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# Application of Cost of Quality and Quality Loss Function in Food Supply Chain System

Tianyuan Zheng

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Application of Cost of Quality and Quality Loss Function in Food Supply Chain System

by

Tianyuan Zheng

A Thesis  
Submitted to the Faculty of Graduate Studies  
through Industrial and Manufacturing Systems Engineering  
in Partial Fulfillment of the Requirements for  
the Degree of Master of Applied Science at the  
University of Windsor

Windsor, Ontario, Canada

2012

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## DECLARATION OF ORIGINALITY

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## ABSTRACT

Food industry is one of the most important industries for human society. It has also contributes in the economical development of local economic. The optimization of interests of parties in the industry, or the food supply chain system, is critical. In this thesis, the scenario of one producer, one retailer and on customer has been studied, with the consideration of all tangible and intangible costs occurs within the supply chain system.

In this thesis, three models have been developed to evaluate the performance of the food supply chain system under different organization functions: producer with retailer functions, producer with no retailer functions, and retailer with no production functions. Their performance is evaluated with the respect to the food quality of nutrition value, physical sense quality, and the opportunity cost of food product risks. Cost of quality and quality loss function has been applied in this model to identify and quantify some of the costs in the system.

Based on the results from the thesis, the proposed models are feasible representation of costs within the food supply chain system. With the changes of different variables in the model, characteristics of different food product and the needs of different parties and business model could be presented. By compare the result from proposed models with other existing models, this thesis proposed a model that could save between 1-97% in overall cost, and 96-99% in overall intangible costs in the food supply chain system.

## DEDICATION

This thesis is dedicated to my wife and my parents for their support.

Wish this thesis and other research on similar topics could help to improve the food safety and health issues, to create a safer and healthier life for my incoming baby and other children.

## ACKNOWLEDGEMENTS

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## CHAPTER I

### INTRODUCTION

Food industry is one of the most important industries in modern society and economic. According to The Ontario Ministry of Agriculture, food and Rural Affairs, in year 2010, it employed 392,500 Ontarian and a total sale of 25.35 billion CAD, about 12.6% of the total good producing industry's value. According to the historical data from the same source, size of average farms in Ontario has been increased by about 30% from 1971. This industry has reached a point of mass production, and results in a huge impact on local economic performance.

Food industry is a typical supply chain system. Its performance is heavily based upon the interactive activities between business entities and nodes. It follows a similar chain structure as other manufacturing industries, and its main objective is to optimize the system performance surplus of the whole system (Chopra et al. 2010). The main factors that distinguish food supply chain from other industry are the food quality and safety that influences the human health, weather related variability (Salin 1998), limited usable shelf life, demand and price variability and so on. All of these factors have increased the complexity of food supply chain issues. (Ahumada et al. 2009)

According to The Ministry of Agriculture, Food and Rural Affairs of Ontario, the entire food industry contains crop and animal production (primary agriculture), food, beverage and tobacco manufacturing, food wholesaling, food retailing, and food services. Crop and animal production could be considered as the raw material production for food manufacturing processes. Food, beverage and tobacco manufacturing are the main processors and producers for food products to serve customers. Food wholesaling, retailing, and food service are the stages where food has been distributed to customers. <sup>1</sup>

Factors that impact modeling of the food supply chain system includes whether the product is perishable or non-perishable; strategic, tactical, and operational level planning for system with regard to mode location, routing, order quantity and other issues; deterministic or stochastic demand, and so on. (Ahumada 2009) Perishable products are the products with shorter shelf life, and its market value is more time-sensitive, whereas the non-perishable product, are the products with longer shelf life, and its quality and value is not very time-sensitive and should not be considered in supply chain system design.

To optimize the interest of parties in the system, interest of each party should be identified in advance to proceed further study. For producers and retailers, costs are the main concerns. Method of cost of quality could be used to identify all the potential sources of costs, which provides a tool in evaluating the impact of product quality on the overall performance of the producers. For customers and end users, how to quantify the cost or loss from product is critical. Since no further study has been conduct on this topic, the value losing of food product during storages should be discussed.

Value of food could be grouped into two categories, as the nutritional values, which provides the energy and nutritional needs for humans; the other value is the physical senses value, which impacts on the goodwill of purchasing food products. Samples for nutritional value, includes vitamin, essential amino acids, and so on. For physical senses, it includes the appearance factor, textural factors, and flavor factors. The appearance factors include size, shape, wholeness, and different forms of damage, transparency, color and consistency of food product. Apperceives of these factors are mainly through sight. Textural factors include firmness, softness, juiciness, chewiness and grittiness from both hand feel and mouth feel. Sweet, salty, sour, bitter, fragrant,

acid, burnt and all the potential factors are considered as flavour factors, and they could be either taste, or the odour. In the industry, due to the interchangeability of measurement and quantification of these physical sense factors, their loss could be quantified by one value. (Potter 1986)

The loss of both values is the result of food deterioration process. Major factors for stability of nutritional value includes pH value, air or oxygen availability, light, heat, and cooking or processing methods. Table 1 illustrates the effect of major factors on the stability of nutrients.

Table 1: stability of nutrients. (Potter 1986)							
Nutrient	Nuetral pH 7	Acid <pH7	Alkaline >pH7	Air or Oxygen	Light	Heat	Cooking Losses (%)
Vitamins							
Vitamin A	S	U	S	U	U	U	0-40
Ascorbic Acid ©	U	S	U	U	U	U	0-100
Biotin	S	S	S	S	S	U	0-60
Carotenes (pro-A)	S	U	S	U	U	U	0-30
Choline	S	S	S	U	S	S	0-5
Cobalamin (B12)	S	S	S	U	U	S	0-10
Vitamin D	S		U	U	U	U	0-40
Folic acid	U	U	S	U	U	U	0-100
Inositol	S	S	S	S	S	U	0-95
Vitamin K	S	U	U	S	U	S	0-5
Niacin (PP)	S	S	S	S	S	S	0-75
Panthenic acid	S	U	U	S	S	U	0-50
p-Amino benzoic acid	S	S	S	U	S	S	0-5
Vatimin B6	S	S	S	S	U	U	0-40
Riboflavin (B2)	S	S	U	S	U	U	0-75
Thiamin (B1)	U	S	U	U	S	U	0-80
Tocopherols (E)	S	S	S	U	U	U	0-55
Essential amino acids							
Isoleucine	S	S	S	S	S	S	0-10
Leucine	S	S	S	S	S	S	0-10

Nutrient	Nuetral pH 7	Acid <pH7	Alkaline >pH7	Air or Oxygen	Light	Heat	Cooking Losses (%)
Lysine	S	S	S	S	S	U	0-40
Methionine	S	S	S	S	S	S	0-10
Phenylalanine	S	S	S	S	S	S	0-5
Threonine	S	U	U	S	S	U	0-20
Tryptophan	S	U	S	S	U	S	0-15
Valine	S	S	S	S	S	S	0-10
Mineral Salts	S	S	S	S	S	S	0-3
S = stable (no important destruction).							
U = unstable (significant destruction).							

Major causes of food deterioration that impact the physical senses of product include: Growth and activities of microorganisms, such as bacteria, yeast and so on; Activities of natural food enzymes (Palazo´n et al. 2009); Insects, parasites, and rodents; Temperature, both heat and cold (Dermesonlouoglow et al. 2009, Torrleri et al. 2011); Moisture and dryness; Air, or more particularly oxygen; Light; Time. Activities of microorganisms are the main sources for the cause of health problem for customers. Food enzymes and microorganisms are the main source of the changes in biochemical structure of the food, as well as the changes of nutrition contents. Insects, parasites and rodents bring contamination sources, such as microorganisms, into the food. Temperature, moisture, light, as well as air offer the energy and preferred condition for the activities of microorganisms and food enzymes. With time passing by, the level for food deterioration increase, results in a bigger loss on food quality. (Hester et al. 2002)

Opportunity loss for food risk is critical for customers’ point of view. Its impact should also be included. According to The Principles and Guidelines for the Conduct of Microbiological Risk Assessment CAC/GL-30, risk is defined as “a function of

probability of an adverse health effect and the severity of that effect, consequential to a hazard(s) in food”. Activities relate to risk could be grouped into three major categories, as risk assessment, risk management, and risk communication. Risk assessment includes the activities of hazard identification, hazard characterization, exposure assessment, and risk characterization, which is the activity for the qualitative or quantitative estimation of risk. Risk management is the activities that react based on the results of risk assessment, includes weighing and decision making for policy alternatives, as well as the implementation of the alternatives. Risk communication is the interactive exchange of information and opinion regarding about the risk among risk assessors, risk managers, consumers and other interested parties. (Lupien 2007) Activities in each stage might be correlated and integrated during application.

## CHAPTER II

### REVIEW OF LITERATURE

To optimize the food supply chain system operation surplus, all tangible and intangible costs should be considered, with consideration of food risk. How to classify and quantify all the costs should be discussed first.

#### 2.1 Concept of Quality

Due to the applications of “quality” in different industries and different management approaches, quality might have two different meanings. From the income or sales oriented point of view, quality means product has the features that satisfy certain customer needs. This approach considers that, with high quality and offering more satisfying features (such as trouble free operation), quality costs more. The other approach considers having quality issues results in more corrective actions, high rate of field failure, customer dissatisfaction and so on. So with higher quality, cost is actually reduced. These two meanings are not in conflict, as they express the different situation where quality means, and its different role under different situation.

In this thesis, costs are grouped into two categories, as the tangible and intangible costs. Tangible costs are the cost that has can be measured directly, or could be recorded from previous data. Intangible costs are the costs that associate with the potential loss from product storage, usage, and future consequences. Another approach to define tangible cost and intangible cost is: tangible costs are the costs that has identifiable source and could be quantified; and intangible costs are the costs that could be identified, but hard to be quantified. Quantification of intangible costs is conducted based on several



existing methods, such as Taguchi's quality loss function. Detail of the modeling and quantification of those costs will be discussed in later sections.

