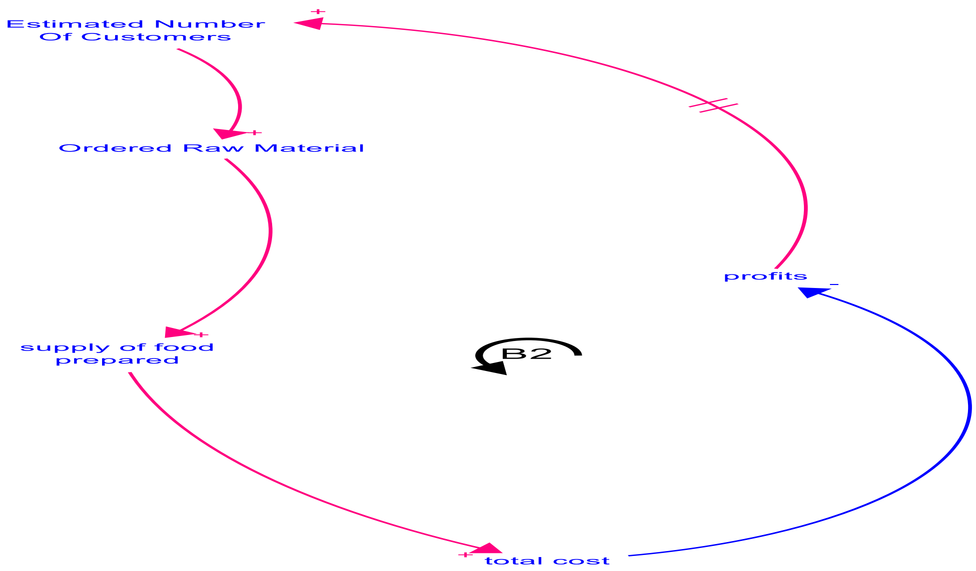

Figure 4: Total sales balancing loop

B2: When managers estimate an increased number of customers that will cause an increase in ordered raw materials, then there will be an increase in the supply of prepared food, and that will cause an increase in expenditures and total costs in general. After that there will be a decrease in profits, then the managers will estimate a lower number of customers when they realise the lower profits after a delay of time because this process takes time as profit accumulates.

Chefs Burnout *B3: Demand of food by customers Burnout of chefs Quality of food prepared*

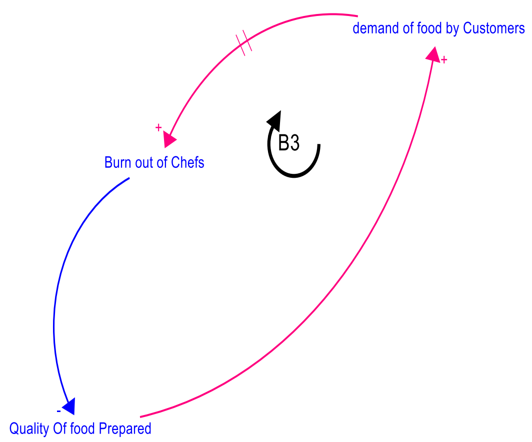

Figure 5: Chefs burnout balancing loop

B3: This feedback loop shows the long-term relationship between chefs burn out which decreases, when there is a higher demand of food in the restaurant, and that causes a decrease in the quality of food prepared, then the demand of customers will decrease as there is lower quality the customers experience.

Supply of Raw materials and food waste *B4: Estimated number of customers Ordered raw materials→ supply of food prepared→ Food waste Available material to prepared food Estimated material needed Supply of raw material → total cost profits*

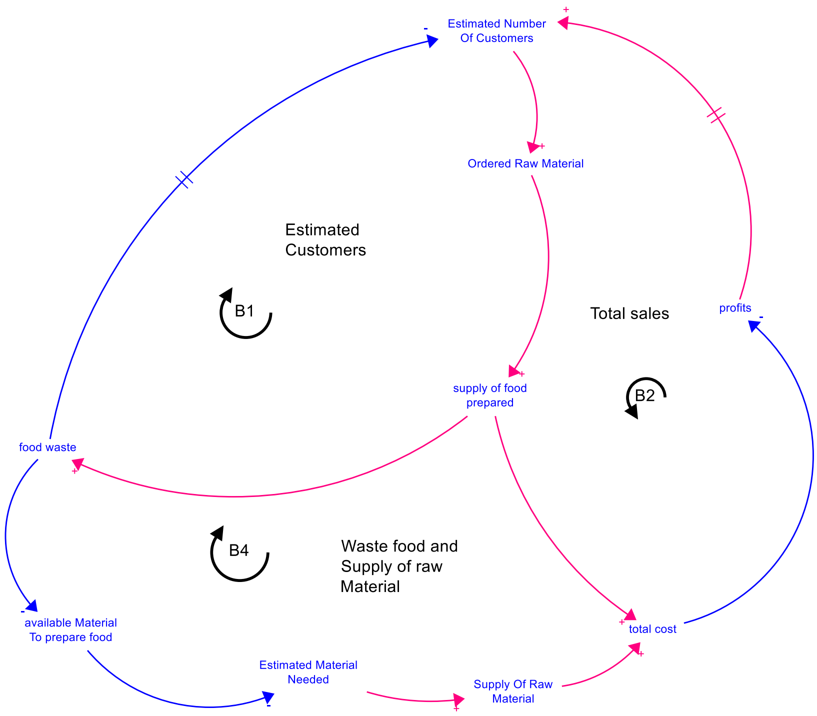

Figure 6: Supply of raw materials and food waste balancing loop

B4: When managers estimate an increased number of customers that will cause an increase in ordered raw materials, then there will be an increase in the supply of prepared food, and that will cause more wastage of food. This will cause a shortage in available raw materials to prepare food and then managers will increase their estimation for needed raw materials and that will cause an increase in supply of raw material, then total cost will increase in general. Then there will be a decrease in profits, where managers will estimate a lower number of customers when they realise the low profits after a delay of time, because this process takes time and profit accumulates.

Consumption and food waste *B5: Actual consumption of food waste*

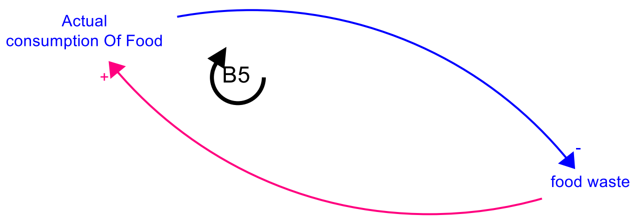

Figure 7: Consumption and food waste balancing loop

B5: this is an important feedback loop that shows that when actual food consumption of customers increases, that will cause a decrease in food waste. Then when there is an increase in the food waste, that causes shortage in the level of the stock of actual consumption of food ordered.

Additionally, not all the factors which lead to food waste are included in the model formulation, as there are model boundaries such as income and price sector, exogenous variables indicating chefs perceived behaviour to measure the exact pressure of his mind while preparing food, degree of store house and so on.

These gaps between the loops in the current thesis study will be covered using different data analysis methods and with the help of *literature* review.

With this balancing loop, the food waste generation is measured in the form of System Dynamics modelling behaviour. This is perhaps a future forecasting method to avoid the uncertainties and to be alert from the loss that might happen. Also, this is the method of studying the problem based on historical facts, functions, and system systematically to get the better version of decision.

Chapter 2. Model Description

2.1 Model Overview

The previous chapter described the problem definition and several issues related to the research designed that aimed at addressing the defined problem. This chapter describes the scope of the model and key concepts that lead to the model structure. The dynamics of relevant variables is generated based on simulation runs. According to this model description, the purpose of the model is explained.

This model structure is so simple for the reader who doesn't have any idea of system dynamics and simulation runs but can understand what generally the model is about without any inconvenience. The next section discusses how the chosen scope, gap and timing of the model translate into the model's assumption. Then the discussion will be more detailed describing the structure of the model's sector in terms of stocks and flow and major formulations. After that, the major loop formulation and their interaction will be described on the following step.

The model focuses on the dynamics of the sustainable reduction of food waste in a restaurant. Therefore, the model generates the dynamics of the following key variable:

- Total food waste in a restaurant

The model is then used for testing hypotheses allowing policies to prevent restaurants from generating huge amounts of food waste.

2.2 Model Assumptions

Assumption 1: System Boundaries

Two important variables are chosen to be exogenous in the model structure, namely:

- **Income is treated as exogenous.**

  We consider the important role of income is determined by the total sales per day. Total sales of food demand by customers and the rest of the food in kitchen sales at discounted prices are included in total sales determined total income of the restaurant.

- **Total cost spent on different sectors is treated as exogenous.**

  We developed an endogenous structure to include the effect of total raw material cost, total preparation cost and government expenditure to evaluate the total income of the restaurant. The restaurant income is measured after the subtraction between restaurant total sales and total cost. Therefore, it is simulated as a variable.

The total cost included the expenses spent on rent, electricity cost, labour salary, total cost spent on the supply of raw materials and government expenditure.

Assumption 2: Effect of perception on ordering

We assume that the effect of the perception is an information delay construction. Then the perception feeds into a graphical function determining the fraction of the food that the chef needs to order. This fraction is used to calculate the amount of food that gets ordered.

Assumption 3: Chefs burnout modifier

When there is an increase in the demand of raw material, that will cause chefs to be pressured to cook more food, and that gives them less motivation to prepare food. This modifier is an important indicator that when it increases it causes a decrease in the quality of food, and when it decreases, the quality of food will increase. This function is presented graphically to calculate qualitatively.

Assumption 4: Before cooking raw materials expiration fraction

We assumed that it is the graphical function which shows the exponential growth of material expired before cooking. This is true also restaurants must be prepared for all kinds of days either busy or with no customers. So, maximum or on an average preparation is must and, in the context, sometimes high customer and sometimes no, that leads to the exponential growth of food storage day by day. This shows the food waste is high.

2.3 Model Structure

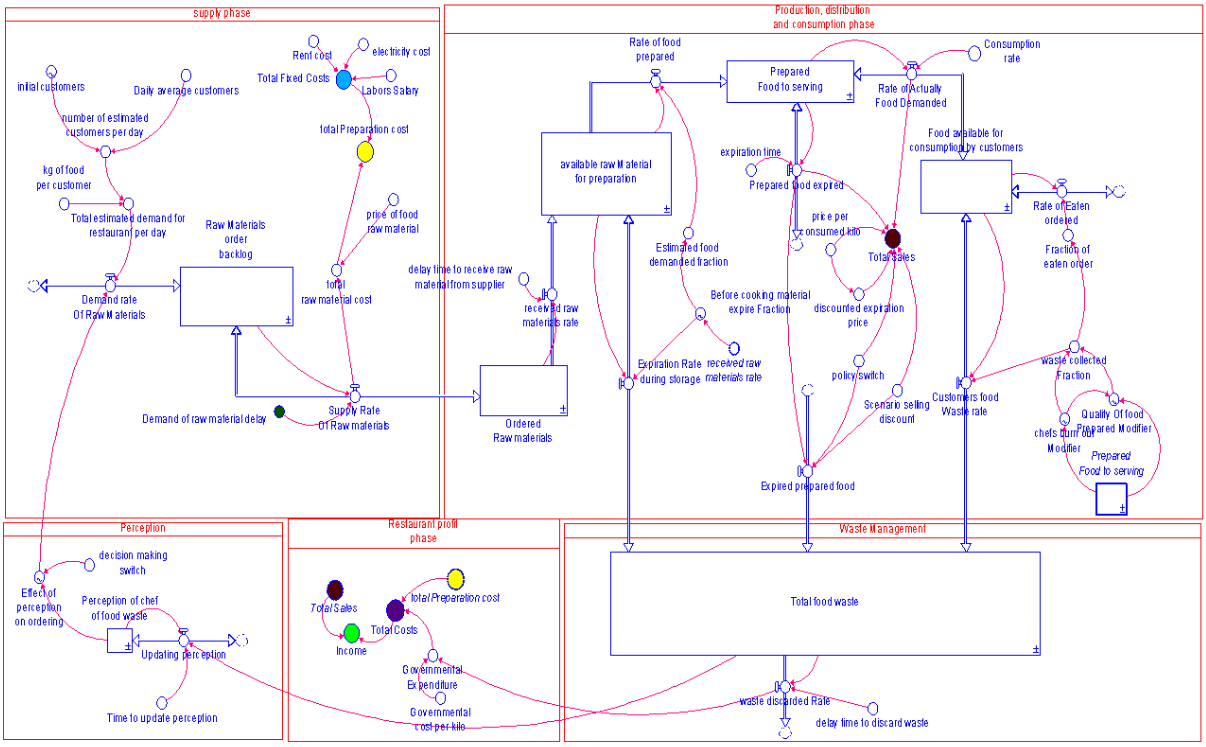

Figure 8: Model Overview

The model has three main components: supply phase, production and consumption phase and waste management. The first one is composed of a supply chain of food raw materials, which recreate the food waste generation over time. The production and consumption phase are represented by the variables, *prepared food to serve, food available for consumption by customers*, and the waste management phase are represented by the *total food waste*, as shown in figure above.

The model structures are based on other research done on similar topics before. The supply phase, production and consumption phase, and waste management has food supply chain generation structure following the literature from *System Dynamic Model for Restaurant's Food Waste in Surabaya Sakura Ayu Oktaviasari, Iwan Vanany and Diesta Iva Maftuhah, Proceedings of the International Conference on Industrial Engineering and Operations Management Sao Paulo, Brazil, April 5 - 8, 202.* Under this research, system dynamics method is used, the purpose of this study is to obtain an overview of the results of research strategy that can be used as a consideration for making policies to reduce food waste in food sector.