## 2.2 Tangible costs

Cost of quality or quality cost, might have different meaning for different people. Some considers it as the cost of poor quality. But actually the cost is not just the loss on defect rework, or the cost of running the quality department, but all the cost associated with the quality of product. Actual cost might be about 25-40% of the operation cost of an organization. Cost from supportive functions might also impacts on the quality. So according to Juran's quality handbook, a model of total cost of quality is showing below:

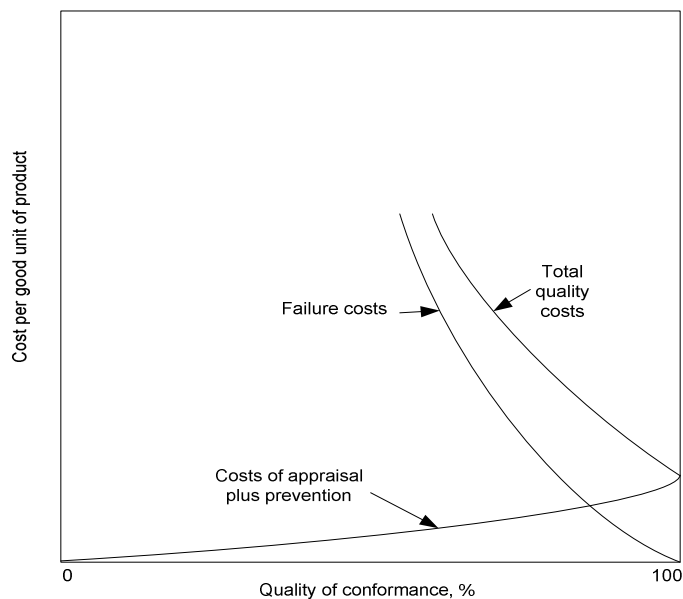


Figure 1: Model for Optimum Quality Costs.(Juran 2009)

Costs are categorized into four major categories: (Juran 2009)

1. Internal failure cost: the costs that occur when product does not meet the standard or conformity level. These costs occur before products reach the external customers. It includes the cost associated with the failure of meet customer requirement and needs, as well as the inefficient processes.
2. External failure cost is the cost occurs after customers receive the products. It includes the cost associated with failure in meeting satisfaction level and potential loss on sales.
3. Appraisal costs are the costs incurred to determine the conformity level and quality requirements, such as the inspection cost and so on.
4. Prevention cost is the cost dedicated to keep failure and appraisal cost as low as possible.

From figure 1, it might seem that perfection is achievable. However, based on the actual practices in industry, perfection could never be achieved. In industry, such as highly automated industries, perfection of product might be achieved from external customers' point of view, where the cost of perfection is not from cost of appraisal and prevention, but with the cost of internal failure. Similar case might be the product is made for affluent clients, who are willing to pay for extra just to insure all the product they received is defect free.

A similar figure from earlier edition of the book might be used to illustrate the case when perfection is achieved by appraisal cost and prevention cost, where the optimum point in total cost is achieved before perfection.

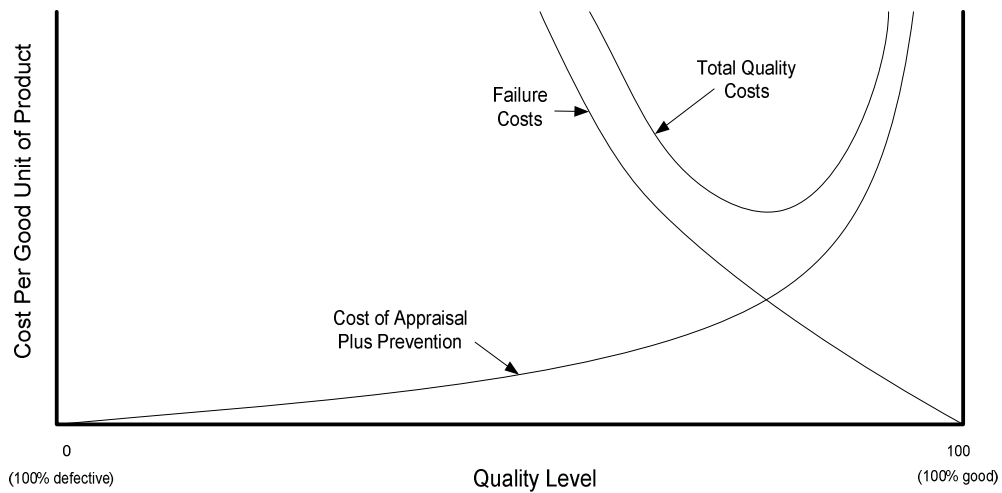


Figure 2: Juran's Quality Model. (Juran 1979)

### 2.3 Intangible costs

Under intangible costs, the costs that need to be measured and quantified are the external failure cost which could be considered as the costs of loss from food product value, and the potential cost from food risks.

#### 2.3.1 Taguchi's quality loss function

Taguchi proposed his approach of quality loss in the late 60s. He considered product specification or product species are related to product functions and market, while the product quality is related to loss and market size. Product species affect the market size by offering more feature, and satisfying more customer needs. On quality side, poor quality might damage the willingness of purchase and the reputation of company, which results in a reduction in market size. So he used the traditional concept of quality as the conformance to specifications, and proposed the loss to be beyond the

internal cost as the loss from external, such as loss from customer's inconvenience and dissatisfaction, warranty loss and so on. (Taguchi 2005)

The traditional quality is in standard of level of inconformity. The loss is illustrated by the following figure, where all products with quality characteristic within the specification, is considered to be equally good, with no loss, and no customer dissatisfaction after customer receive product. If a product has its quality characteristic exceed the specification, then the product is equally bad. However, a 59% results from academic test might not be far from 60% pass grade.

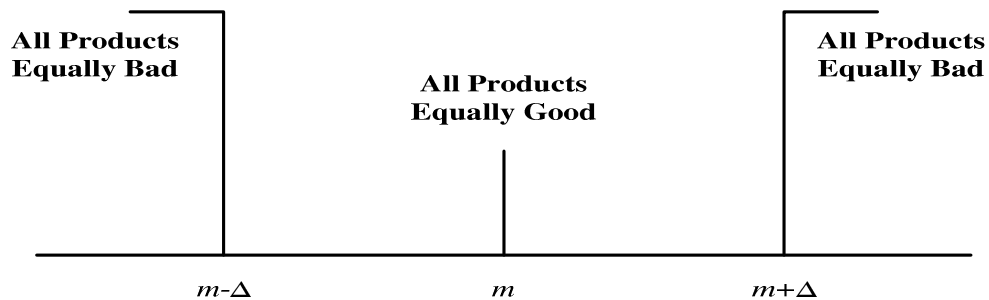


Figure 3: Traditional Relationship between Product Quality Characteristic and Quality Loss.

His method for quality loss function is based upon the following assumptions:

1. Conformance to specification limits is an inadequate measure of quality or of loss due to poor quality;
2. Quality loss is caused by customer dissatisfaction and the following events results from such dissatisfaction, such as loss of willingness for future purchase, warranty loss, and so on.
3. Quality loss can be related to product characteristics, which is measurable.

4. Quality loss is a financial loss, in term of the loss of market size or market sales.

So that, the loss of certain product from its quality, could be measured by the level of inconformity to specification. The following figure shows the quality loss per unit product from Taguchi's loss function:

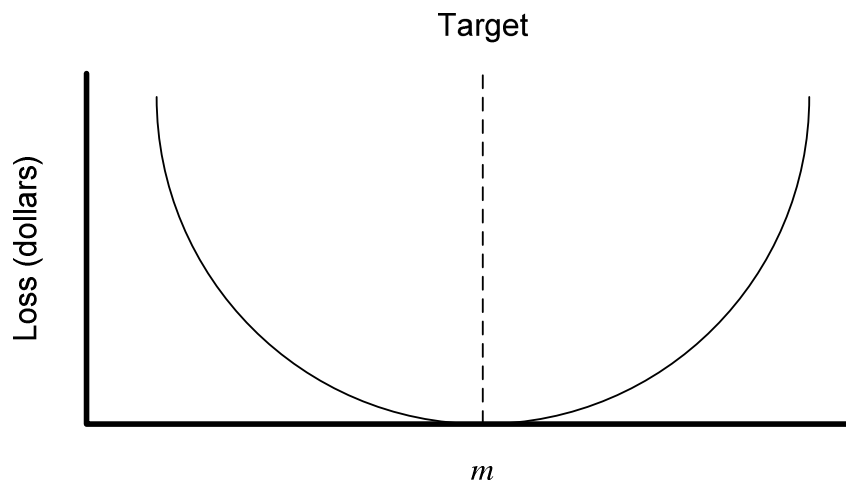


Figure 4: Quality Loss Per Unit Product from Taguchi's Loss Function.

So the quality loss function is given to be:

$$L = k(y - m)^2$$

Where  $k$  is the loss rate and  $y$  is the actual characteristic value.

With the reality in industry, Taguchi's quality function could be grouped to three cases with accordance to the quality characteristics. They are: nominal-the-best, smaller-the-better, and larger-the-better.

Nominal-the-best is the type that there is a finite target to achieve, where the loss could be managed to a minimum point. This is the case where the upper and lower specifications are located on both side of the target. Sample might be the thickness of certain point on a machining part. If the quality characteristic value varies from the target

value, there still exists the upper specification limit for the maximum allowable thickness and the lower specification limit for the minimum allowable thickness.

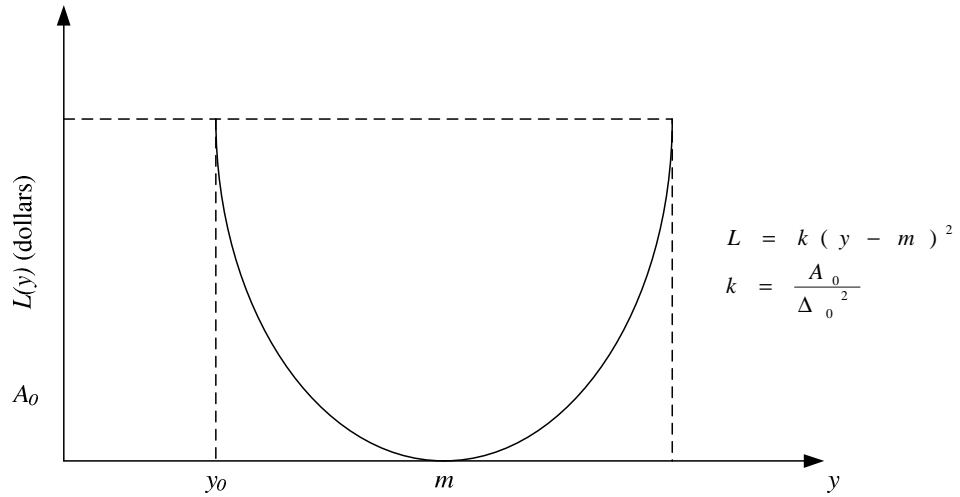


Figure 5: Quality Loss Function for Nominal-the-best Characteristics.

Smaller-the-better is the case where the desired target is considered to its minimum value, with the idea target to be zero. Pollution content levels, noise level, wearing of components, are all in the case of smaller-the-better.

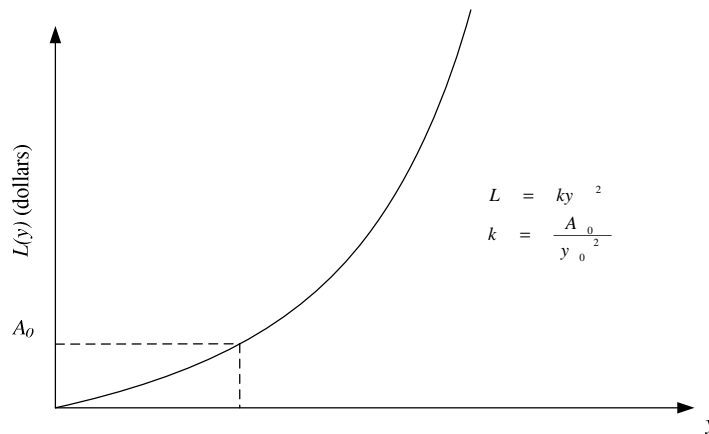


Figure 6: Quality Loss Function for Smaller-the-better Characteristics.

The larger-the-better is the opposite case with smaller-the-better, where the desired target value of quality characteristics is considered to be infinity large, or the maximum value of it. Strength of material, usable life of product, are the samples of this case.

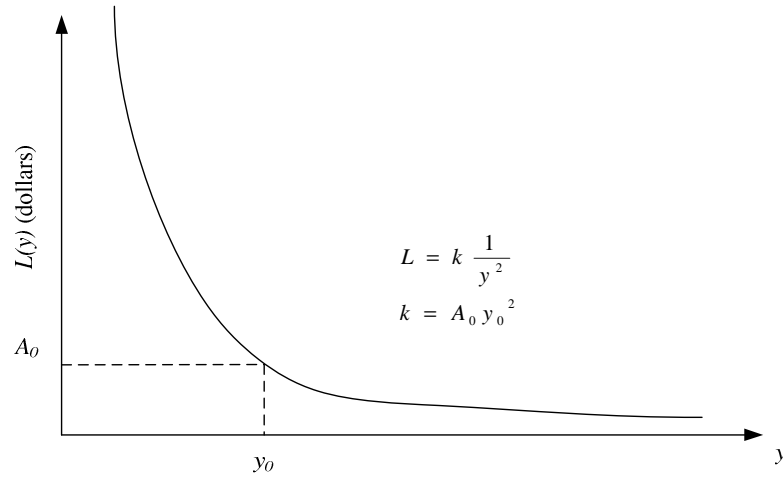


Figure 7: Quality Loss Function for Larger-the-better Characteristics.

### 2.3.2 Costs of the loss from food product value

As has been discussed in the introduction chapter of this thesis, the value of food products includes two parts, the nutritional value, and the physical senses value.

Traditionally, these two categories of value are considered as one in modeling.

The numerical modeling methods include zero-order reaction kinetics, first-order reaction kinetics, fractional conversion kinetics, the Bigelow model, and non-linear microbiological death model. (Fujiwara 1993) Zero-order reaction kinetics is the traditional model, with its calculation simplicity, but larger errors in estimation. First-order reaction kinetics and fractional conversion kinetics are the models observed from

the experiments that test the changes of content during certain stages and period for food storage. The Bigelow model and non-linear microbiological death model are models that are used to illustrate the changes of nutrients within the food product during a more complex situation, including the effects of changes in temperature during food cooking and after. (Palazon et al. 2009)

In most of the literatures, the costs due to the loss of product value is considered as result of food deterioration, and normally is modeled with linear or exponential deterioration rate to illustrate the cost of such loss. Their assumption is that, the reduction of inventory level is a result of joint operation of both demand and deterioration. Two models could be used as being developed by Okitsugu Fujiwara (Fujiwara 1993) with linear deterioration rate, and Kun-Jen Chung, Tien-Shou Huang (Chung 2007) with an exponential deterioration rate.

$$Q = \sqrt{\frac{2DC}{hS + \pi}}, \pi \text{ is the linear deterioration rate;}$$

$$Q = \frac{D}{\theta}(e^{\theta T} - 1), T \text{ is the time for each ordering cycle measured in year, } \theta \text{ is the}$$

parameter for exponential deterioration rate.

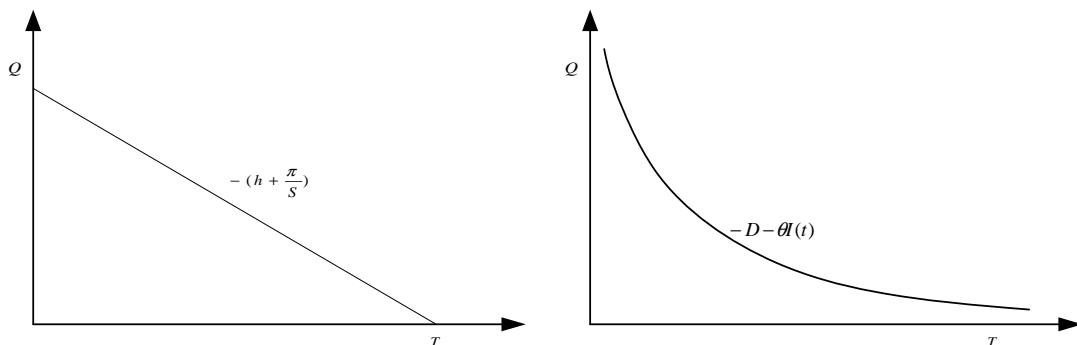


Figure 8: Changes of Inventory Level with Linear and Exponential Deterioration Rate.



### 2.3.3 Costs of food risks

With the consideration of the chain structure of food supply chain system and the interactive activities among each party, factors that needs to be discussed and included in the modeling of food risks includes the quantification of costs, and the assignment of costs among different parties in the system.

#### 2.3.3.1 Quantification of the food risks.

Quantification of risk is part of the risk assessment process. Due to the difficulty to gather all information regarding the risk, semi-quantitative risk assessment has been used. In this method, value of risk could be represented in forms of linguistic, numerical scales, and quantitative measures of the risk.

Huss developed a semi-quantitative assessment system to evaluate the risk of seafood products. He created six categories of risk factors, and using symbols of “+”, “-” to represent the risk for each factor. By calculating the overall number of “+” to rank the all risks associated with seafood product.(Huss et al. 2009)

Other approaches use scale of individual category of risk factors to calculate the overall risk. Van Gerwen developed a SIEFE system, and by setting different scale of risk factors on each risk level, the overall quantitative risk could be obtained.(Van Gerwen 2000)