Following the relationships identified in the Causal Loop Diagram (CLD), there is a process which is associated with the possibility of waste that can be generated. Each sector are explained with figure and their connection as follows:

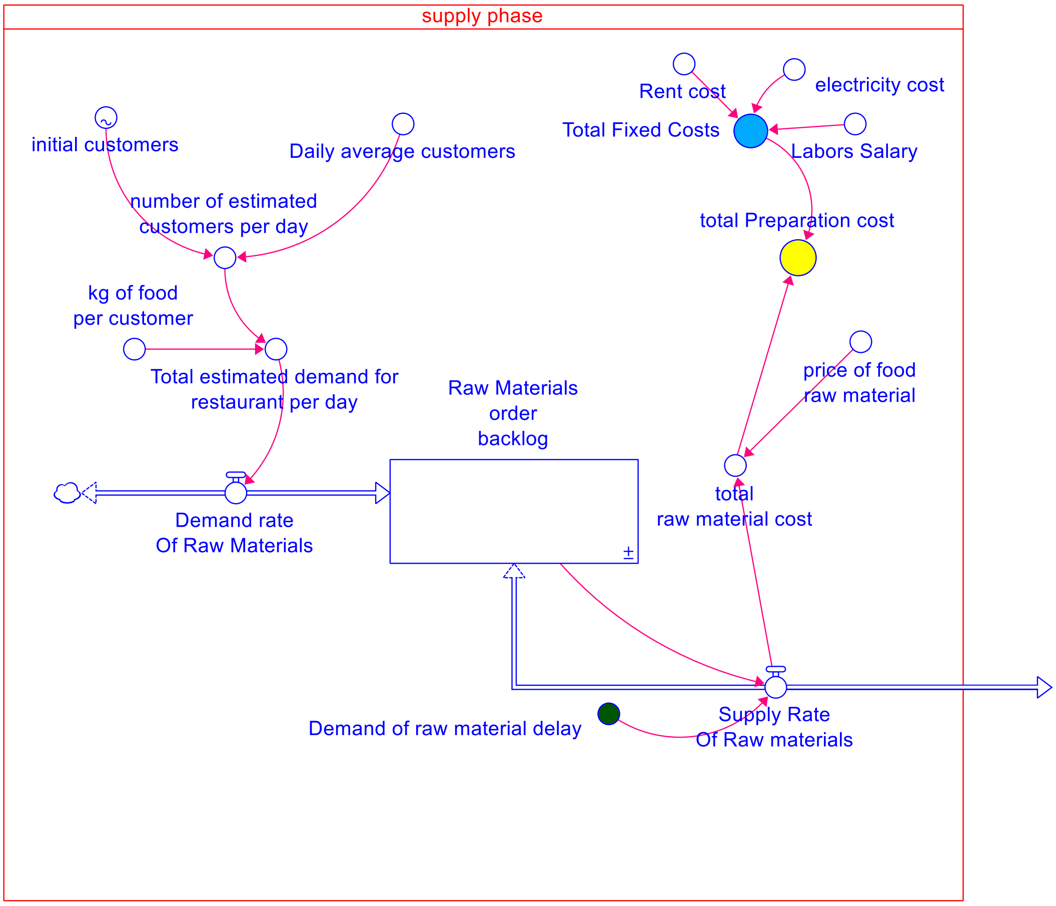

Figure 9: Supply phase

In figure 9 supply phase, the raw materials are ordered as per the number of customers in a restaurant per day. This includes the extra amount of food raw materials demanded for future. The decision-making process plays an important role which is termed as ordering food raw materials. In this phase, lack of active decision-making by restaurant owners or managers or chefs generates more food waste. Food waste occurs due to overstock and storage conditions.

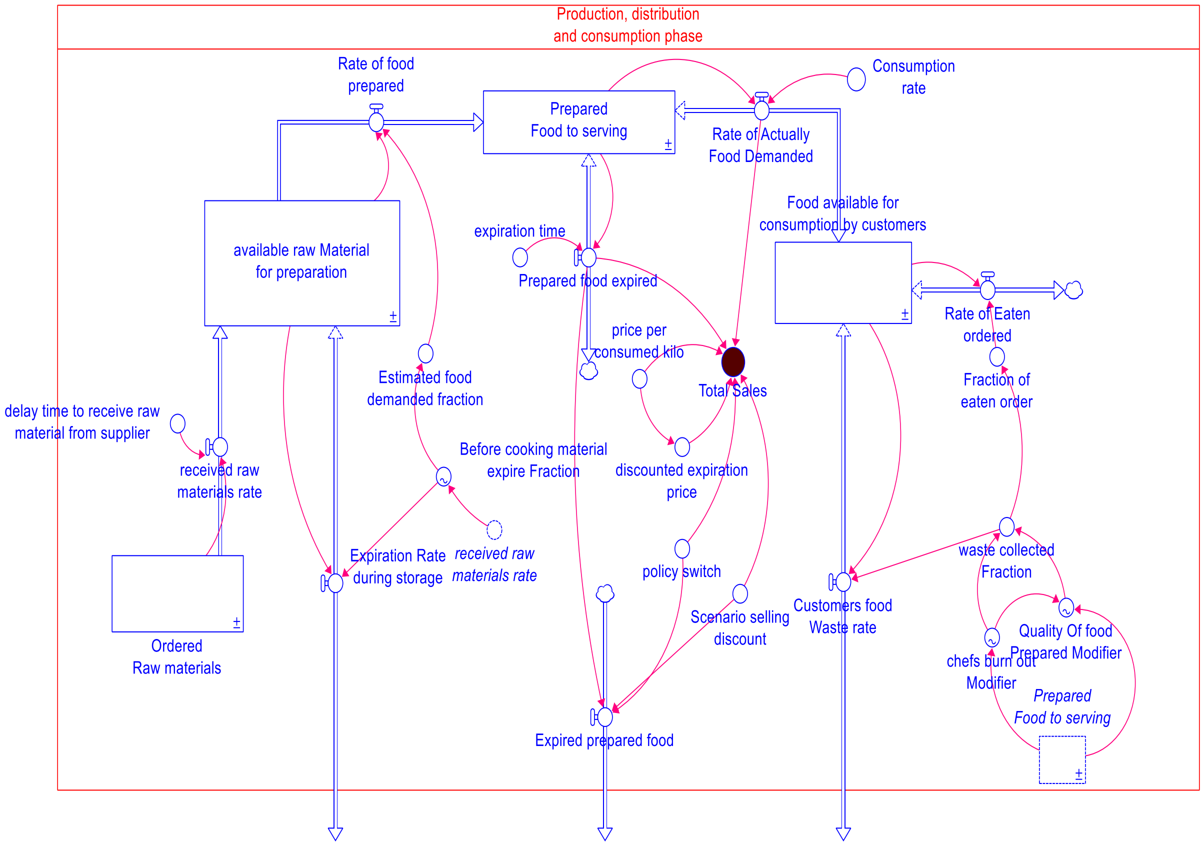

Figure 10: Production, distribution, and consumption phase

In the figure 10 production, distribution, and consumption phase, the food waste generated is influenced by the high demand for restaurants that is number of customers. Because of the higher demand, the more food that will be ordered and stored by the restaurant. This affects the amount of food waste due to storage which is termed expiration of food during storage. Similarly, production of food generates food waste termed as expired prepared food. The rest of the food produced by the restaurant is largely caused by the food leftover by customers in their plate. The consumption of food by customers also depends on the quality of food prepared.

In the process of quality food, it involves food taste, portion, and time limitation. Time limitation refers to the time taken to prepare the food ordered by customers. If the waiting time is high, it also decreases the food taste and customer preference to not eat that food. While the total food is prepared to serve, there is always some portion of food left in kitchen, to save from the loss, we decided to sell the rest food in discounted price. This would probably save restaurant food waste little in terms of quality check and suitability of food consumption.

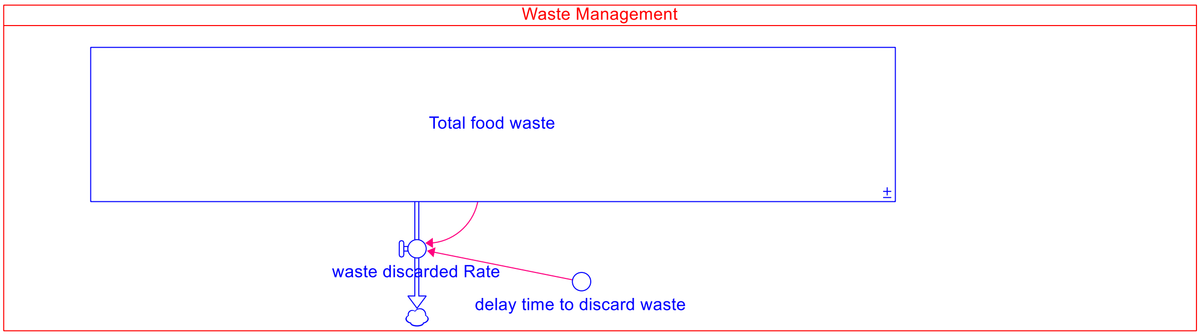

Figure 11: Waste Management

Therefore, in the model structure figure 11, we can see that there are three direct sources from Figure 10, of food waste in a restaurant. They are available raw materials for preparation expired while storage, prepared food to serve expiration rate and the customers food waste rate. This all leads to the total food waste.

The model structure assumes that initially the number of customers is declining every day. The restaurant was aware of the declining number of customers; however, the restaurant must be prepared for any situation whether there is less or high number of customers. The flow of demand rate of raw materials per day increases the raw material order backlog. The more the supply, in terms of less or more customers, the raw materials are stored in the store house. Everyday storage calculates the expiration of food raw materials during storage and creates food waste. The ordered food is prepared for customers where it is said 80% of food is served and 20% of food is wasted during preparation. The food eaten by customers is over 80%, we assume due to the quality of food or chef's burnout modifier, the food would be left by customers which generates food waste.

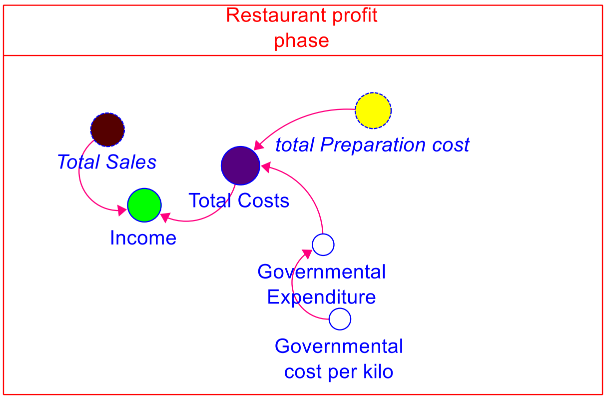

Figure 12: Restaurant Profit phase

In figure 12, restaurant profits are measured which shows the total income of a restaurant is generated from the total sales per day and total expenditure spent on total preparation cost. The total preparation cost includes total fixed costs such as rent cost, electricity cost, labours salary as shown in Figure 9. The total food waste is discarded where the restaurant will pay a government charge per kilo. The more the waste, the restaurant must pay more for the waste discarded by the government.

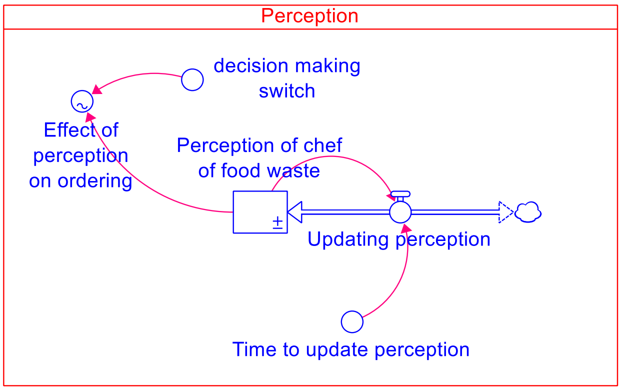

Figure 13: Perception

The figure is represented as Perception phase as shown in figure 13. This figure suggests that there is a stock called perception of chefs of food waste which refers to the chef perception towards the food waste. If there are high waste chefs would perhaps take more action to control the food waste. It is set as stock it accumulated over time. The phase also includes the effect of perception on ordering lead by the stock perception of chef of food waste. This means that the perception is an information delay construction. Then the perception feeds into a graphical function determining the fraction of the food that the chef needs to order. This fraction is used to calculate the amount of food that gets ordered. There is also a decision-making switch implemented as policy 2 which is explained in Policy section chapter 4.

Chapter 3. Validation

3.1 General considerations and model validations

Various validation tests were derived from the literature from Forrester (1980) to the internal and external validity of the model. Validation shows that the model is credible. The results and findings in the model are important to build the conclusions. The model validation is explained in different points below.

Test	**Explanation validity**
Sensitivity test	A sensitivity test is performed. A few variables that are considered sensitive are explained and shown Figure. Rest of the results can be found in **Appendix B**.
Extreme condition test	The extreme conditions test was performed evaluating the behaviour of different systems stock **Appendix C.**
Dimensional consistency	The variables within the model have units and no unit error detected. The results can be found in **Appendix D**.
Boundary adequacy	The model includes all the crucial variables regarding food waste that can affect the outcome **Appendix E**.
Structure assessment	The model considers some of the model assumption, can be found in **Chapter 2**, results can be found in **2.2**.
Integration error	Runs with the use of different integrations were conducted and showed no different behaviour, therefore the model was not sensitive to this. The results of these runs can be found in **Appendix F**.

Table 1: General considerations and model validations

3.2 Sensitivity Analysis

Sensitivity analysis is used in the system dynamics model to determine how “sensitive” a model is to change in the value of the parameters and to the change in the model structure. In this part of validation, we focus on parameter sensitivity.

Parameter sensitivity is usually performed as several tests in which a modeller sets different parameter values to examine how a change in a parameter causes a change in the behaviour of the stocks. Sensitivity analysis helps to build confidence in the model by studying the uncertainties that are often associated with parameters in models Forrester, J. W., Breierova, L., & Choudhari, M. (1996). An Introduction to Sensitivity Analysis. Sensitivity analysis is a useful tool while building a model as well as plays an important role in model evaluation. Because it shows how the model behaviour responds to change in parameter values.

In this section, we conduct sensitivity analysis on all the constant parameters presented in the model formulation. Here, few or highly sensitive parameters are represented with the explanation and rest of the parameters are presented in Appendix part.

Parameter 1: Expiration time after food prepared to be served

While running a sensitivity run on “expiration time” following an incremental distribution with a starting value of 0.5 days and ending value of 3 days, the result is as expected.

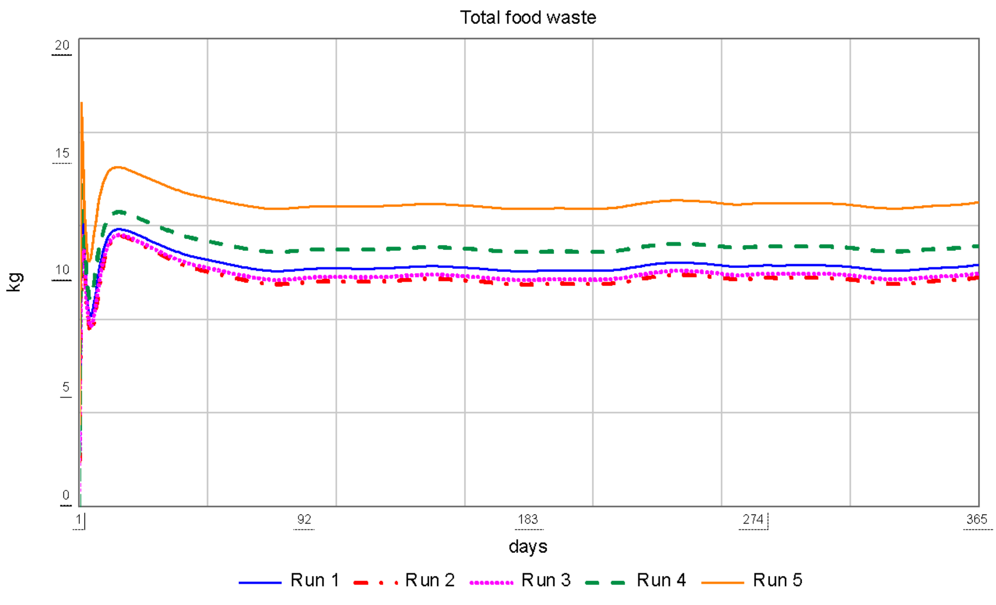

Figure 14: Sensitivity runs- expiration time

Parameter 2: Consumption rate

While running a sensitivity run on "consumption rate" following an incremental distribution with a starting value of 0.5 dimensionless/ days and ending value of 1 dimensionless/ days, the result is expected. Higher the consumption rate, lower is the food waste and vice versa.

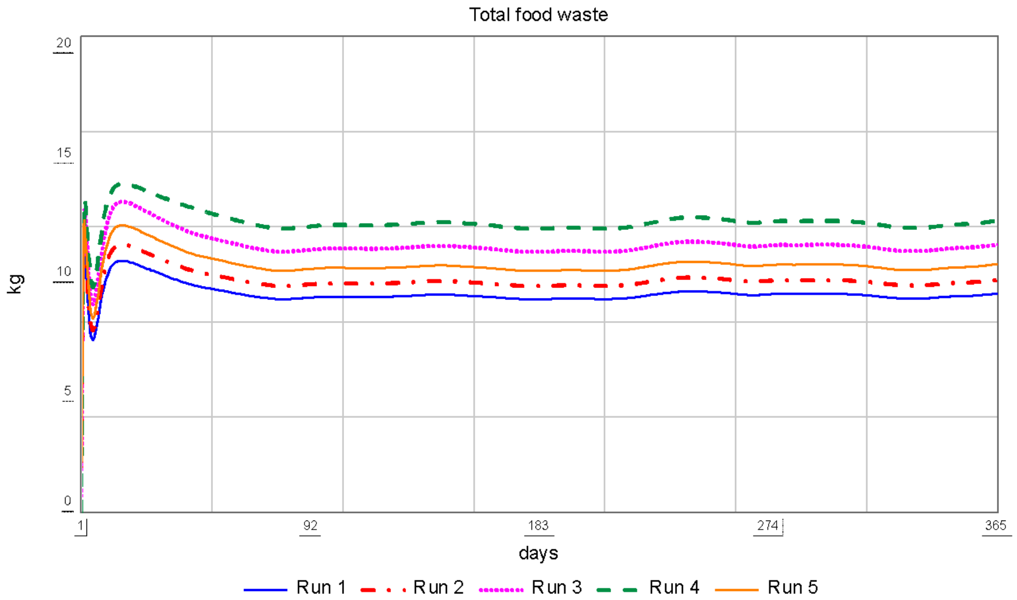

Figure 15: Sensitivity runs- consumption rate

Parameter 3: Delay time to discard waste

While running a sensitivity run on "delay time to discard time" following an incremental distribution with a starting value of 0.5 days and ending value of 2 days, the result is expected. Higher the delay time to discard waste, higher the food waste in dump side and vice versa

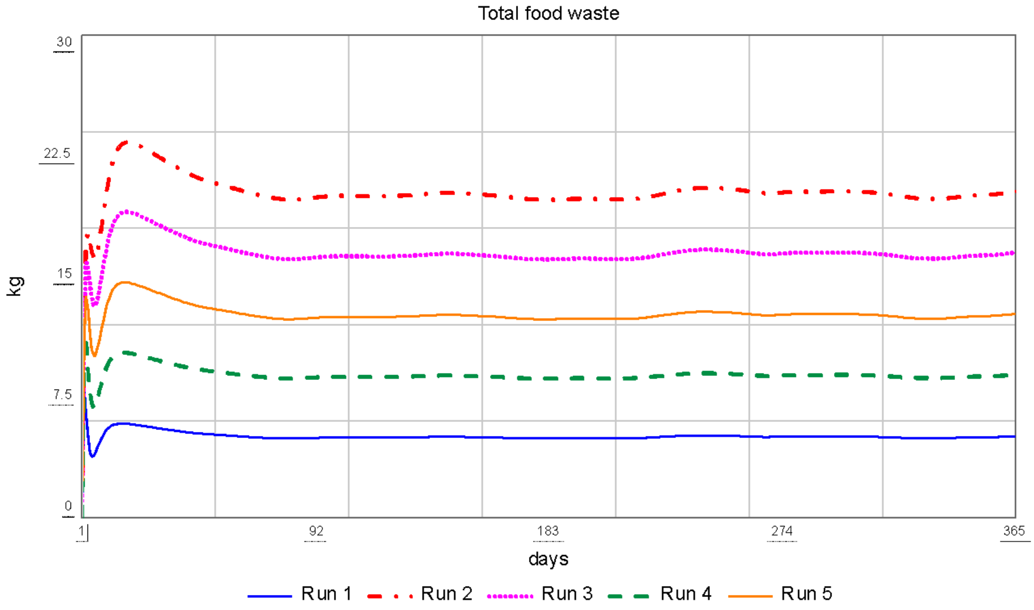

Figure 16: Sensitivity runs- delay time to discard waste

3.3 Base Run

The base run is the model simulation in "business as usual" scenario. This means that the modeler starts the model simulation with the initial values. The food waste generation is the core of the model, and the initial value of the restaurant food waste corresponds to the real data from day 1. The main variable of the model is displayed in the below graph which the total food waste in a restaurant. The total food wastes follow an increasing growth behaviour from day 1 to day 20 from 5kg to 11.7 kg per day, as it expected because of the combination of expired food raw materials, expired cooked food and consumer leftover. Then the food waste behaviour shows sudden decrement from day 20 with 11.6 kg per day because of the balancing loop which helps to decrease the food waste generation. Then it continues to fall from day 21 with 11.6 kg to 9.89 kg up to day 83. After that the behaviour shows an interesting growth from day 84, 9.9 kg up to day 163 with 10 kg. After day 164, the food waste decreases from 10 kg to 9.2 and the pattern of increasing and decreasing of food waste continues whole year. It means the food waste growth or reduction is driven by the variable namely number of customers.

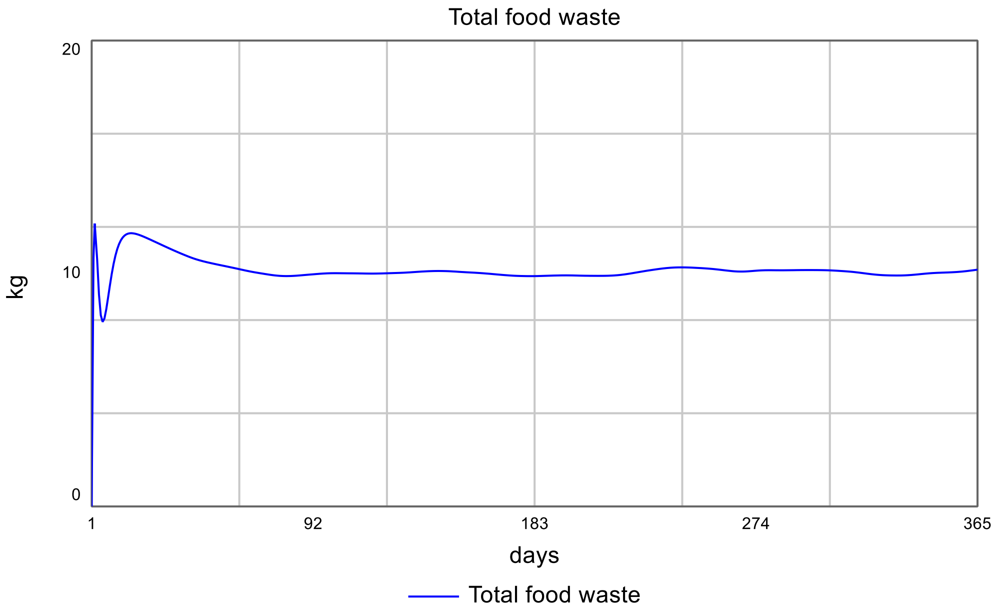

Figure 17: Base run: Total food waste

There are various factors responsible for the growth of food waste such as number of customers, ordered food raw materials in the store house expired, the cooked food expired and the consumer leftovers. The figure shows that there is not so much difference shown initially but is interesting that food waste is a problem for a restaurant.

After referring to the simulation run till 365 days one could clearly see that there is need for the policy interventions as the problematic behaviour shows growth and fall over time. If a restaurant could save some from unnecessary food waste pattern, it can save a lot. The awareness is must in this problematic behaviour because one can decide the amount of food raw materials that they can order. As there is nothing, we can do in customer side, it depends on customer they will consume all served food or not.

During the simulation period, we find an interesting factor that could reduce the food waste and increase the total sales of restaurant. We defined as prepared food expired variable which referred the food prepared to serve, the whole food is not served, and rest is counted as food waste. Whereas it is good idea to collect such and sell it in discounted price. However, while making that conclusion one must realize that the exogenous parameter namely discounted expiration price has been considered to remain constant over model run time which may not be realistic. Therefore, we try to examine and below shared are the results from 3 different scenario analysis i.e.,

- Scenario 1: 100%, less food waste

- Scenario 2: 60%, less food waste
- Scenario 3: 40%, more food waste

Scenario selling discount 100%, 60% and 40%: While running simulation having all other parameters value constant as base run. This scenario supposed that the food waste continues showing same behaviour as base run **Figure 17.** The results are shown in below **figure 18**. It is because this scenario does not provide expected behaviour without policy implementation. It is because the scenario is based on policy switch to sell the food at discounted prices. Therefore, we create two different policies namely Policy 1 and Policy 2 to reduce restaurant food waste sustainably.

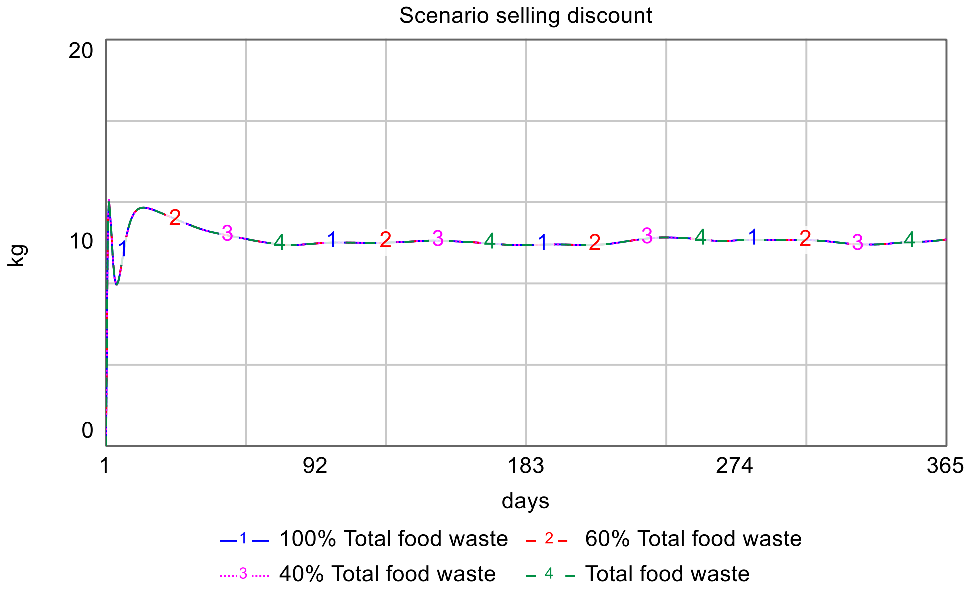

Figure 18: Base run: Scenario selling discounted price

3.4 Policy Implementation

There are two policies identified during model development, explained below:

1. **Policy 1- Selling food at discounted prices-**

   This policy is drives by policy switch option between 0 to 1. As shown in **figure 9,** compared to base run with scenario, the behavior has shown as increasing and decreasing over time, then decreased with small amount and increased with same process, somewhere stabilize thereafter over 365 days (about 12 months) of simulation period after an implementation of Policy 1. This policy is interfering with balancing loop B5 i.e., Actual consumption and Food waste. The loop shows that prepared food to serve and food waste are indirectly proportional to each other, one is increasing and the other decreases. Policy 1 interferes with the B4 loop between food waste and prepared food to serve, because it is taking a factor out by selling it into a different market.