Ross and Sumner developed another model with nine risk input values, by completing the six steps calculation; the overall risk could be obtained. The most important part of their model is the concept of comparative risk. This risk contains the evaluation of probability of illness over all servings, annual exposures per person in a daily basis, and the hazard severity factor. (Ross et al. 2002)

$$CR = C3 * \frac{C4}{365} * HazardSeverity$$

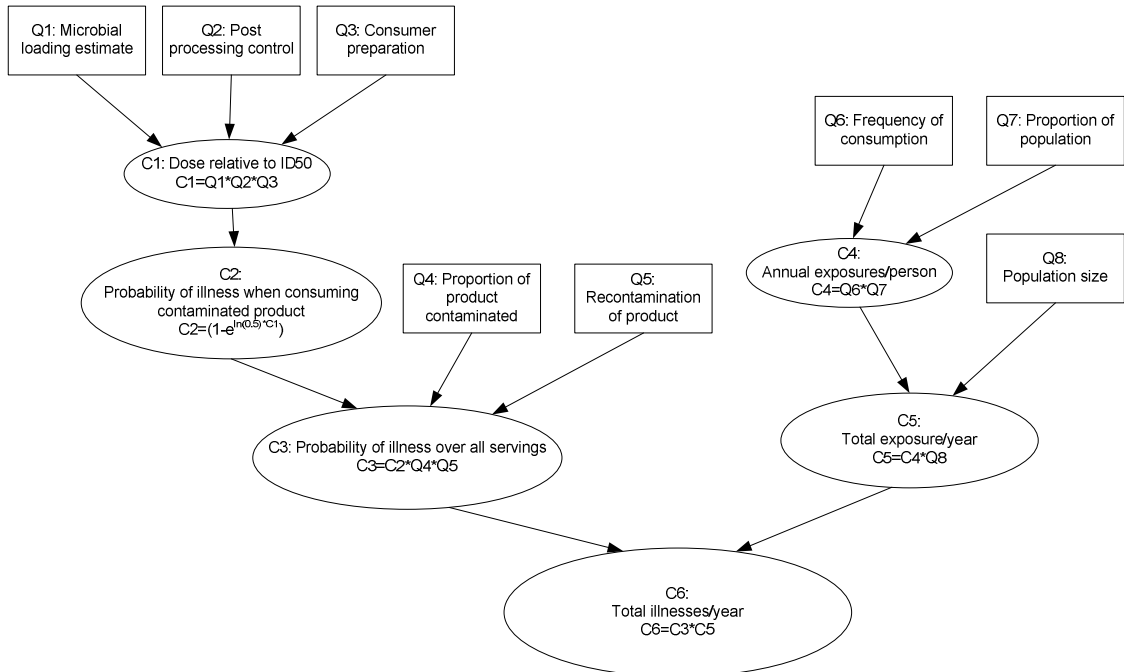


Figure 9: Chain of Factors in Ross and Sumner's Model of Food Risk. (Ross et al. 2002)

### 2.3.3.2 Assignment of costs

Government and industry regulators are one of the major players in the risk assessment and risk management stage. Risk assessment is mainly conducted by academic and government institute, as consumers considered they should be responsible for the regulation and safety assurance of food product. Consumer expects government and producers to act more positively on the risk management, and The Agriculture and Agri-Food Administrative Monetary Penalties Regulation is a sample of such awareness. For risk communication, the failure of Canadian government to explain high risk of BSE exposure to local industry results in seven years of loss in international market. (Leikas et al. 2009) The severity of risk loss increases dramatically with time passing and level of

risk exposure increases. So customers consider government and press should be more responsible for risk communication.

Another interesting influential factor in responsibility assignment might be what type of risk customer concerns more. The activities of consumers regarding food safety have several characteristics: consumers tend to be more insensitive to food safety issues that is generated by their diet or life-style related problem; consumers are more concerning with the potential risk, but not the identified actual risk evaluated and released by academic or government regulation; consumers react more to new released or discovered risk, rather than long existing risks. The causes of these characteristics include the gap between daily language and scientific terms, lack in exchange of information, and so on. Consumers tend to prefer academic institutes to contribute more on the evaluation and identification of risk, government acts on the quality monitoring, producer and retailer works on the quality assurance of food product, and third party or press to concern more on the risk communication. (Rohr et al. 2005) However, with the progress in risk management and social movement, public opinions have changed towards more reasonable and controllable manner. (Gibbons, 1979)

### CHAPTER III

#### DESIGN AND METHODOLOGY

As has been described in the earlier sections of this thesis, the main goal is to find a way to evaluate and optimize the food product quality in food supply chain system. Major factors that contribute to the performance of such a system includes: cost, and potential risks; or classified as tangible and intangible costs.

Before proceeds to the cost analysis of food supply chain system, the scope of the thesis needs to be defined. In this thesis, the supply chain system is defined as a system with one producer, one retailer, and one customer, with finite large quantity of product flow between them. The activities of the system ends by the time customer purchase and receive the product. Loss occurs after that is not included in the model. Further study could be conducted upon the case of multiple producers, multiple retailers, the multiple customers, and the more complex interaction between each entity in system. Demand for product is assumed to be large, which the results of quality level on batch production could be reduced, and results from model could be more feasible in application.

The discussion of methodology starts with the classification of all costs in the food supply chain system; include cost of quality and the detail listing of the costs under certain category. Efforts from the deterioration process of food product may results in loss for customer and market sales for retailer. So the effort of deterioration will be discussed under the category of external cost of quality. Then, how to quantify the loss from deterioration, and how the Taguchi's quality loss functions is feasible to apply for food product, is discussed. The last topic is modeling of the risk in system, with the

discussion of the response assignment and so on, followed by the final objective function contains all categories of costs.

The following is the list of assumptions used in this model:

- a. Replenishment rate is infinite and lead time is zero.
- b. No shortage is allowed.
- c. The deterioration rate for food products follows its general form of deterioration, and its impact is discussed and model in later section.
- d. All cost occurs in the model are known.
- e. Selling price for producer and retailer are known, and is not changing with demand or other factors.
- f. Demand is deterministic, and is a constant value for each day.
- g. Deterioration process is assumed to start when retailer receive product, and no deterioration during transportation.
- h. During storage, transportation, and on shelf period, the environment, such as temperature, lighting, packaging quality, are assumed to be steady and unchanged.

The following table is the list of all notations that has been used in this thesis:

Table 2: Table of Notations.	
D	Annual demand;
S	Daily demand, $S=D/365$
Q	Order quantity in each order period, or could be considered as , where $Q = S \cdot n$ , n as number of days in each order period;
C <sub>O</sub>	order cost, all cost associate with the placement of an order;
C <sub>S</sub>	Set up cost, all cost associate with the set up of product for each batch;
Q <sub>P</sub>	Size for each production batch;
S <sub>r</sub>	Sales price of food product at retailer;
S <sub>p</sub>	Sales price of food product at producer;
y	Producer's quality level;
h	Holding cost rate at retailer, during the storage and on shelf period before being purchased by customer;
Q <sub>10</sub>	Food deterioration parameter, in our model used in the modeling of loss of nutrition loss of food product;
F1	Product usable life labeled, which is obtained at storage temperature T1.
F2	Product real shelf life, which is obtained at actual storage temperature of T2.
N <sub>Li</sub>	Nutritional loss on ith day in an ordering cycle.
L <sub>nutri</sub>	Total nutritional loss for an ordering cycle.
N	Population of microorganisms in product.
A	Initial population of microorganisms in product.
L <sub>micro</sub>	Loss from microorganisms.
L <sub>enzyme</sub>	Loss from food enzyme.
k	Deterioration rate or quality loss rate: k1: Deterioration rate from microorganisms' activity; k2: Deterioration rate from enzymes' activity;
k <sub>NL</sub>	Quality loss rate from nutrition loss;
k <sub>PS</sub>	Quality loss rate from physical senses loss;

Table 2: Con't	
$L_{NL}$	Nutrition loss;
$L_{PS}$	Physical senses loss;
$PS_i$	Physical senses loss on ith day in an ordering cycle.
$P_p$	Production cost per unit of product;
$P_q$	Cost of quality for per unit of product, sum of cost of internal failure, prevention and appraisal cost;
$P_t$	Cost of transportation of each food product unit;
$a$	Weight assignment factor to nutrition loss;
$b$	Weight assignment factor to physical senses loss;
	$a+b=1$ ;
$Q_1$	Microbial loading estimate, or the original risk.
$Q_2$	Post processing control quality.
$Q_3$	Consumer preparation.
$Q_4$	Proportion of product contaminated.
$Q_5$	Recontamination of product.
$Q_6$	Frequency of consumption
$Q_7$	Proportion of population
$\pi$	Linear Deterioration rate in Fujiwara's model.
$\theta$	Exponential factor in Huang's model.
$\eta$	Market Share Rate of Company
$\alpha$	Percentage of food risk financial costs responsible for producer
$\beta$	Percentage of food risk financial costs responsible for retailer
	$\alpha + \beta = 1$
$R_f$	Financial food risks.
$\bar{R}$	Average food risk on each day.
$k_{fr}$	Rate of financial risk for food.
$R_{frp}$	Financial food risk responsible for producers.
$R_{frr}$	Financial food risk responsible for retailers.

### 3.1 Cost of quality and quality loss.

#### 3.1.1 DIRECT COSTS:

Direct cost, are the cost associated with the production of food product, management, storage, transportation, and other costs. These costs are directly related to the production and distribution of food product. The cost associated with the quality of food product, is also being considered under this category. According to the information from literature review, costs under this category are:

1. Cost of production: includes cost for the purchasing and usage of raw material, direct labour cost associated with production of product, and so on;
2. Set up cost for production: cost for the setup for each batch of production, potential failure in quality results in defect of product in whole batch;
3. Cost of transportation: cost of transport products from manufacturer to retailer;
4. Ordering cost: cost for retailer to make order for replenishment from producer;
5. Holding cost: cost for retailer to store products before sales. This cost includes the cost the occurs in storage, and on shelf;
6. Cost of quality: these cost could be grouped into four major sectors:
  - a. Internal failure costs: costs that occur during the manufacturing process. Such cost includes: scrap, rework, re-inspection or retest, changing process, redesign hardware or software, and downgrading and more. Other sets of cost that is also includes here



are the cost of inefficient processes, such as unplanned downtime of equipment, inventory differences between actual inventory and recorded inventory, and so on. These cost are mainly occurs within the producer.

- b. External failure costs: cost that is directly linked to the response of customer, which is caused by the potential failure of product. In this thesis, these costs are considered to be the cost associated with customers' action towards the quality of product. And these costs usually occur between customer and retailer. Examples for such costs could be: complaint adjustment, revenue losses in support operations (customer refuses to pay), warranty charges, and more. Another loss in this sector is the loss in good will.
- c. Appraisal costs: these are the costs incurred to monitor and control the degree of conformance to quality requirement. These costs are mainly the cost of quality inspection, and cost of operating TQM system, and so on. Other samples could be incoming inspection and test, or document review and product quality audits.
- d. Prevention costs: these are cost associated with the actions to maintain failure cost and appraisal costs low. Such costs include: cost of quality planning, process planning, training, and more.