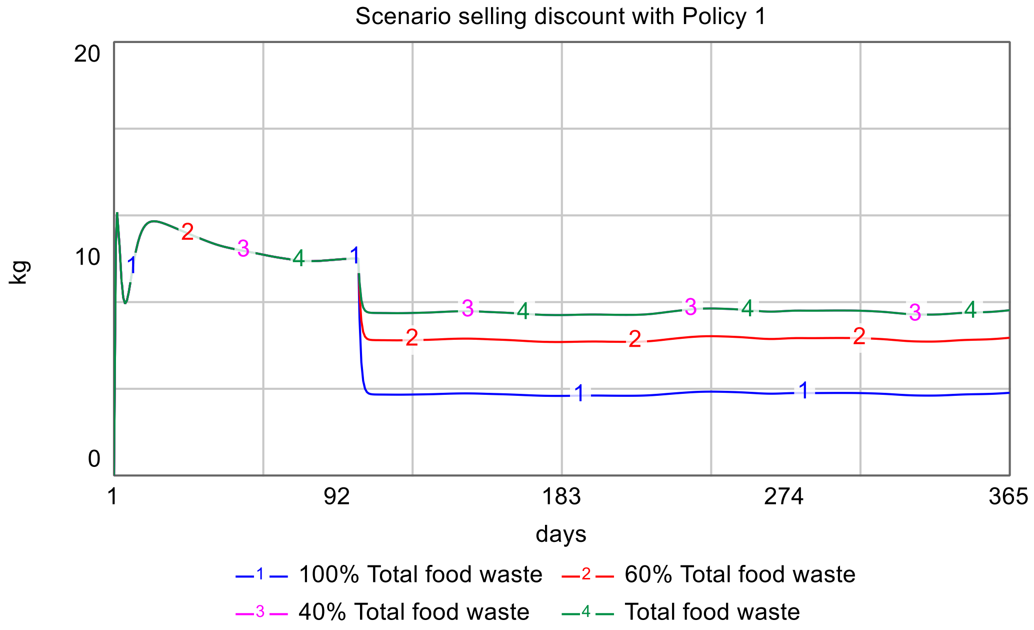

Figure 19: Base run: Scenario selling discount with Policy 1

In addition, we have tried three different scenarios, 1, 2, and 3 explained previously in 3.3 chapter 3.3. Where scenario 1 discounts the food price completely, however, doesn't decrease the food waste to zero. It is because of customer food waste and storage food waste. We do not have control over consumer eating habit, but to overcome food waste there is storage where we can look after. To decrease food waste completely, more control should be given to storage and consumers too. For example, potion control, like smaller portions and more regular check storage.

Scenario 2 and 3 has more food waste than scenario 1 compared as shown in figure 9.

2. **Policy 2: Decision-making switch**

Policy 2 is affected by B1 loop, B1 refers as **Estimated Customers** *B1: Estimated number of customers Ordered raw materials→ supply of food prepared→ Food waste.* When managers estimate an increased number of customers that will cause an increase in ordered raw materials, then there will be an increase in the supply of prepared food and more storage eventually leads to more wastage of food. This loop lacks the factor of being aware, owners can have control over storage and demand of raw materials. During this policy implementation figure 10, the food waste is not completely gone and only decreased by 4%, because the behavior is driven by B1.

In more detail, the investment made by the owner on purchase of food raw materials and store house has negative effect on controlling food waste. The fluctuations of the number of customers cannot help the restaurant manager to stop the demand for raw materials increasingly, because one must be prepared for any circumstances. The investment is not worth it on this occasion of controlling or reducing food waste.

.

Figure 20: Base run: decision making switch

3.5 Results and Findings

Policy 1: Base run: Scenario 1 (100%)

According to the figure 21, after implementation of Policy 1 Scenario 1, the policy seems effective reducing food waste. Food waste decreased by 70%, it is effective because of selling food completely at discounted price. It referred to profit efficiency and effects immediately. However, it is not cost efficient, as it required similar action such as preparation, packing and delivery.

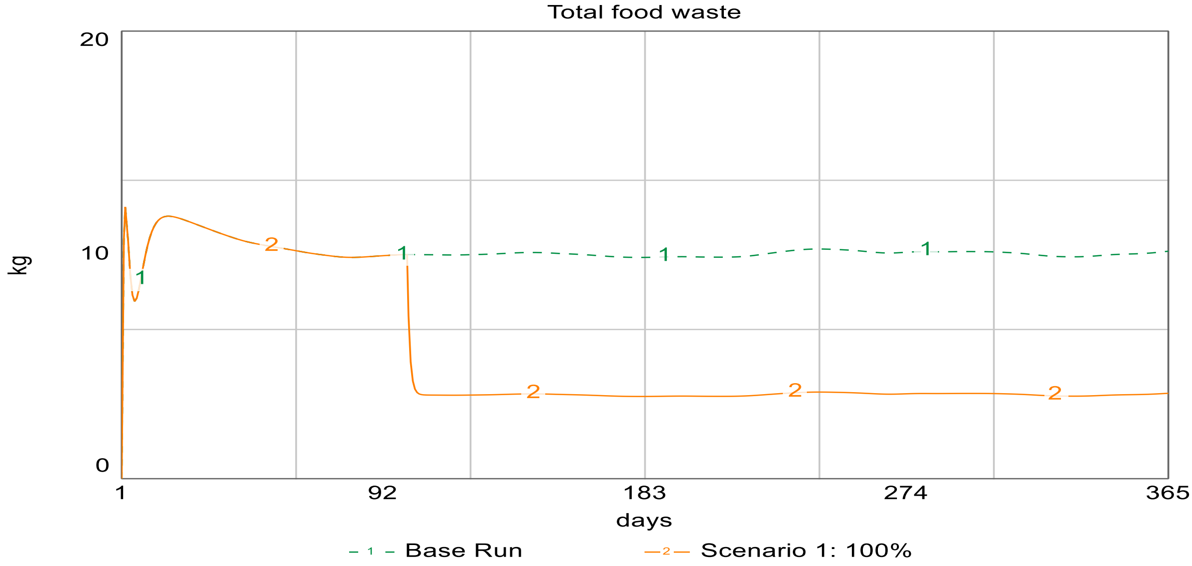

Figure 21: Policy 1: Base run: Scenario 1 (100%)

Policy 1: Base run: Scenario 2 (60%)

Figure 22 shows there is reduction of food waste and is effective immediately. However, the case is it is not cost efficient. Food waste decreased by 40%. The figure shows the behaviour of the total food wase without policy and with policy has effective implementation and shows difference in behaviour with huge range.

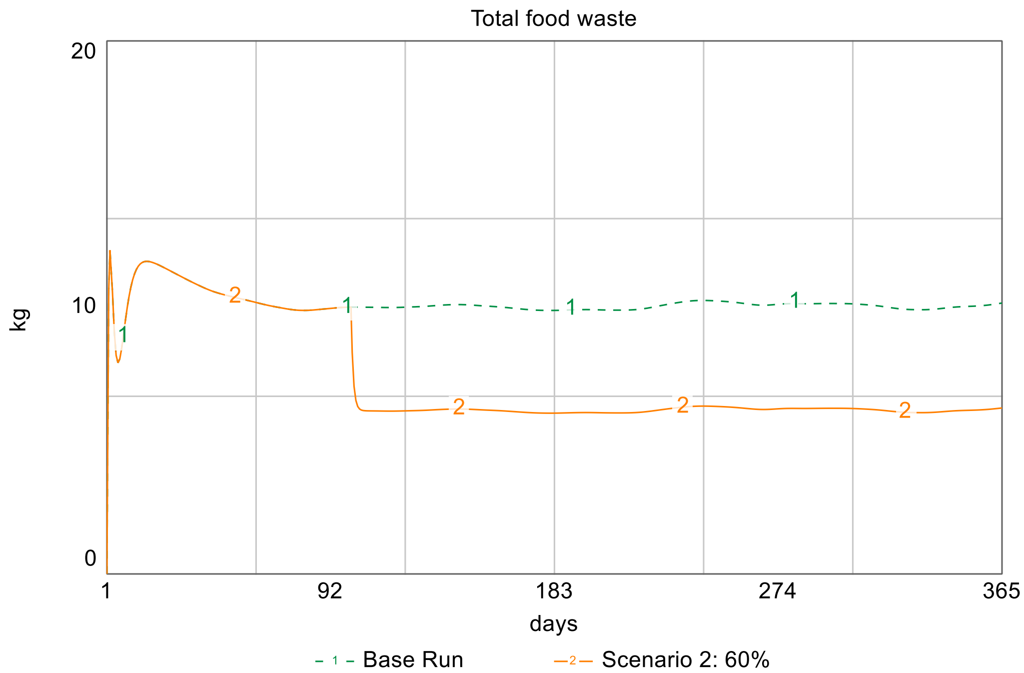

Figure 22: Policy 1: Base run: Scenario 2 (60%)

Policy 1: Base run: Scenario 3 (40%)

Figure 23 shows that there is more food waste than scenario 2 and a lot than scenario 1. Therefore, it is certainly not effective compared to the previous scenarios. It shows that if the implementation has done to reduce the waste, the results is not effective. It is because the more waste creation is a problem shown by this scenario. It added more waste than reduce and counted as the food waste creation scenario.

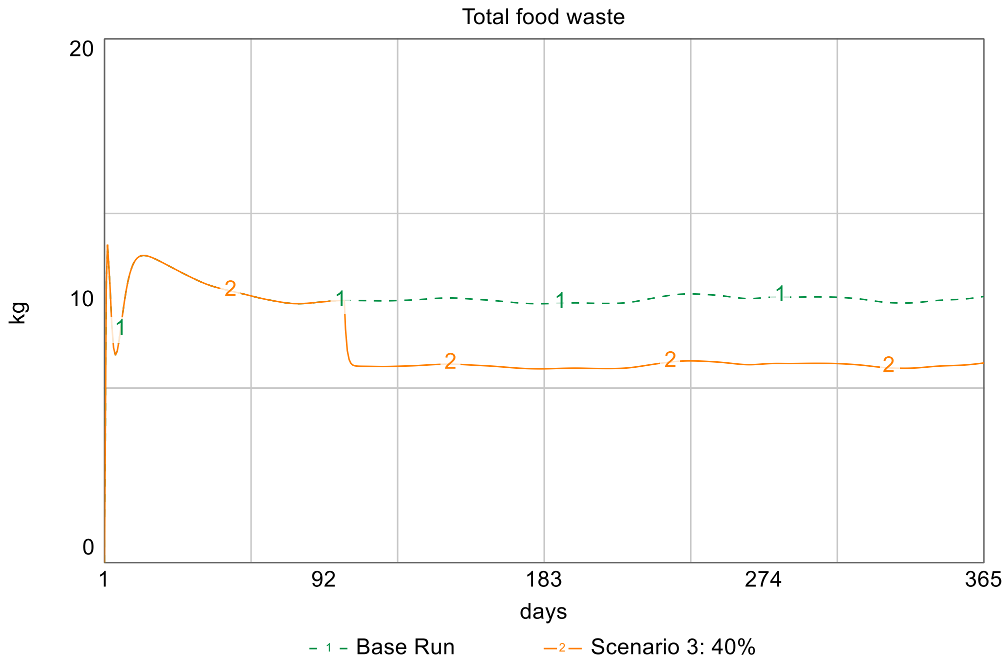

Figure 23: Policy 1: Base run: Scenario 3 (40%)

Combination of Policy 1 with different scenarios and Policy 2

1. **Combination of Policy 1 with scenario 1 (100%) and Policy 2**

As shown in figure 24, the combination of Policy 1 and Policy 2 has been successfully introduced to reduce food waste. Compared to base run, this policies combination is way better and effective. Food waste decreases up to 90%. These policies can be implemented in future. There are huge differences in terms of combination. Thus, it is what the restaurant owner would consider for future implementation.

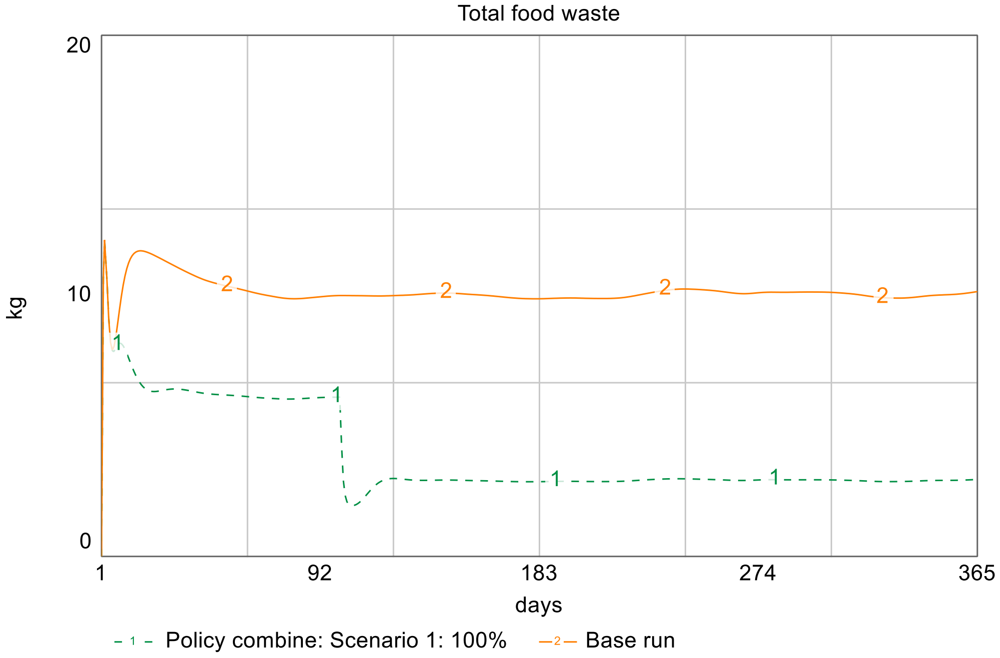

Figure 24: Combination of Policy 1 with scenario 1 (100%) and Policy 2

2. Combination of Policy 1 with scenario 2 (60%) and Policy 2

As shown in figure 25, the combination of Policy and Policy: Scenario 60%, has negative effect on reducing waste. In fact, these policies combination has increased the food waste from 2.95 kg to 4.36. therefore, it is a red sign that these policies combination will increase food waste and works only when there are 100% sales of food.

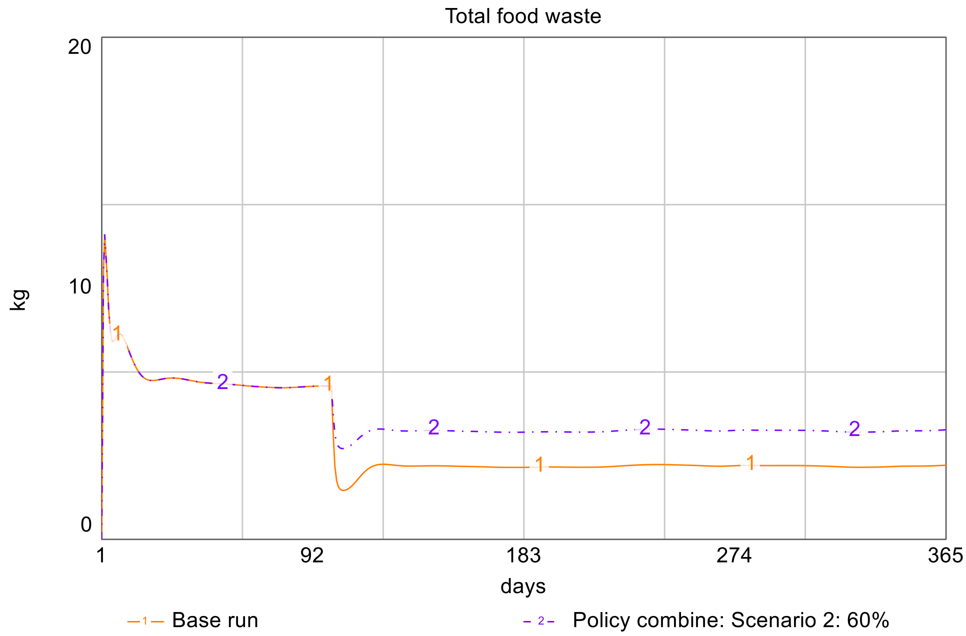

Figure 25: Combination of Policy 1 with scenario 2 (60%) and Policy 2

3. Combination of Policy 1 with scenario 3 (40%) and Policy 2

Similarly, scenario 4 also increases the food waste while combining both policies. Although the amount is more 4.96 kg, it is not effective to use.

The reason behind the growth of food waste in these policies combination Scenario 2 and Scenario 3 is there is still food waste measured after selling 60% or 40%. As after selling at 60% or 40% discount price, they create more waste. But 100% selling reduce the food waste.

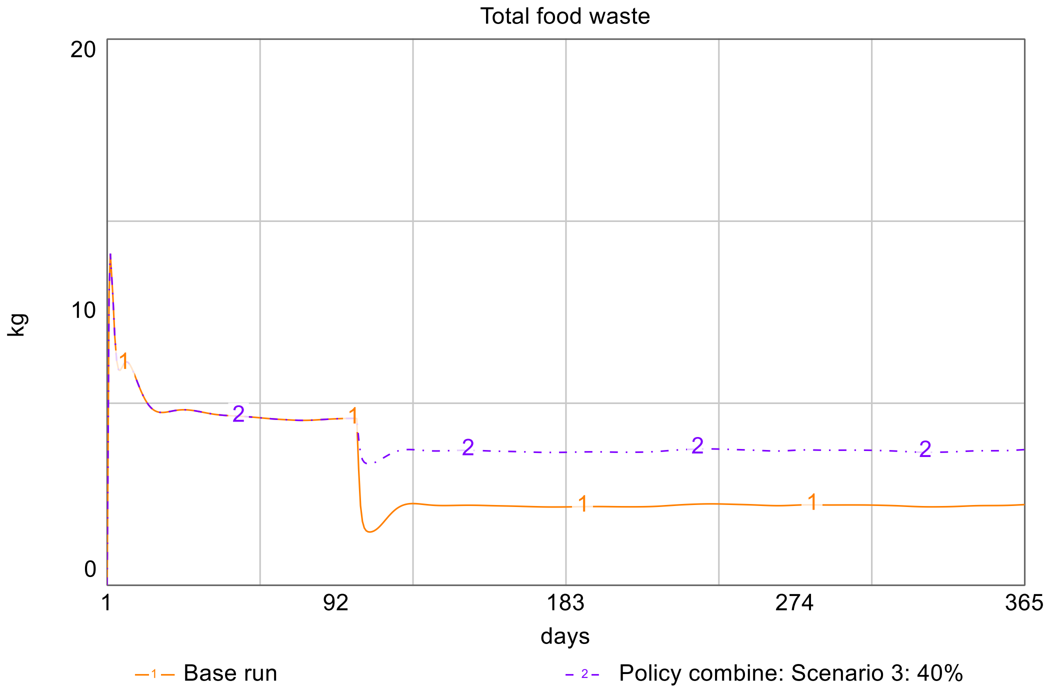

Figure 26: Combination of Policy 1 with scenario 3 (40%) and Policy 2

When a combination of policies is to be implemented, this might result in favors of a perfect reduction of food waste. As described before, the implementation of Policy 2- decision making is recommended the most. Policy 2 provides important insights that Policy 1 can aggressively reduce food waste but can be problematic in future, as it costly. However, Policy 2 helps to decrease food waste and can be implemented easily in the long- term which can be seen in below figure.

Figure 27: Combination of Policy 1 with different scenarios and Policy 2

Based on all findings from base run, Policy 1, Policy 2 and combination of Policy 1 and Policy 2, we advise not to choose Policy 1 because it is costly, not to combine those two Policies, it is not real. So, it is better to choose Policy 2 as suggested by results.

Chapter 4: Policy Suggestions

The model is based on explanatory basis, within the model formulation and structured, the model produced the reference mode behavior. Therefore, we find there can be two policy analyses to find out the best results and future implementation of the policy. The two policies are as follows:

1. Policy 1: Scenario selling discounted price 100%
2. Policy 2: Decision making

1. **Policy 1: Scenario selling discounted price 100%:** As the results produced by Policy 1 in **figure 19,** selling expired food with discounted price, the implementation of policy can be beneficial for the restaurant to overcome the loss that restaurant is having from food waste. Whereas the result provides the feedback that if the restaurant can sell 100% expired food, the food waste is low as seen in figure. Similarly, even a 60% discounted selling scenario has less food waste compared to 40%, which is high.

2. **Policy 2: Decision making:** This policy refers to awareness or alertness of restaurant owners or chefs about the need for raw materials. This is the initial phase of being aware of all the facts that if the restaurant demands more than they need it has direct and negative impacts on the restaurant income and causes more food waste. As shown in the results figure, during the implementation of Policy 2 in **figure 20**, the food waste has decreased compared to base run. Therefore, we summaries that the Policy works. There needs to be proper awareness, in fact more awareness than usual to reduce food waste.

As we discussed earlier, we figured out two kinds of important policies, which have their own existence and importance to find out the proper solution to the problem that has been generated during model formulation. Thus, it is noticeably clear that both policies work.

Policy recommendations

According to the modeler's view, although both policies are useful, only one could exist and can be implemented for future terms. Both the policies of having a trend of decreasing the restaurant food waste stabilize after certain years. The amount of food waste per day decreases after the implementation of food waste compared to the base run. Therefore, modelers suggest choosing policy 2 i.e., Decision making policy. It is because although a basic policy scenario analysis performed as of policy 1, Policy 2 is more realistic.

During the implementation of Policy 2, there is involvement of mental awareness rather than economical. Therefore, it is simple and easy to figure out where the restaurant can focus directly with less effort. Whereas Policy 1 cost a lot compared to Policy 2. Policy 1 must be carried out after the food expires, which requires the same amount of effort, while preparing or packing and so on.

Thus, to make it simple and real, the modeler suggested implementing Policy 2. The differences and effectiveness are shown below figure 17.

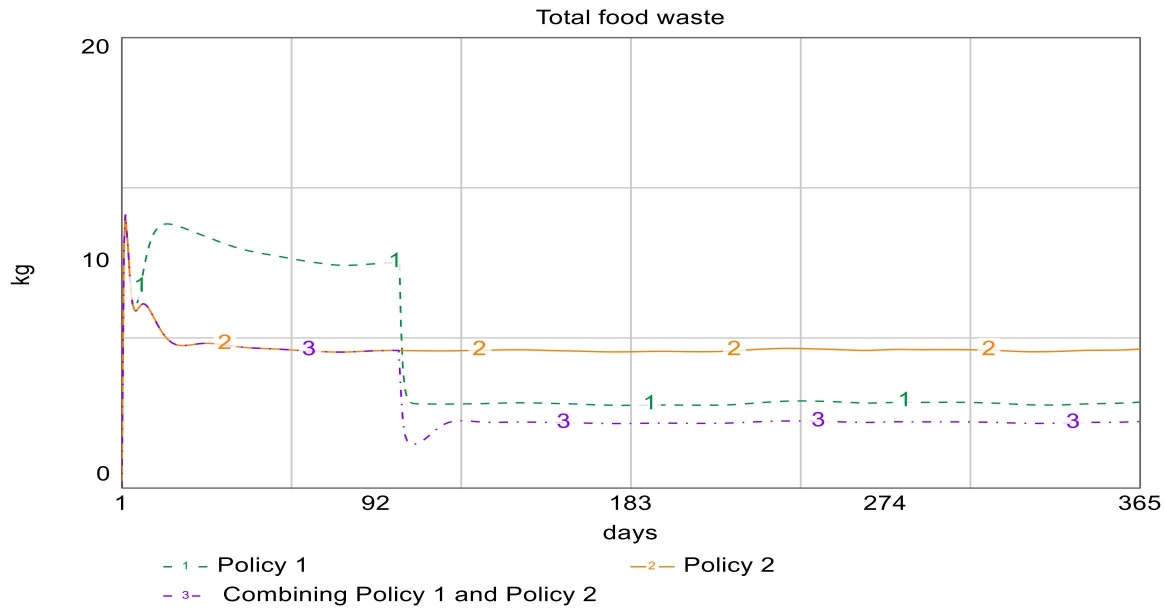

Figure 28: Policy recommendation result showing comparison between Policy 1 and Policy 2 and both

Conclusions

The main objective of this master thesis was to understand and discover ways to reduce the amount of food waste in a restaurant under system dynamics modelling. During the model formulation, multiple policies were identified. The findings show the expected behavior at the end, and I was satisfied enough to recommend this project result for further study. Our problem was that every day the restaurant was suffering from a huge amount of food waste, which can be reduced systematically. Many factors have potential to cause food waste, oversupply of food raw materials, expired raw materials while storing and preparation loss, serving loss and consumer behavior.

All the factors are shown in model structure which drives the model behavior in each way. Then we decided to figure out the main factors responsible for food waste. All those factors play a key role in identifying the problem and the policies were effectively implemented to overcome the problem. To reduce the restaurant food waste, we figure out two kinds of policies. Policy 1 would be selling the food at discount rate and Policy 2 would be decision making process before ordering plenty of food raw materials. During the simulation, results were drawn clearly following both policies. Therefore, as shown and described in figure 12, implementing Policy 2 would be effective and beneficial for the restaurant owner. It is because of its simplicity and easiness.

Limitations and Further Work

This thesis study contributes to literature in several diverse ways. First, it presents a System Dynamic model that allows researchers to analyze the food waste in a restaurant as a big problem globally. Whereas this literature offers multiple examples of System Dynamic models within the supply chain, food waste generation, perception of managers while placing the order of raw materials in restaurant, storage condition and expiration of food raw materials, considering the consumption rate, government expenditure. Since the process of modelling the research that has been taken place through other literature, all results show the growth of food waste due to some internal and external factor. Therefore, this research study will be helpful for future research and other research can be done with this literature as reference.

Although the study has addressed the interaction of feedback loops, the model has some limitations imposed by its scope and assumptions, as discussed in previous sections. For example, the Sd model is based on food waste generation. It does not incorporate variables related to consumer behavior, income earnings and the price of food raw materials. Similarly, the policy structure and policy scenario analysis could be done to estimate the applicability and feasibility of the suggested policy.

There is further research required in multiple fields such as income wise, consumer perspective to overcome the limitations in this study. To improve decision-making processes associated with the effect of perception on ordering, it is necessary to take suggestions from accountants, chefs, and staff within restaurants to control food waste. This research study gives confidence to evaluate the problem and try more research in similar areas.

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Appendix A. Model Documentation

The following pages provide the complete model documentation generated by the Stella Architect software, that is used for the model formulation and simulation. The documentation includes all the equations, properties, variables, units, initial values, parameters, graphical functions and pie charts, and the explanation including sources for the estimated values and so on. This documentation has the potential to make readers understand what is going on model simulation.