In actual application, the safety of food products are highly monitored by government during production, so retailers are not well aware the cost of appraisal and prevention during the whole food product supply chain system. The appraisal and

prevention cost for retailer could be considered as part of its holding cost. So in this model, cost assignment among producer and retailer was barely touched, but discussion in the objective function for different models.

### 3.1.2 Quality loss and external cost of quality

Due to the unique characteristics of food products and food industry, the sector of external failure costs are discussed and modeled separately from the other costs. External failure costs are used to represent the cost related to the quality loss of food that could influence the action of customer. These could be measured as the level of satisfaction of product.

According to literature, quality factors for food could be divided into two major categories: nutrition & energy supply, and quality senses from physical senses. Nutrition and energy supply serves the basic function of food: to supply energy and bio-chemical needs to maintain the survival and functions of human body. Quality senses includes the physical senses customer received from the food product. Such senses include sight, touch, smell, taste, and even hearing. So in general, these senses are grouped into appearance factors, textural factors, and flavor.

With the consideration of the high level of government involvement in food industry regarding food safety, so in this thesis, the deterioration of food is assumed to be the loss of physical senses, but not related to the nutrition category.

### 3.1.3 Nutrition and energy supply loss.

The behavior of nutrition within food during the supply chain system should be discussed first before proceed to the modeling of the loss. There are several factors that heavily influence different type of nutrients. These factors are:

1. pH value;
2. air, or Oxygen;
3. light;
4. heat
5. Cooking methods, which influence the loss of nutrient during the cooking process.

Table 1 in literature review chapter has illustrated the stability of nutrients under certain condition.

In our case, due to the different storage method that was used for food, such as frozen, canned and normal condition, we assume that the storage environment is steady and stable, which means the factors listed above are steady and does not change during the food storage process and all the stages between food production and customer purchase.

Vitamin C is one of the most important nutrients in some fruit product, such as orange. Insufficient supply of Vitamin C could causes easy bleeding of gums, loosening of teeth, and bone joint diseases. So in this model, the change of vitamin C during the storage is used as the sample to illustrate the changes of nutrition during the modeled supply chain process.

Data used are the experimental data from a research paper studied in literature review. In the source, the researchers were trying to analyze the impact of temperature on the determination of shelf life of apple-based beikost. The fruit-based beikost, or as known as “Apple compote”, was composed of apple puree, lemon juice, and others, that were packed into 130g glass bottles. They analyzed 1225 bottles, and monitored the changes of vitamin C concentration during the storage period. All samples were taken periodically during a period of 420 days. The result is shown below:

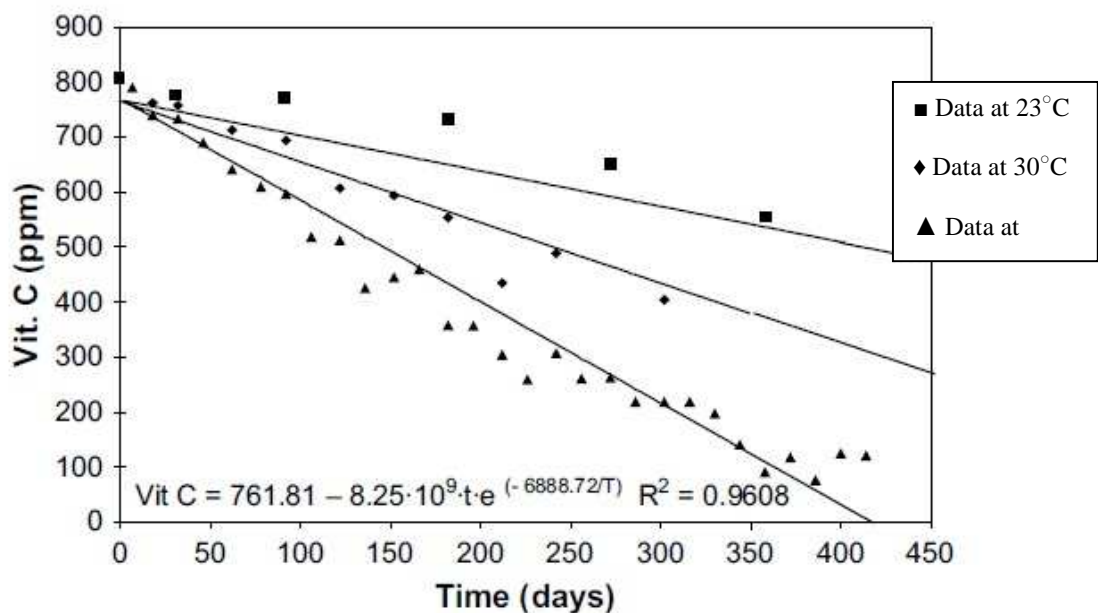


Figure 10: Measure of Loss of Vitamin C in Beikost in Period of 420 Days. (Palazzo'n et al 2009)

So based on the results showing above, the changes of concentration of vitamin C could be represented by a linear relationship with time. With a  $R^2$  value of 0.9608, we consider the linear relationship between time and loss of nutrition is acceptable, and could be used as an accurate estimate of the loss of nutrition.

However, from the figure, the impact of temperature should also be considered into the modeling of the loss. So the widely used method of  $Q_{10}$  in food science is used. The equation of  $Q_{10}$  used to describe the duration of storage to reach the same nutrition level under different temperature is:

$$f_2 = f_1 * Q_{10}^{\frac{\Delta}{10}} \quad (\text{Equation 1})$$

where  $f_1$  is the reference duration at reference temperature  $T_1$ ,  $f_2$  is the duration of the targeting temperature  $T_2$ .  $\Delta$  is the difference between targeting temperature  $T_2$  and sample temperature of  $T_1$ .

So the loss of nutrition value could be considered as the loss of oversized safety factor of food shelf life under performance of steady storage condition. A figure is developed to explain the loss.

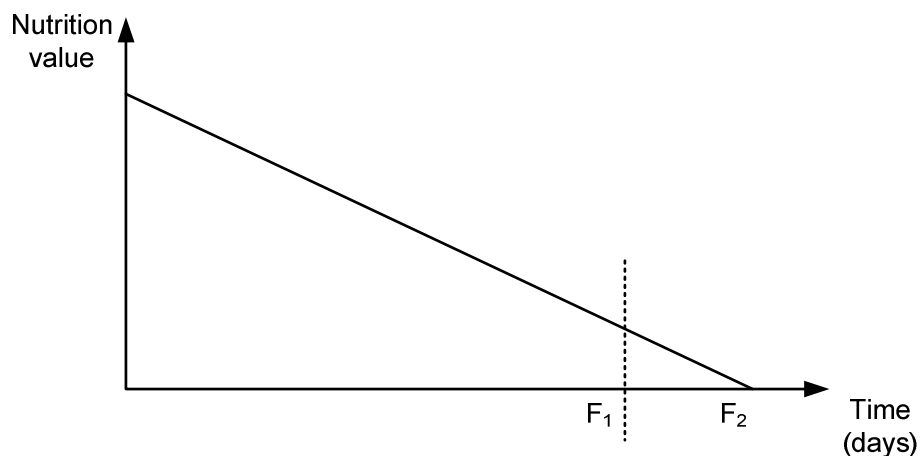


Figure 11: Nutrition Loss with Time.

So if we considered  $F_1$  to be the labeled shelf-life of food product, which has a higher temperature than normal storage temperature; and  $F_2$  to be the actual shelf-life under the normal storage temperature.

So we have: at day  $F_1$ , the nutrition loss is:

$$NL_{F_1} = \frac{a \cdot S_r}{F_2} \cdot F_1$$

At  $F_1-1$  day, the loss is:

$$NL_{F_1-1} = \frac{a \cdot S_r}{F_2} \cdot (F_1 - 1)$$

So we have the general equation of nutrition loss is:

$$NL_i = k_{NL} \cdot T = \frac{a \cdot S_r}{F_2} \cdot T,$$

where  $k_{NL}$  is the nutrition loss rate, T is the time after production measured in days.

So we have the equation of the total nutrition loss for an order period of n days is:

$$\begin{aligned} L_{NL} &= \sum NL_i = NL_1 + NL_2 + NL_3 + \dots + NL_n \\ &= \frac{a \cdot S_r}{F_2} \cdot (1 \cdot S_1 + 2 \cdot S_2 + 3 \cdot S_3 + \dots + n \cdot S_n) \end{aligned}$$

Where  $S_i$  is the number of product unit that has been sold on ith day.

So, if the sales on each day is equal in number, as

$$S_1 = S_2 = S_3 = \dots = S_n = S$$

Then we have the total loss of nutrition in each order period to be:

$$\begin{aligned} L_{nutri} &= \sum NL_i = NL_1 + NL_2 + NL_3 + \dots + NL_n \\ &= \frac{a \cdot S_r}{F_2} \cdot (1 \cdot S_1 + 2 \cdot S_2 + 3 \cdot S_3 + \dots + n \cdot S_n) \end{aligned}$$

$$L_{nutri} = \frac{a \cdot S_r}{F_2} \cdot (1 + 2 + \dots + n) \cdot S$$

$$L_{nutri} = \frac{a \cdot S_r \cdot Q^2}{2F_2 \cdot S} \quad (\text{Equation 2})$$

### 3.1.4 Physical senses loss.

To discussed more on the loss in physical senses, the interchangeability in measuring appearance factors, textural factors, and flavor factors must be discussed. Generally speaking, according to the definition of food science, appearance factors include size, shape, wholeness, color, consistency for liquid, and so on. Textural factors include hand feel and mouth feel of firmness, softness, juiciness, chewiness, grittiness. Flavor factors include both taste and odor.