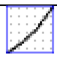
		Equation	Properties	Units	Documentation
	Top-Level Model:				
	available_raw_Material_for_preparation(t)	available_raw_Material_for_preparation(t - dt) + (received_raw_materials_rate - Rate_of_food_prepared - Expiration_Rate_during_storage) * dt	INIT available_raw_Material_for_preparation = Ordered_Raw_materials	kg	This stock represents the available material for food materials that needed for preparation, so every day in a restaurant on an average including all the varieties cooked items such as curry sauce, meat, creams, vegetables and so on. This stock increases by the inflow (the rate of received row materials) and decreases by two outflows, firstly(the expiration rate during storage of raw materials), and the other one is(the rate of food prepared).
	Food_available_for_consum	Food_available_for_consumption_by_customers(t - dt) +	INIT Food_availab	kg	This stocks represents the

	ption_by_customers(t)	(Rate_of_Actually_Food_Demanded - Customers_food_Waste_rate - Rate_of_Eaten_ordered) * dt	le_for_consumption_by_customers = Prepared_Food_to_serving		amount of food that is actually consumed by customers. This stocks increases by the rate of food that is demanded by customers, and decreases by the customers waste of food , and also decreases by the amount of food eaten by customers . The initial value of this stock is the historical available food for consumption by customers
	Ordered_Raw_materials(t)	Ordered_Raw_materials(t - dt) + (Supply_Rate_Of_Raw_materials - received_raw_materials_rate) * dt	INIT Ordered_Raw_materials = Raw_Materials_order_backlog	kg	According to the restaurant owner, 500 gram per person and 30 person per day, which means restaurant order 6 kg of raw materials per day. (30 person/500 gram =0.06). So, 6 kg per day. But we referred ordered raw materials as the stock of raw materials order backlog.
	Perception_of_chef_of_food_waste(t)	Perception_of_chef_of_food_waste(t - dt) + (Updating_perception) * dt	INIT Perception_of_chef_of_food_waste = 0	kg	The stocks represent the chef perception towards food waste. It is stock because it

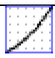
					accumulates over time.
	Prepared_Food_to_serving(t)	Prepared_Food_to_serving(t - dt) + (Rate_of_food_prepared - Rate_of_Actually_Food_Demanded - Prepared_food_expired) * dt	INIT Prepared_Food_to_serving = available_raw_Material_for_preparation	kg	This stock represents the amount of food that is prepared from the order by customers. This stock increases by the rate of food prepared that is demanded by customers, and decreases by the food that is not sold, and decreases by the amount of actual food consumption.
	Raw_Materials_order_backlog(t)	Raw_Materials_order_backlog(t - dt) + (Demand_rate_Of_Raw_Materials - Supply_Rate_Of_Raw_materials) * dt	INIT Raw_Materials_order_backlog = 20	kg	This is estimated raw materials needed to a restaurant. Everyday restaurant demanded for the raw materials which includes milk, cream, vegetables, meat, tomato, fruits and so on. So, the estimation of raw materials needed initially is 15- 20 kg per day.
	Total_food_waste(t)	Total_food_waste(t - dt) + (Expiration_Rate_during_storage + Customers_food_Waste_rate + Expired_prepared_food - waste_discarded_Rate) * dt	INIT Total_food_waste = Prepared_Food_to_serving-Food_available_for_consu	kg	This stock is the accumulation of food waste that are accumulated from different possible waste variables such as demand of

			mption_by_customers		food, preparation to serve and the consumption phase. Historical data or rate of food waste in a restaurant with personal experience, a restaurant discarded average weight of waste is 10 kg per day including all the other stocks, from preparation to expiration during storage, to consumption and leftover.
	Customers_food_Waste_rate	waste_collected_Fraction*Food_available_for_consumption_by_customers		kg/days	It is the total waste from consumer side after food eaten. The fraction of waste collected is an outflow that decreases the actual food consumption.
	Demand_rate_Of_Raw_Materials	Total_estimated_demand_for_restaurant_per_day*Effect_of_perception_on_ordering		kg/days	
	Expiration_Rate_during_storage	Before_cooking_material_expire_Fraction*available_raw_Material_for_preparation		kg/days	This is the multiplication of available food material and those material are expired before cooking with any kind of issues.
	Expired_prepared_food	IF TIME > 100 THEN (IF policy_switch=0 THEN		kg/days	If the policy does not apply,

		Prepared_food_expired ELSE Prepared_food_expired*(1-Scenario_selling_discount)) ELSE Prepared_food_expired			the food will be waste. If policy is on after 100 days, it decreases the food waste.
	Prepared_food_expired	Prepared_Food_to_serving/expiration_time		kg/days	It is the waste from restaurant side after the prepared food not sold. This rate of not sold is an outflow that increases the total food waste. Sometimes there is more customer and food demand is high, so the preparation is also high. The order food is sold, and the rest will not be sold, that goes to waste. This is the relation as outflow from prepared food to serving is showing to total food waste.
	Rate_of_Actually_Food_Demanded	Prepared_Food_to_serving*Consumption_rate		kg/days	
	Rate_of_Eaten_ordered	Fraction_of_eaten_order*Food_available_for_consumption_by_customers		kg/days	This outflow is determined by the actual food consumption multiplies with fraction of eaten ordered. Also, here we exclude the food quality and the preference of customer as the

					model boundary.
	Rate_of_food_prepared	available_raw_Material_for_preparation*Estimated_food_demanded_fraction		kg/days	
	received_raw_materials_rate	Ordered_Raw_materials/delay_time_to_receive_raw_material_from_supplier		kg/days	The delay time also influence the received raw materials rate, ordered raw materials is divided by the time taken.
	Supply_Rate_Of_Raw_materials	Raw_Materials_order_backlog/Demand_of_raw_material_delay		kg/days	
	Updating_perception	(Total_food_waste-Perception_of_chef_of_food_waste)/Time_to_update_perception		kg/days	
	waste_discarded_Rate	Total_food_waste/delay_time_to_discard_waste		kg/days	
	Before_cooking_material_expire_Fraction	GRAPH(received_raw_materials_rate) Points: (3.00, 0), (3.18333333333, 0.0000243503483214), (3.36666666667, 0.0000489044640638), (3.55, 0.000073664052384), (3.73333333333, 0.000098630832708), (3.91666666667, 0.00012380653885), (4.10, 0.000149192919132), (4.28333333333, 0.000174791736509), (4.46666666667, 0.000200604768686), (4.65, 0.000226633808246), (4.83333333333, 0.00025288066277), (5.01666666667, 0.000279347154968), (5.20, 0.0003060351228), (5.38333333333, 0.00033294641961), (5.56666666667, 0.000360082914248), (5.75, 0.000387446491203), (5.93333333333, 0.000415039050735), (6.11666666667, 0.000442862509005), (6.30, 0.000470918798208), (6.48333333333, 0.000499209866711), (6.66666666667, 0.00052773767918), (6.85, 0.000556504216726), (7.03333333333, 0.000585511477037), (7.21666666667, 0.000614761474518), (7.40, 0.000644256240429), (7.58333333333, 0.000673997823031), (7.76666666667, 0.000703988287723), (7.95, 0.000734229717188), (8.13333333333, 0.000764724211538), (8.31666666667,		Dimensionless/days	This is the graphical function which shows the exponential growth of material expired before cooking. This is true also restaurant has to be prepared for all kinds of days either busy or no customers. So, maximum or on an average preparation is must and in the context sometime high customer and sometimes no, that leads to the exponential growth of food storage day by day. This shows the food waste is high.

		0.000795473888459), (8.50, 0.000826480883356), (8.68333333333, 0.000857747349505), (8.86666666667, 0.000889275458203), (9.05, 0.000921067398913), (9.23333333333, 0.000953125379422), (9.41666666667, 0.000985451625991), (9.60, 0.00101804838351), (9.78333333333, 0.00105091791566), (9.96666666667, 0.00108406250506), (10.15, 0.00111748445342), (10.3333333333, 0.00115118608174), (10.5166666667, 0.00118516973041), (10.70, 0.00121943775943), (10.8833333333, 0.00125399254853), (11.0666666667, 0.00128883649736), (11.25, 0.00132397202567), (11.4333333333, 0.00135940157342), (11.6166666667, 0.00139512760102), (11.80, 0.00143115258945), (11.9833333333, 0.00146747904047), (12.1666666667, 0.00150410947677), (12.35, 0.00154104644213), (12.5333333333, 0.00157829250163), (12.7166666667, 0.00161585024184), (12.90, 0.00165372227093), (13.0833333333, 0.00169191121892), (13.2666666667, 0.00173041973784), (13.45, 0.00176925050191), (13.6333333333, 0.00180840620773), (13.8166666667, 0.00184788957445), (14.00, 0.00188770334399), (14.1833333333, 0.00192785028122), (14.3666666667, 0.00196833317412), (14.55, 0.00200915483404), (14.7333333333, 0.00205031809582), (14.9166666667, 0.00209182581804), (15.10, 0.0021336808832), (15.2833333333, 0.00217588619792), (15.4666666667, 0.00221844469313), (15.65, 0.00226135932431), (15.8333333333, 0.00230463307165), (16.0166666667, 0.0023482689403), (16.20, 0.00239226996053), (16.3833333333, 0.00243663918801), (16.5666666667, 0.00248137970393), (16.75, 0.0025264946153), (16.9333333333, 0.00257198705511), (17.1166666667, 0.00261786018258), (17.30, 0.00266411718337), (17.4833333333,			

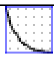
		0.00271076126978), (17.6666666667, 0.002757795681), (17.85, 0.00280522368334), (18.0333333333, 0.00285304857042), (18.2166666667, 0.00290127366344), (18.40, 0.00294990231137), (18.5833333333, 0.00299893789123), (18.7666666667, 0.00304838380828), (18.95, 0.0030982434963), (19.1333333333, 0.00314852041777), (19.3166666667, 0.00319921806418), (19.50, 0.00325033995621), (19.6833333333, 0.00330188964401), (19.8666666667, 0.00335387070744), (20.05, 0.00340628675633), (20.2333333333, 0.00345914143069), (20.4166666667, 0.00351243840101), (20.60, 0.00356618136849), (20.7833333333, 0.0036203740653), (20.9666666667, 0.00367502025485), (21.15, 0.00373012373203), (21.3333333333, 0.00378568832349), (21.5166666667, 0.00384171788791), (21.70, 0.00389821631626), (21.8833333333, 0.00395518753205), (22.0666666667, 0.00401263549165), (22.25, 0.00407056418452), (22.4333333333, 0.00412897763351), (22.6166666667, 0.00418787989513), (22.80, 0.00424727505984), (22.9833333333, 0.00430716725233), (23.1666666667, 0.0043675606318), (23.35, 0.00442845939226), (23.5333333333, 0.00448986776282), (23.7166666667, 0.00455179000797), (23.90, 0.0046142304279), (24.0833333333, 0.00467719335876), (24.2666666667, 0.00474068317301), (24.45, 0.00480470427969), (24.6333333333, 0.00486926112474), (24.8166666667, 0.00493435819129), (25.00, 0.005)			
	chefs_burn_out_Modifier	GRAPH(Prepared_Food_to_serving) Points: (6.00, 0.0000), (6.09166666667, 0.00121751741607), (6.18333333333, 0.00244522320319), (6.275, 0.0036832026192), (6.36666666667, 0.0049315416354), (6.45833333333, 0.00619032694249), (6.55, 0.00745964595662), (6.64166666667, 0.00873958682547), (6.73333333333,		Dimensionless/ days	When there is a increase in the demand of raw materials, that will cause that chefs will be pressed to cook more food, and that gives them

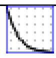
		0.0100302384343), (6.825, 0.0113316904123), (6.91666666667, 0.0126440331385), (7.00833333333, 0.0139673577484), (7.10, 0.01530175614), (7.19166666667, 0.0166473209805), (7.28333333333, 0.0180041457124), (7.375, 0.0193723245601), (7.46666666667, 0.0207519525367), (7.55833333333, 0.0221431254502), (7.65, 0.0235459399104), (7.74166666667, 0.0249604933355), (7.83333333333, 0.026386883959), (7.925, 0.0278252108363), (8.01666666667, 0.0292755738519), (8.10833333333, 0.0307380737259), (8.20, 0.0322128120215), (8.29166666667, 0.0336998911516), (8.38333333333, 0.0351994143862), (8.475, 0.0367114858594), (8.56666666667, 0.0382362105769), (8.65833333333, 0.0397736944229), (8.75, 0.0413240441678), (8.84166666667, 0.0428873674753), (8.93333333333, 0.0444637729101), (9.025, 0.0460533699456), (9.11666666667, 0.0476562689711), (9.20833333333, 0.0492725812995), (9.30, 0.0509024191756), (9.39166666667, 0.052545895783), (9.48333333333, 0.0542031252529), (9.575, 0.0558742226712), (9.66666666667, 0.057559304087), (9.75833333333, 0.0592584865207), (9.85, 0.0609718879715), (9.94166666667, 0.0626996274265), (10.0333333333, 0.0644418248682), (10.125, 0.0661986012833), (10.2166666667, 0.0679700786709), (10.3083333333, 0.0697563800508), (10.40, 0.0715576294726), (10.4916666667, 0.0733739520237), (10.5833333333, 0.0752054738383), (10.675, 0.0770523221063), (10.7666666667, 0.0789146250817), (10.8583333333, 0.0807925120918), (10.95, 0.0826861135463), (11.0416666667, 0.084595560946), (11.1333333333, 0.0865209868921), (11.225, 0.0884625250956), (11.3166666667,			less motivation to prepare food. This modifier is an important indicator that when it increases so it causes a decrease in the quality of food, and when it decreases , so the quality of food will increase. this function is presented graphically to calculate the qualitatively. Many human resources studies improve that for example: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4911781/

		0.0904203103864), (11.4083333333, 0.0923944787224), (11.50, 0.0943851671995), (11.5916666667, 0.0963925140609), (11.6833333333, 0.0984166587062), (11.775, 0.100457741702), (11.8666666667, 0.102515904791), (11.9583333333, 0.104591290902), (12.05, 0.10668404416), (12.1416666667, 0.108794309896), (12.2333333333, 0.110922234656), (12.325, 0.113067966215), (12.4166666667, 0.115231653582), (12.5083333333, 0.117413447015), (12.60, 0.119613498027), (12.6916666667, 0.1218319594), (12.7833333333, 0.124068985196), (12.875, 0.126324730765), (12.9666666667, 0.128599352755), (13.0583333333, 0.130893009129), (13.15, 0.133205859168), (13.2416666667, 0.135538063489), (13.3333333333, 0.13788978405), (13.425, 0.140261184167), (13.5166666667, 0.142652428521), (13.6083333333, 0.145063683172), (13.70, 0.147495115568), (13.7916666667, 0.149946894561), (13.8833333333, 0.152419190414), (13.975, 0.154912174815), (14.0666666667, 0.157426020889), (14.1583333333, 0.159960903209), (14.25, 0.16251699781), (14.3416666667, 0.1650944822), (14.4333333333, 0.167693535372), (14.525, 0.170314337816), (14.6166666667, 0.172957071534), (14.7083333333, 0.17562192005), (14.80, 0.178309068424), (14.8916666667, 0.181018703265), (14.9833333333, 0.183751012742), (15.075, 0.186506186601), (15.1666666667, 0.189284416175), (15.2583333333, 0.192085894396), (15.35, 0.194910815813), (15.4416666667, 0.197759376603), (15.5333333333, 0.200631774583), (15.625, 0.203528209226), (15.7166666667, 0.206448881675), (15.8083333333, 0.209393994756), (15.90,			

		0.212363752992), (15.9916666667, 0.215358362616), (16.0833333333, 0.21837803159), (16.175, 0.221422969613), (16.2666666667, 0.224493388141), (16.3583333333, 0.227589500399), (16.45, 0.230711521395), (16.5416666667, 0.233859667938), (16.6333333333, 0.237034158651), (16.725, 0.240235213985), (16.8166666667, 0.243463056237), (16.9083333333, 0.246717909564), (17.00, 0.2500)			
	Consumption_rate	.8		Dimensionless/days	Daily demand fraction of food is 80% including take away and table order in a normal day.
	Daily_average_customers	RANDOM(25,45, 10) {30		person/days	Random is a stochastic built-in function if the daily average customers fluctuate between two numbers. There is no control over the range in which it fluctuates or when it takes a certain value. Therefore, the researcher assumes this is stochastic. Some days there is less customers and some days there are more.
	decision_making_switch	0		Dimensionless	When decision making switch is 0 then the policy is non-active. Here, we can see there is no change in the

					behaviour of food waste. the total waste 10.2 kg. When the policy is 1, the policy is active and there is huge difference on the total food waste. It decreased up to 6.17 kg. So, the policy works and save from being food waste.
○	delay_time_to_discard_waste	1		days	Twice a week government discarded the waste from restaurant. But restaurant waste requires 1 day time for outflow, that decrease the food waste and send to management. As it is per day model development.
○	delay_time_to_receive_raw_material_from_supplier	2		days	When a restaurant order raw material, let suppose today, the supplier will deliver the next day. So, we can say 2 days.
○	Demand_of_raw_material_delay	2		days	There is always some delay for the supply of raw materials. According to my personal experience every week

					there is the supply of raw materials from suppliers which is 2 days of delay time.
	discounted_expiration_price	0.25*price_per_consumed_kilo		kr/kg	The expired food sold on 25% discounted rate.
	Effect_of_perception_on_ordering	GRAPH(IF decision_making_switch=0 THEN 1 ELSE Perception_of_chef_of_food_waste) Points: (0.00, 1.000), (5.00, 0.670320046036), (10.00, 0.449328964117), (15.00, 0.301194211912), (20.00, 0.201896517995), (25.00, 0.135335283237), (30.00, 0.0907179532894), (35.00, 0.0608100626252), (40.00, 0.0407622039784), (45.00, 0.0273237224473), (50.00, 0.0183156388887)		Dimensionless	The perception is an information delay construction. Then the perception feeds into a graphical function determining the fraction of the food that the chef needs to order. This fraction is used to calculate the amount of food that gets ordered.
	electricity_cost	1500/30		kr/days	
	Estimated_food_demanded_fraction	1-Before_cooking_material_expire_Fraction		Dimensionless/days	
	expiration_time	2		days	As we prepared food, all the food are not sold eventually counted as food waste. So, we assume after 2 days the food is counted as food waste. The lower the days, less food waste.
	Fraction_of_eaten_order	1-waste_collected_Fraction		Dimension	According to the restaurant

				less/days	experience, people eat 80% of food they order. Therefore, 20% will be food waste.
	Governmental_cost_per_kilo	10		kr/kg	According to the restaurant data, every month the owner pays 1000kr- 1500kr for the waste as charge. It might be increased per kilo but is constant whether there is less waste. So, we determine 10 kr/kg as government cost per kilo.
	Governmental_Expenditure	waste_discarded_Rate*Governmental_cost_per_kilo		kr/days	
	Income	Total_Sales-Total_Costs		kr/days	
	initial_customers	GRAPH(TIME) Points: (1.0, 40.00), (2.42745098039, 39.6887222863), (3.85490196078, 39.3822892634), (5.28235294118, 39.0806255291), (6.70980392157, 38.7836568546), (8.13725490196, 38.4913101666), (9.56470588235, 38.203513529), (10.9921568627, 37.9201961254), (12.4196078431, 37.6412882415), (13.8470588235, 37.366721248), (15.2745098039, 37.0964275838), (16.7019607843, 36.8303407393), (18.1294117647, 36.56839524), (19.5568627451, 36.3105266306), (20.9843137255, 36.0566714587), (22.4117647059, 35.8067672596), (23.8392156863, 35.560752541), (25.2666666667, 35.3185667673), (26.6941176471, 35.0801503453), (28.1215686275, 34.8454446092), (29.5490196078, 34.6143918064), (30.9764705882, 34.386935083),		person/days	The initial number of customers are decreasing day by day. Therefore, this is the graphical function which shows the declining number of customers. It might be because of some external factors.

		(32.4039215686, 34.1630184701), (33.831372549, 33.9425868697), (35.2588235294, 33.7255860415), (36.6862745098, 33.5119625894), (38.1137254902, 33.3016639483), (39.5411764706, 33.0946383712), (40.968627451, 32.8908349166), (42.3960784314, 32.6902034356), (43.8235294118, 32.49269456), (45.2509803922, 32.29825969), (46.6784313725, 32.1068509821), (48.1058823529, 31.9184213374), (49.5333333333, 31.7329243902), (50.9607843137, 31.5503144963), (52.3882352941, 31.3705467218), (53.8156862745, 31.1935768325), (55.2431372549, 31.0193612823), (56.6705882353, 30.847857203), (58.0980392157, 30.6790223936), (59.5254901961, 30.5128153099), (60.9529411765, 30.3491950542), (62.3803921569, 30.1881213654), (63.8078431373, 30.0295546092), (65.2352941176, 29.8734557678), (66.662745098, 29.7197864309), (68.0901960784, 29.568508786), (69.5176470588, 29.4195856091), (70.9450980392, 29.2729802555), (72.3725490196, 29.1286566509), (73.8, 28.9865792823), (75.2274509804, 28.8467131897), (76.6549019608, 28.709023957), (78.0823529412, 28.5734777037), (79.5098039216, 28.4400410768), (80.937254902, 28.3086812423), (82.3647058824, 28.1793658773), (83.7921568627, 28.0520631618), (85.2196078431, 27.9267417712), (86.6470588235, 27.8033708685), (88.0745098039, 27.6819200963), (89.5019607843, 27.5623595701), (90.9294117647, 27.4446598703), (92.3568627451, 27.3287920351), (93.7843137255, 27.2147275537), (95.2117647059, 27.1024383588), (96.6392156863, 26.9918968201), (98.0666666667, 26.8830757373), (99.4941176471, 26.7759483334), (100.921568627, 26.6704882481), (102.349019608, 26.5666695316), (103.776470588,			

		26.4644666377), (105.203921569, 26.3638544179), (106.631372549, 26.2648081153), (108.058823529, 26.1673033579), (109.48627451, 26.0713161535), (110.91372549, 25.9768228829), (112.341176471, 25.8838002948), (113.768627451, 25.7922254997), (115.196078431, 25.7020759641), (116.623529412, 25.6133295057), (118.050980392, 25.525964287), (119.478431373, 25.4399588105), (120.905882353, 25.3552919135), (122.333333333, 25.2719427623), (123.760784314, 25.1898908478), (125.188235294, 25.10911598), (126.615686275, 25.0295982829), (128.043137255, 24.9513181902), (129.470588235, 24.8742564399), (130.898039216, 24.7983940699), (132.325490196, 24.7237124131), (133.752941176, 24.6501930931), (135.180392157, 24.5778180194), (136.607843137, 24.5065693831), (138.035294118, 24.4364296524), (139.462745098, 24.3673815684), (140.890196078, 24.299408141), (142.317647059, 24.2324926442), (143.745098039, 24.1666186125), (145.17254902, 24.1017698367), (146.6, 24.0379303599), (148.02745098, 23.9750844734), (149.454901961, 23.9132167131), (150.882352941, 23.8523118555), (152.309803922, 23.7923549141), (153.737254902, 23.7333311358), (155.164705882, 23.6752259968), (156.592156863, 23.6180251995), (158.019607843, 23.5617146689), (159.447058824, 23.506280549), (160.874509804, 23.4517091993), (162.301960784, 23.3979871919), (163.729411765, 23.3451013077), (165.156862745, 23.2930385334), (166.584313725, 23.2417860581), (168.011764706, 23.1913312705), (169.439215686, 23.1416617554), (170.866666667, 23.092765291), (172.294117647, 23.0446298456), (173.721568627, 22.9972435747), (175.149019608,			

		22.9505948183), (176.576470588, 22.9046720979), (178.003921569, 22.8594641134), (179.431372549, 22.8149597408), (180.858823529, 22.7711480292), (182.28627451, 22.7280181981), (183.71372549, 22.6855596347), (185.141176471, 22.6437618916), (186.568627451, 22.6026146837), (187.996078431, 22.5621078863), (189.423529412, 22.522231532), (190.850980392, 22.4829758088), (192.278431373, 22.4443310572), (193.705882353, 22.406287768), (195.133333333, 22.3688365803), (196.560784314, 22.3319682785), (197.988235294, 22.2956737908), (199.415686275, 22.2599441864), (200.843137255, 22.2247706734), (202.270588235, 22.190144597), (203.698039216, 22.1560574369), (205.125490196, 22.1225008054), (206.552941176, 22.0894664455), (207.980392157, 22.0569462286), (209.407843137, 22.0249321526), (210.835294118, 21.9934163401), (212.262745098, 21.9623910361), (213.690196078, 21.9318486063), (215.117647059, 21.9017815354), (216.545098039, 21.872182425), (217.97254902, 21.8430439918), (219.4, 21.8143590658), (220.82745098, 21.7861205887), (222.254901961, 21.758321612), (223.682352941, 21.7309552955), (225.109803922, 21.7040149051), (226.537254902, 21.677493812), (227.964705882, 21.65138549), (229.392156863, 21.625683515), (230.819607843, 21.6003815627), (232.247058824, 21.575473407), (233.674509804, 21.550952919), (235.101960784, 21.526814065), (236.529411765, 21.5030509055), (237.956862745, 21.479657593), (239.384313725, 21.4566283714), (240.811764706, 21.4339575739), (242.239215686, 21.4116396222), (243.666666667, 21.3896690245), (245.094117647, 21.3680403746), (246.521568627,			

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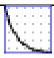
		20.6147001644), (319.321568627, 20.6051330413), (320.749019608, 20.5957148198), (322.176470588, 20.5864431825), (323.603921569, 20.5773158478), (325.031372549, 20.56833057), (326.458823529, 20.5594851379), (327.88627451, 20.5507773752), (329.31372549, 20.5422051391), (330.741176471, 20.5337663203), (332.168627451, 20.5254588423), (333.596078431, 20.517280661), (335.023529412, 20.5092297639), (336.450980392, 20.5013041701), (337.878431373, 20.4935019293), (339.305882353, 20.4858211217), (340.733333333, 20.4782598573), (342.160784314, 20.4708162755), (343.588235294, 20.4634885448), (345.015686275, 20.4562748621), (346.443137255, 20.4491734523), (347.870588235, 20.442182568), (349.298039216, 20.4353004891), (350.725490196, 20.428525522), (352.152941176, 20.4218559998), (353.580392157, 20.4152902813), (355.007843137, 20.4088267508), (356.435294118, 20.402463818), (357.862745098, 20.3961999171), (359.290196078, 20.3900335069), (360.717647059, 20.38396307), (362.145098039, 20.3779871127), (363.57254902, 20.3721041645), (365.0, 20.3663127778)			
○	kg_of_food_per_customer	0.5		kg/person	Restaurant estimates that a customer will get 500-gram quantity of food per dish which means 500/1000 kilo = 0.5 kilo that includes meat, vegetables, rice and naan bread. Source: https://ndla.no/subject:1:9e515764-0ce6-49d5-