In reality, color of product, such as fruit, is part of the appearance factors. But it is also being used as an indication of acceptable texture. So in some controlled conditions, automatic color measurement is used as a nondestructive measure of texture. People often consider red color of cherry, and strawberry is an indication of flavor, but the chemical that generates this taste is colorless. This means, people often using appearance factors to judge flavor. Further example could be brown beef on the dining table.

With the consideration of the diversity of quality factors, as well as the interchangeability in quality inspection, all the physical senses quality could be measured in one equation with limited variables. Since the loss of physical senses is the results of food deterioration, the variables are generally the major causes of food deterioration and the potential impact of these causes. Major causes of food deterioration include:

1. Growth and activities of microorganisms, such as bacteria, yeast and so on;

2. Activities of natural food enzymes;
3. Insects, parasites, and rodents;
4. Temperature, both heat and cold;
5. Moisture and dryness;
6. Air, or more particularly oxygen;
7. Light;
8. Time.

With the consideration of the quality of the packing and assumption of steady and stable storage environment, the impact of these potential variables is discussed below.

#### 3.1.4.1 Growth and activities of microorganisms;

Hundreds types of microorganisms out of the overall number of thousands types in total are associated with food product. Some of them are valuable in certain food processing stages, or was included in food for certain purposes. However, the negative impact of certain microorganisms should not be ignored, as they are one of the major sources that spoiling food. They also cause several diseases to human body after the consumption of contaminated food. Certain samples are the Staphylococcus, that causes Staphylococcus food poisoning, which could be found in cooked ham or other meat sources; of over 800 different types of Salmonella bacteria, which could causes Salmonellosis, which is popular in meat and poultry, or even egg products. To evaluate the changes and results from the growth and activities of microorganisms, how this microorganism was introduced into food, how they act within food should be discussed first.



Microorganisms are everywhere; the only place they were not found is living tissue. They invade the healthy tissue by a break on the skin, or when the skin is weakened by diseases or death. All food products are processed. This means that the original protection of microorganisms has corrupted, and could not perform its function. Proper packing could help in preventing, but during the manufacturing process, as well as the packing process, the microorganisms could still contaminate the food product.

According to research from food science, microorganisms could only be eliminated in 20-30 minutes under temperature of 124 degree, which is often generated by steam. This method is not applicable to all types of food product. The appearance of microorganisms in food product is unavoidable. So the focus is how to reduce its growing and activity in food product.

Their growing and activity is heavily influenced by temperature and moisture level of the environment. Most of them grow and multiply best at temperature between 16 degree and 38 degree. The other types could grow at temperature as high at 82 degree, or as low as 0 degree of water freezing point. Then the matter is the multiplying rate of these microorganisms. Microorganisms' grow by cell division, and will end when it reaches its maximum population. For some type of microorganisms, they could double the number within 30 minutes under their ideal environment. So based on these, if we assume the original number of microorganisms in food is A, then the number of microorganisms in food is under an equation of time T.

$$N = A \bullet T^2$$

The more microorganisms in the food, more loss the customer is suffering. If the loss rate is k, then the loss from microorganisms is:

$$L_{micro} = k \bullet N = k \bullet A \bullet T^2 = k_1 \bullet T^2 \quad (\text{Equation 3})$$

The formula is generated based on the previous assumptions that the storage environment is steady and unchanged, which means the temperature and moisture level of food in storage and shelf is unchanged.

#### 3.1.4.2 Activities of natural food enzymes;

According to Norman N. Potter, bacteria or microorganisms are the greatest factors in food deterioration, and the activity of enzyme is the second greatest. However, the certain factors that impact the activity of microorganisms, such as temperature, moisture level, light, radiation and so on are also applicable to enzymes.

So the results of control of microorganisms' activity, also impact on the activity level of enzyme. With no further data from literature, and based on the information and data that has been observed from literature, we consider the activity of enzyme follows the same trend as microorganisms, and the loss of it could be modeled with the following equation under steady and stable storage environment:

$$L_{enzyme} = k_2 \bullet T^2 \quad (\text{Equation 4})$$

#### 3.1.4.3 Insects, parasites, and rodents;

Annually, about 5 to 10% of U.S. grain crop was destroyed by insects. In some part of the world, the number could reaches 50%. The impact of insects are not what food

the insects could be consumed, but also the impacts from the bacteria and other microorganisms that is carried by these insects.

Factors of insects and other factors are controlled by controlling food import for new source of insects, restricted food processing and storage and so on. With the consideration of the proper packing of food product, the impact of insect is related to the quality loss of food during the raw material storage stage, which is not considered in our model. So the impact of insects are not discussed and included in our model.

#### 3.1.4.4 Temperature, moisture and dryness, air or oxygen, and light;

Based on the results in figure 1, conclusion could be drawn that storage temperature has a huge impact on the shelf-life, or storage life of food product. Its impact is not direct, but by applying its influence on the activity level of microorganisms, and enzymes.

For different type of food, under different temperature, their storage life is different. Table 3 is a list of useful storage life of some food product under certain temperature of storage.

In reality and actual application, after the food product leaves the producers' warehouse for shipment to retailer, the storage condition, such as temperature, moisture level, oxygen exposure, and light exposure is under a relatively steady and continuous environment. So they could be considered to be under a controllable manner, and be a fixed value, rather than a variable. So their impact in our model is not formulated.

Table 3: Useful Storage Life of Plant and Animal Tissues at Various Temperatures (Potter 1986)			
Food	Average Useful Storage Life (days)		
	0°C(32°F)	22°C(72°F)	38°C(100°F)
Meat	6-10	1	less than 1
Fish	2-7	1	less than 1
Poultry	5-18	1	less than 1
Dry meats and fish	1000 and more	350 and more	100 and more
Fruits	2-180	1-20	1-7
Dry fruits	1000 and more	350 and more	100 and more
Leafy vegetables	3-20	1-7	1-3
Root crops	90-300	7-50	2-20
Dry seeds	1000 and more	350 and more	100 and more

#### 3.1.4.5 Time

To wrap up all the discussion above, the impact of all food deterioration factors has been considered. Their impact is either influenced by time, or has been controlled during all the stages considered in our model to a fixed value. So we conclude that, the only changing factor in our model is time.

The other factor, such as deterioration factor activity rate, or the food deterioration rate, is defined as the mix value of the deterioration rate of different factors, such as microorganisms and enzymes. So we have the overall deterioration rate for physical senses loss is:

$$k_{PS} = k_1 + k_2$$

And then we have the total loss function of physical senses loss as:

$$L_{PS} = L_{micro} + L_{enzyme} = k_1 \cdot T^2 + k_2 \cdot T^2 = k_{PS} \cdot T^2 \quad (\text{Equation 5})$$

Since the value of it varies from different type of food and storage condition, the modeling of their impact is consulting the modeling of quality loss function in the case of “Smaller the better” from Taguchi’s model.

#### 3.1.4.6 Taguchi’s quality loss function and quality loss from physical senses

Taguchi’s quality loss function is originally designed to evaluate the quality loss associated with the design of tolerance in manufacturing industry. The assumption is that, products offers greatest satisfaction to customer with lowest level of functional defect occurs at certain value of quality parameter. For example, an iPod that could operates longer time without repair; its quality is considered to be better as it causes less inconvenience in usage, and results in higher level of customer satisfaction. This is a typical sample of the “larger the better” case of Taguchi’s Quality Loss Function. For “Smaller the better”, a typical sample is the waiting time for call center. The longer the waiting time is, the less satisfaction customers received. The formula of “Smaller the better” is showing below:

$$L(y) = \frac{A_0}{\Delta_0^2} \cdot y^2 = k \cdot y^2 \quad (\text{Equation 6})$$

In this formula,  $A_0$  is defined as the cost of defect, or cost of inconformity.  $\Delta_0$  is defined as the maximum allowable level of inconformity.  $y$  is defined as the actual level of inconformity. In the case of “Smaller the better”, the greater the value  $y$  is, the greater the loss is.

In our case, according to the discussion in previous section, the longer product stored, the greater loss customer is suffering. From equation 5, the loss of physical senses is measured by an equation with respect to time square.

So we conclude that the Taguchi’s Quality Loss function, the case of “Smaller the better” could be used to represent the loss of physical senses, where

$$k_{ps} = k = \frac{A_0}{\Delta_0^2} ;$$

$$y = T ;$$

And the value of  $A_0$  is the cost of maximum level of inconformity, and in our case as the sales price that customer pay.  $\Delta_0$  is the shelf-life labelled on product.  $y$  is the time measured in days after the product has been produced. So in this manner, we could convert the loss of physical senses, into economical data that could be modeled in our discussion.

Nutrition loss is a loss due to the nature of chemical reaction, and is considered as a loss upon acceptable limit. (Labeled nutrition value is the value estimated at the expiration date. Actual value is more than labeled value.) So it could be grouped into the quality loss within the stages of producer and retailer. However, the loss of physical

senses is mainly suffered by customer who is paying the price for food. At expiration date, to protect the safety of family, customer might have to dispose the food product, leave food with no salvage value, and cost the customer full price they paid. So the loss of physical senses mainly occurs on the customer side, and could be grouped into the cost of external failure.