					8ecd-1cde8b08a33f/topic:2:083a4a5f-d46c-4b85-8921-b398ae7e4dbf/topic:ccf57258-47b3-4d2e-b589-2c37ffaeec9b/resource:1:141246 It is common to calculate approx. 500-600 grams of food per person including accessories, and then approx. half be fish or meat.
◯	Labors_Salary	(15000*3)/30		kr/days	
◯	number_of_estimated_customers_per_day	SMTH3(Daily_average_customers,30, initial_customers) {RANDOM(30, 70, 50)		person/days	According to the limited data get from the restaurant, the number of estimated customers is 30 person per day. If a restaurant estimate per day sales is 10500 then it is divided by 30%. That means the price per plate is 350 kr. Kroner~ kr. It is the estimation of people per day. The number of customers in a restaurant varies

					every day. Therefore, to validate data, everyday customer is estimated as 30 persons regarding daily sales. Also the external factor such as covid impacts the declining number of customers influencing the number of estimated customers per day.
◯	policy_switch	0		Dimension less	When policy is 0 then the policy is non-active. Here, we can see there is no change in the behaviour of food waste. the total waste 30 kg. When the policy is 1, the policy is active and there is huge difference on the total food waste. It decreased up to 13.8 kg. So, the policy works, and we can get some profit from the expired food still and save

					from being food waste.
○	price_of_food_raw_material	65		kr/kg	Regarding to data, the price of food raw materials in an average is 50-80 kroner per kg, including vegetables, meat and so on. So, the researcher assumes that in average the price per kilo of row material will be 65.
○	price_per_consumed_kilo	518		kr/kg	http://www.ieomsociety.org/brazil2020/papers/666.pdf The price of one dish including curry, salad, rice, meat is 259 kroner. So, to determine the price per consumed kilo will be (259*2 =518), so this is a price per consumed kilo.
○	Quality_Of_food_Prepared_Modifier	GRAPH(Prepared_Food_to_serving*chefs_burn_out_Modifier) Points: (6.00, 0.2500), (7.10, 0.167580011509), (8.20, 0.112332241029), (9.30, 0.0752985529781), (10.40, 0.0504741294987), (11.50, 0.0338338208092), (12.60, 0.0226794883224), (13.70, 0.0152025156563), (14.80, 0.0101905509946), (15.90, 0.00683093061182), (17.00, 0.00457890972218)		Dimensionless/days	This modifier indicates the relationship between customers' acceptance of food quality and their desired to eat or not eat it or an amount of it . the increase in this modifier will cause less

					amount of wasted food and vice versa. This modifier is determined by the chef's burnout modifier, because quality of food prepared depends mainly on chefs ability to do a good tasty food.
◯	Rent_cost	45000/30		kr/days	It is constant number per day paid every month.
◯	Scenario_selling_discount	1		Dimensionless	The percentage of food sold in discounted price with 3 scenarios are as follows: Scenario 1: 100 percent sold, less food waste Scenario 2: 0.6 percent sold, less food waste Scenario 3: 0.4 percent sold, more food waste
◯	Time_to_update_perception	5		Days	Normally, it takes 5 days' time to update perception.
◯	Total_Costs	Governmental_Expenditure+total_Preparation_cost		kr/days	
◯	Total_estimated_demand_for_restaurant_per_day	kg_of_food_per_customer*number_of_estimated_customers_per_day		kg/days	This is the estimated raw materials needed to the restaurant. before preparation of food. The restaurant

					always needs raw materials so this indicates the demand of raw materials estimated by manager per day. This is the multiplication of number of estimated customers and the food for customer in kilo.
	Total_Fixed_Costs	Rent_cost+electricity_cost+Labors_Salary		kr/days	
	total_Preparation_cost	Total_Fixed_Costs+total_raw_material_cost		kr/days	This is the multiplication of the total preparation cost required to prepare one dish.
	total_raw_material_cost	Supply_Rate_Of_Raw_materials*price_of_food_raw_material		kr/days	This is multiplication of supply rate of raw materials and price of food raw materials.
	Total_Sales	IF TIME > 100 THEN (IF policy_switch=0 THEN (Rate_of_Actually_Food_Demanded*price_per_consumed_kilo) ELSE (Rate_of_Actually_Food_Demanded*price_per_consumed_kilo)+(Prepared_food_expired*Scenario_selling_discount*discounted_expiration_price)) ELSE (Rate_of_Actually_Food_Demanded*price_per_consumed_kilo)		kr/days	Total sales are the total dishes sale by restaurant per day multiply by the food demand by customer on that day.
	waste_collected_Fraction	Quality_Of_food_Prepared_Modifier+chefs_burn_out_Modifier		Dimensionless/days	This fraction mainly depends on the quality and the taste of food that is served to customers. It is not easy to

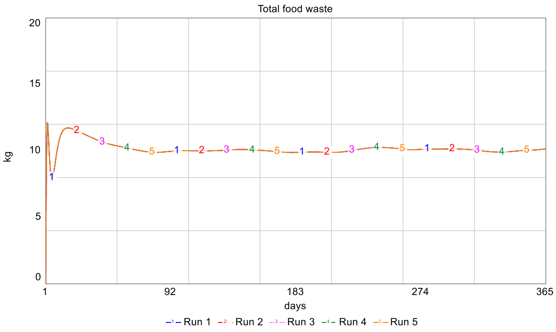
					quantify the relationship between the taste of food and customers' acceptance of it. But the researcher found that the chef's burnout will affect the quality of food. Therefore the rest of food that customers will not eat will be affected by the quality of food. The higher quality, there will be less waste or rest of food, and vice versa.

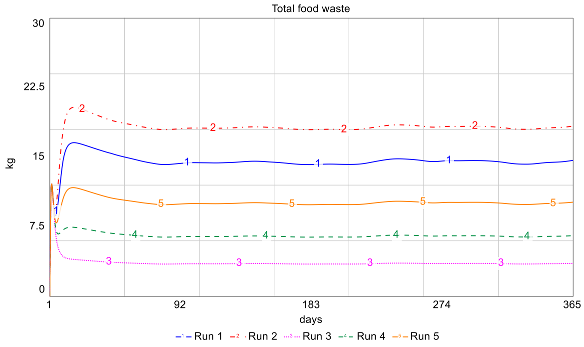
Run Specs	
Start Time	1
Stop Time	365
DT	¼
Fractional DT	True
Save Interval	0.25
Sim Duration	1
Time Units	days
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	True
Exhaustive Search Threshold	1000

Appendix B. Sensitivity Analysis

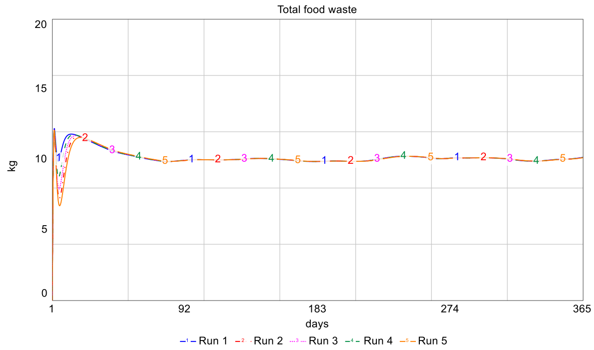
Sensitivity test is conducted with 5 runs each using the Limited runs (Latin Hybercube Sampling).

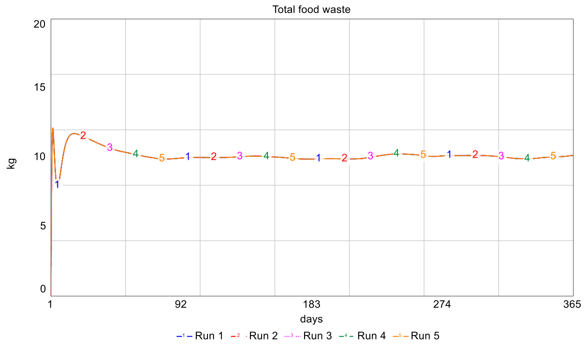
Parameter 4: price per consumed kilo **Parameter 5: kilogram of food per customer**



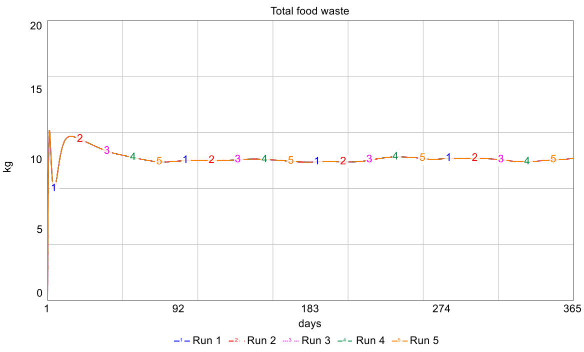


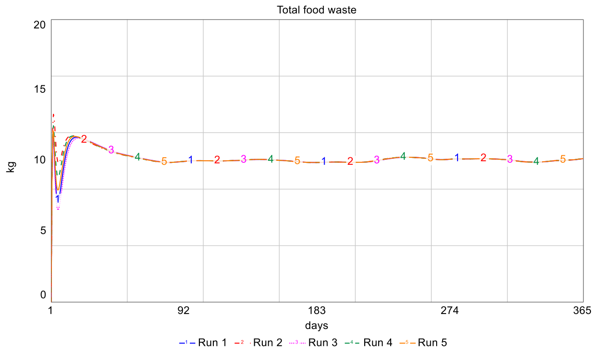
Parameter 6: demand of raw material delay **Parameter 7: price of food raw material**



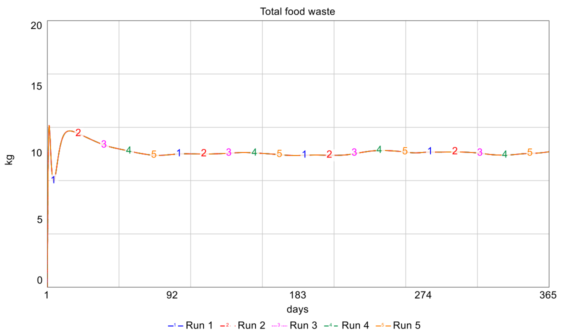


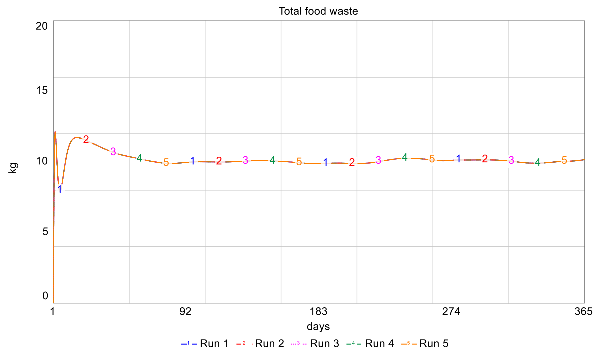
Parameter 8: rent cost **Parameter 9: delay time to receive raw material from supplier**





Parameter 10: time to update perception **Parameter 11: government cost per kilo**





Parameter test	**Sensitivity**
Parameter 1: Expiration time after food prepared to be served	Fairly sensitive
Parameter 2: Consumption rate	Fairly sensitive
Parameter 3: Delay time to discard waste	Highly sensitive
Parameter 4: price per consumed kilo	Not sensitive
Parameter 5: kilogram of food per customer	Highly sensitive
Parameter 6: demand of raw material delay	Less sensitive
Parameter 7: price of food raw material	Less sensitive
Parameter 8: rent cost	Not sensitive
Parameter 9: delay time to receive raw material from supplier	Less sensitive
Parameter 10: time to update perception	Not sensitive
Parameter 11: government cost per kilo	Not sensitive

Table 2: Parameter testing

Appendix C: Extreme conditions test

A critical test in the model is to observe what happens if customers do not require any food (i.e., daily average customer= 0). The expected systems behaviour would be that the restaurant does not sell and earn anything. The results are shown in below figure 29: Scenario 1: Blue line and the scenario under extreme conditions Scenario 2: Red line.

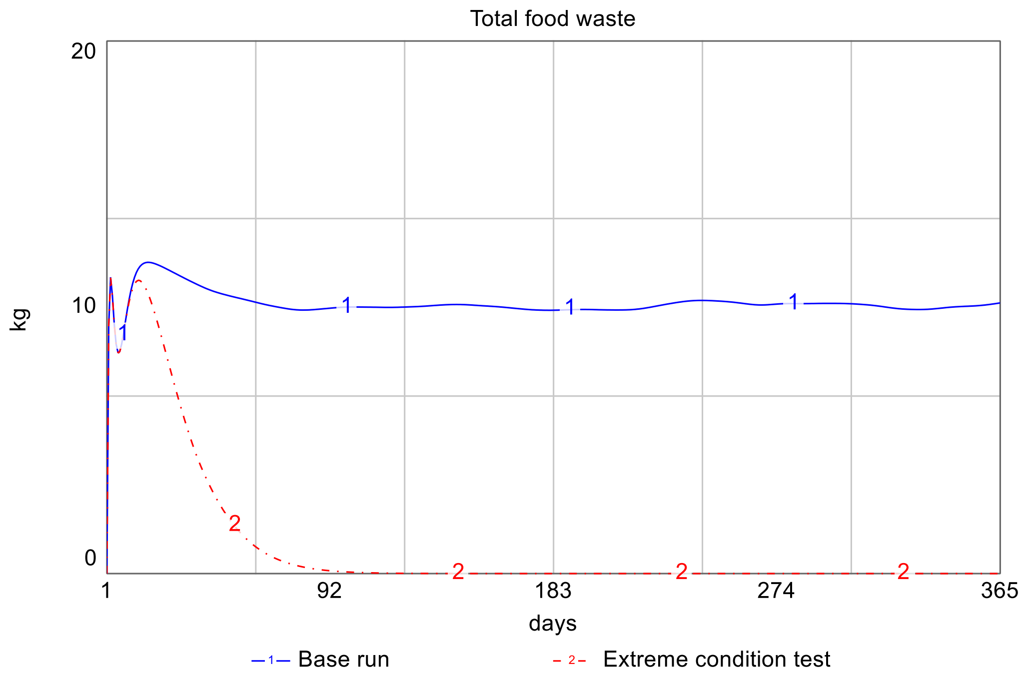


Figure 29: Simulation results for total food waste in extreme conditions (red lie) compared to base run (blue line)

Considering the results, there are days having more or less customers. There is no control over the range in which it fluctuates or when it takes a certain value. However, due to some external factors such as covid effects, the number of customers is 0, then the restaurant would still produce maximum food waste initially as shown in figure 19. Then the wastage slightly goes to 0. No customers referred as the backlog raw materials counted as total food waste.

Appendix D: Dimensional consistency

All the variables within the model have units. When the variable is not quantifiable, a “dimensionless” unit is assigned. During the simulation period, no units’ errors, type- graphical error, an inverted ratio or a missing time constant were identified. All the units can be seen in Appendix A.

Appendix E: Boundary adequacy

Boundary adequacy is a test which is responsible for checking whether the model boundaries have a structure that is needed to solve the address problem (Senge & Forrester 1980). In this model all the possible variables are included that causes the problem behaviour (Total food waste). The model matches the purpose for which the model is developed. The model doesn’t seem to contain any exogenous variables directly. All variables are shown respectively regarding the real cause and effects of it. The relationship between one variable to other shows the consistency of model structure.

Appendix F: Integration Error