So we have:

At day 1, under consistent sales, loss is:

$$PS_1 = k_{PS} \cdot 1^2 \cdot S = k_{PS} \cdot S$$

At day 2, under consistent sales, loss is:

$$PS_2 = k_{PS} \cdot 2^2 \cdot S = 4 \cdot k_{PS} \cdot S$$

At day n, the loss is:

$$PS_n = k_{PS} \cdot n^2 \cdot S = n^2 \cdot k_{PS} \cdot S$$

So we have the total physical senses loss in an order period is:

$$L_{PS} = PS_1 + PS_2 + PS_3 + \dots + PS_n = k_{PS} \cdot (1^2 + 2^2 + 3^2 + \dots + n^2) \cdot S$$

$$L_{PS} = \frac{b \cdot Sr \cdot Q^3}{3F_1^2 S^2} \quad \text{(Equation 7)}$$

### 3.2 Food risk

So from all the previous sections, all aspect of cost of quality according to Juran's cost of quality has been discussed and covered with a certain parameter and variable.

However, to consider the characteristic of food product on its social sector, the opportunity and intangible cost of further risk should be evaluated. Figure in literature

review section regarding Ross and Sumner's model has described the structure of the food risk clearly.

To fully model the financial cost of food risk, there are two sections needs to be included. The first section is targeting on the overall risk for food product, regarding the opportunity of occurrence, risk exposure, and severity assessment. The second section is dedicated to model the potential impact of time on the financial costs.

### 3.2.1. Overall food risk.

In this section, the model is started with the concept of "Comparative risk" as defined by Ross and Sumner. Basically, three main sectors as the probability of illness over all servings, total exposures per year for products, and the final quantification of the financial costs of risks are included here.

#### a. Probability of illness over all servings.

Under this section, five variables contribute to it.

1. Microbial loading estimate, or the original risk. Q1
2. Post processing control quality. Q2
3. Consumer preparation. Q3
4. Proportion of product contaminated. Q4
5. Recontamination of product. Q5

Q1 to Q3 overcomes the probability of illness when consuming contaminated product, where the overall of these five variables forms the probability of illness over all servings.

The recommended reference number for each variable could be found at Ross and Sumner's paper.



b. Total exposures per year.

The “total exposures per year” is a general estimation of occurrence for a certain population. It contains the frequency of consumption Q6, proportion of population Q7, and the population size Q8.

Usually Q6 is measured by weekly, daily, or monthly. In numerical expression, could be 365 for daily, 52 for weekly, and 12 for monthly. For proportion of population, this is used to represent the case that not all the population of the society is consuming a certain product. So a percentage number is used to indicate the proportion of the population that might be impacted by the product. the population size is a reference number to finalize the total number of potential exposures for each year, which could be the population of a city, a province, or a country, which is defined by the scope of the usage.

However, one further variable has to be included to ensure the feasibility of the application of this model in this thesis. Due to the scope of this thesis, a market share variable should be included. Under this action, the overall risk for the industry, could be clarified into each company.

c. Quantification of financial costs.

To combine the result from the previous two sections, the overall possibility of risk occurrence could be obtained. However, the severity of each case might vary, and results in the difficulty of quantification of risk.

In Ross and Sumner’s model, they developed the Hazard Severity variable, which has a maximum value of 1 represent certainly death, and 0.001 for minor hazard which patient rarely seeks medical attention. So this variable has been used, and given more

value into it. For different products, the risk severity varies. Product with higher risk, such as seafood, has a higher value of severity, such as 1. And for canned food product, or dehydrated food product, the risks caused by them are rare, so the number is 0.01, as the minimal value. So by setting the value of this severity variable, the characteristic of different type of food product could be represented.

The last value needs to be discussed is the financial cost of certain risk. In our model, by considering the effect of the severity factor, the overall costs could be set as a fix number among all products, which results the final outcome of the model still valid to represent the intangible opportunity cost of food risk.

So the final overall food risk financial cost is:

$$R_f = C_3 \times \frac{C_4}{365} \times HazardSeverity = Q_1 \times Q_2 \times Q_3 \times Q_4 \times Q_5 \times \frac{Q_6 \times Q_7 \times Q_8}{365} \times \eta \times HS \times 3000000 \quad (\text{Equation 8})$$

Where HS is the hazard severity factor, and  $\eta$  is the market share.

### 3.2.2 Time value for food risk

The model developed by Ross and Sumner is dedicated to represent the food risk in a general format, with the consideration of the occurrence of risk in an average scale. The comparative risk is the risk of occurrence for a certain day in one year. It does not concern the impact of time.

As we have mentioned earlier in this thesis, the major source for food deterioration and food-borne illness is the growth and activities of microorganisms. So the

timing of product for its food risk should follow the same trend of the growing of these microorganisms.

So, if  $R_f$  is the average financial risk for each day, and the expression for food risk for a product ordering cycle is  $R = k_{fr}T^2$ , where  $k_{fr}$  is the coefficient of financial risk, and  $T$  is the time. So by using numerical knowledge, the overall risk for a certain period of  $T$  is  $\sum R = \frac{1}{3}k_{fr}T^3$ , so the average risk is  $\bar{R} = \frac{1}{3}k_{fr}T^2$ .

So we have:

$$\bar{R} = \frac{1}{3}k_{fr}T^2 = Q1 \times Q2 \times Q3 \times Q4 \times Q5 \times \frac{Q6 \times Q7 \times Q8}{365} \times \eta \times HS \times 3000000$$

(Equation 9)

Since the quantification of risk over time should consider the time period of product shelf life, so in the equation above,  $T$  value equals to the product shelf life  $F_1$ , and the coefficient of  $K_{fr}$  should be obtained.

The financial risk coefficient is:

$$k_{fr} = \frac{3 \times Q1 \times Q2 \times Q3 \times Q4 \times Q5 \times \frac{Q6 \times Q7 \times Q8}{365} \times \eta \times HS \times 3000000}{F_1^2}$$

So the overall risk for a year could be modeled as:

$$R_f = \frac{3 \times Q1 \times Q2 \times Q3 \times Q4 \times Q5 \times \frac{Q6 \times Q7 \times Q8}{365} \times \eta \times HS \times 3000000}{F_1^2} \times \left(\frac{365Q}{D}\right)^2$$

(Equation 10)

For each and different parties in the model, as the producer, retailer, and customer, the overall financial risks are assigned to each based on the risk assignment factors. So the financial risk for each party is presented as:

For producer:

$$R_{fr,p} = \alpha \times Rf$$

For retailer:

$$R_{fr,r} = \beta \times Rf$$

And we have:  $\alpha + \beta = 1$ .

### 3.3 Objective function:

In industry, there are three business models. The more traditional model is the case that food producer is also the distributor. Newer sample for this includes the brand or product developed and manufacturing by retailer themselves. This case is considered as Model 1. The other two cases are the producer or retailer simply focuses on their core function in the supply chain system, which is: producer only performs the function and activities of producer (Model 2), and retailer only operates the core functions and activities of retailer (Model 3). Model 3 is the case that is most close to the EOQ model, and the results from this model could be used to compare with other existing model to evaluate the proposed model.

### 3.3.1 Model 1: Organization acts as both producer and retailer

The objective function is:

$$\begin{aligned} \text{MIN} \quad & Pp \bullet D + C_s \bullet \frac{Q}{y \bullet Q_p} + Pq \bullet D \bullet \frac{(1-y)}{y} + Pt \bullet D + C_o \bullet \frac{D}{Q} + h \bullet Sp \bullet \frac{Q}{2} + \frac{a \bullet Sr \bullet D}{2F_2 \bullet S} \bullet Q \\ & + \frac{b \bullet Sr \bullet D}{3F_1^2 \bullet S^2} \bullet Q^2 + \frac{3 \times Q1 \times Q2 \times Q3 \times Q4 \times Q5 \times \frac{Q6 \times Q7 \times Q8}{365} \times \eta \times HS \times 3000000}{F_1^2} \times \left(\frac{365Q}{D}\right)^2 \end{aligned} \quad (\text{Equation 11})$$

The optimal solution of this objective function occurs when:

$$\begin{aligned} \frac{d}{dQ} = 0 = & \frac{C_s}{y \bullet Q_p} + \frac{h \bullet Sp}{2} + \frac{a \bullet Sr \bullet D}{2F_2 \bullet S} + \frac{2b \bullet Sr \bullet D}{3F_1^2 \bullet S^2} \bullet Q \\ & + \frac{2 \times 133225 \times 3 \times Q1 \times Q2 \times Q3 \times Q4 \times Q5 \times \frac{Q6 \times Q7 \times Q8}{365} \times \eta \times HS \times 3000000}{F_1^2 \times D^2} \times Q - \frac{C_o \bullet D}{Q^2} \end{aligned}$$

Simplify the equation, we have:

$$\left(\frac{2b \bullet Sr \bullet D}{3F_1^2 \bullet S^2} + \frac{2 \times 133225 \times k_{fr}}{D^2}\right) \bullet Q^3 + \left(\frac{C_s}{y \bullet Q_p} + \frac{h \bullet Sp}{2} + \frac{a \bullet Sr \bullet D}{2F_2 \bullet S}\right) \bullet Q^2 - C_o \bullet D = 0 \quad (\text{Equation 12})$$

As a Cubic equation, from knowledge of mathematics, the equation could be modeled as:

$$ax^3 + bx^2 + cx + d = 0 \quad (\text{Equation 13})$$

In our case, c=0, so the test of root,

$$\Delta = 18abcd - 4b^3 + b^2c^2 - 4ac^3 - 27a^2d^2 \quad (\text{Equation 14})$$

, the test of root is:

$$\Delta = -4b^3 - 27a^2d^2 \quad (\text{Equation 15})$$

As all numbers in our model are all positive value, the value of  $\Delta$  is negative, which means the equation has only one real root, and two nonreal complex conjugate roots.

The value of real root could be calculated by using certain calculator, or by following the following equation:

$$Q = -\frac{b}{3a} - \frac{1}{3a} \sqrt[3]{\frac{1}{2}[3b^3 + 27a^2d + \sqrt{(2b^3 + 27a^2d)^2 - 4(b^2)^3}]} - \frac{1}{3a} \sqrt[3]{\frac{1}{2}[3b^3 + 27a^2d - \sqrt{(2b^3 + 27a^2d)^2 - 4(b^2)^3}]} \quad (\text{Equation 16})$$

Where :

$$a = \frac{2b \bullet Sr \bullet D}{3F_1^2 \bullet S^2} + \frac{2 \times 133225 \times k_{fr}}{D^2},$$

$$b = \frac{C_s}{y \bullet Q_p} + \frac{h \bullet Sp}{2} + \frac{a \bullet S_r \bullet D}{2F_2 \bullet S},$$

$$d = -C_o D.$$

### 3.3.2 Model 2: Organization only performs as producer. No functions of distributor.

The general concept of cost of quality and quality loss function was both designed to evaluate the quality on the manufacturer's interest. From model 1, the factors that are related to their interest are the cost of quality from defect products, the cost of set up, as well as the external loss. Cost of quality from defect products, are the cost that could not be recovered by the sales of product. Since most of the food products are produced in batch production, a single product that has been contaminated will results in the defect of all products from the same batch. In order to fulfill the order, the producer has to set up more batches for production. Taguchi's quality loss function is one of the earliest functions to explore the external loss of quality. In our model, the loss in physical senses

is the results from some of the controllable factors, such as microorganisms and temperature. So they are considered as the external loss of quality. Loss of nutrition is the results from nature, and it could still offer its basic function at the expiration day, so its loss does not considered as part of the loss for producer as results from product quality, and will not be included in the objective function for model 2.

Ordering cost is shared among both retailer and producer, as both parties needs to contributes in such activity. But since the holding of raw material is not included in our model, so holding cost is not for producers concern.

So the objective function for producer could be shown as follow:

For model 2: producer has no retailing functions:

$$\begin{aligned} \text{MIN} \quad & Pp \cdot D + C_s \cdot \frac{Q}{y \cdot Q_p} + Pq \cdot D \cdot \frac{(1-y)}{y} + Pt \cdot D + C_o \cdot \frac{D}{Q} + \frac{a \cdot Sr \cdot D}{2F_2 \cdot S} \cdot Q + \frac{b \cdot Sr \cdot D}{3F_1^2 \cdot S^2} \cdot Q^2 \\ & + \alpha \times \frac{133225 \times k_{fr}}{D^2} Q^2 \end{aligned}$$

(Equation 17)

The optimal value of Q could be found:

$$\frac{d}{d(Q)} = \left( \frac{C_s}{y \cdot Q_p} + \frac{a \cdot Sr \cdot D}{2F_2 \cdot S} \right) - \frac{C_o \cdot D}{Q^2} + 2 \cdot \left( \frac{b \cdot Sr \cdot D}{3F_1^2 \cdot S^2} + \alpha \times \frac{133225 \times k_{fr}}{D^2} \right) \cdot Q = 0$$

(Equation 18)

Simplify function we have:

$$\frac{d}{d(Q)} = 2 \cdot \left( \frac{b \cdot Sr \cdot D}{3F_1^2 \cdot S^2} + \alpha \times \frac{133225 \times k_{fr}}{D^2} \right) \cdot Q + \left( \frac{C_s}{y \cdot Q_p} + \frac{a \cdot Sr \cdot D}{2F_2 \cdot S} \right) - \frac{C_o \cdot D}{Q^2} = 0$$

(Equation 18)

By applying mathematical cubic equation solving techniques, the optimal value of Q could be found.

### 3.3.3 Model 3: organization only performs functions of retailer.

For the interests for retailer, their major source for profit is the difference between the sales price of goods and the cost of goods. Cost of goods includes the purchasing price, ordering cost, holding and managerial cost, cost of good will and reputation and so on. Managerial cost, such as the cost of running freezer for frozen food could also be considered as part of holding cost. So in this model could be considered that they are integrated into holding cost.

According to some study in literature review, public and customer consider retailer has responsibility for some food safety and risk issues. Risk for food product should be included in the cost modeling for retailer.

So based on the discussion above, the objective function for retailer with no production function is:

$$\text{MIN} \quad Sp \cdot D + C_o \cdot \frac{D}{Q} + h \cdot Sp \cdot \frac{Q}{2} + \frac{a \cdot Sr \cdot D}{2F_2 \cdot S} \cdot Q + \frac{b \cdot Sr \cdot D}{3F_1^2 \cdot S^2} \cdot Q^2 + \beta \times \frac{133225 \times k_{fr}}{D^2} \cdot Q^2$$

(Equation 19)

Optimal value for Q could be found by:

$$\frac{d}{d(Q)} = -\frac{C_o \cdot D}{Q^2} + \frac{h \cdot Sp}{2} + \frac{a \cdot Sr \cdot D}{2F_2 \cdot S} + 2 \cdot \left( \frac{b \cdot Sr \cdot D}{3F_1^2 \cdot S^2} + \beta \times \frac{133225 \times k_{fr}}{D^2} \right) \cdot Q = 0;$$

(Equation 20)

Simplify function we have:

$$\frac{d}{d(Q)} = 2 \cdot \left( \frac{b \cdot Sr \cdot D}{3F_1^2 \cdot S^2} + \beta \times \frac{133225 \times k_{fr}}{D^2} \right) \cdot Q + \left( \frac{h \cdot Sp}{2} + \frac{a \cdot Sr \cdot D}{2F_2 \cdot S} \right) - \frac{C_o \cdot D}{Q^2} = 0$$

(Equation 21)



By applying mathematical cubic equation solving techniques, the optimal value of Q could be found.

#### 3.3.4 Feasibility and scope of models:

In industry, some company may have product that has been directly retailed, and some others being sold to other retailer. In this or other combined cases, the choice of model is made based on the division of product that follows the business model. Which means a company could use both model 1 for self retailed product, and model 3 for other products.

Also, model one is more feasible in retailer with production model. Primary food industry, such as crop and animal production, is not considered as producer in this model. Model 1 is not feasible for their case.

CHAPTER IV  
ANALYSIS OF RESULTS

The analysis is conducted separately for each model.

4.1 Model 1: Organization acts as both producer and retailer

The major distinguishable factors among all food products are the duration of shelf life, and the food risk level. For usable shelf life for food product, as we have mentioned before, the key factors are the initial shelf life, and the storage temperature. The end results in the initial shelf life, and the  $Q_{10}$  value. For food risk level, as we have proposed in the methodology chapter, the hazard severity variable could represent the risk level variability of different food products. To demonstrate the results of model, four types of product have been chosen to illustrate the application of the model for products under certain characteristics.

The sample products are bread, milk, frozen seafood, and fresh packed sausage.

Value for variables being used are illustrate below:

Table 4: Value for Variables in Model 1				
	Bread	Milk	Seafood	Sausage
D	1460000	730000	365000	730000
Q	430	1800	3800	351
$C_O$	50	100	200	50
$C_S$	50	200	50	50
$Q_P$	50	50	50	50
$S_r$	3	5	10	5
$S_p$	2.2	3.5	7	3.5
y	0.99	0.99	0.99	0.99
h	0.02	0.02	0.03	0.03
$Q_{10}$	2 (Karel 2003)	2	2.4	2.4
F1	7	90	365	7

	Bread	Milk	Seafood	Sausage
F2	8.61	110.7	474.5	9.1
Pp	2	3	5	3
Pq	2	3	5	3
Pt	0.1	0.1	0.1	0.1
Q1	0.000001	0.000001	0.001	0.001
Q2	1	1	2	1
Q3	1	1	5	1
Q4	0.01	0.01	0.01	0.01
Q5	1	1	1	1
Q6	365	365	26	120
Q7	0.75	0.75	0.75	0.75
Q8	31000000	31000000	31000000	31000000
C3	0.00000001	0.00000001	0.0001	0.00001
C4	8486250000	8486250000	604500000	2790000000
HS	0.01	0.05	0.5	0.05
CR	0.002325	0.011625	82.80821918	3.821917808
$\eta$	0.3	0.3	0.5	0.3
a	0.3	0.3	0.3	0.3
b	0.7	0.7	0.7	0.7

Population data is obtained from Statistic Canada, reference number 28.

Based on these variables, the results of each type of costs, includes the tangible and intangible costs, and are listed below:

Table 5: Results from Model 1 for four Different Products.

	bread		milk		seafood		sausage	
Production Cost	2920000	85.8685%	2190000	92.6742%	1825000	95.1732%	2190000	88.5512%
Set-up Cost	434.3434	0.0128%	7272.727	0.3078%	3838.384	0.2002%	354.5455	0.0143%
Quality Cost	29494.95	0.8674%	22121.21	0.9361%	18434.34	0.9613%	22121.21	0.8945%
Transportation Cost	146000	4.2934%	73000	3.0891%	36500	1.9035%	73000	2.9517%
Ordering Cost	169767.4	4.9924%	40555.56	1.7162%	19210.53	1.0018%	103988.6	4.2047%
Holding Cost	9.46	0.0003%	63	0.0027%	399	0.0208%	18.4275	0.0007%
Nutrition Loss	99429.84	2.9239%	26977.09	1.1416%	13286.71	0.6929%	63993.51	2.5875%
Physical Senses Loss	35413.09	1.0414%	3128.252	0.1324%	847.663	0.0442%	19663.46	0.7951%
Food Risk Loss	0.00148	0.0000%	0.003139	0.0000%	40.3894	0.0021%	6.486393	0.0003%
Total Cost	3400549		2363118		1917557		2473146	
% Intangible Costs	3.97%		1.27%		0.74%		3.38%	

Bread is used to showcase the application of model for product with shorter usable life, and milk to represent for longer shelf life. Both of these samples has low risk level, and according to literature, tissue enzyme is not the major source for deterioration, so their  $Q_{10}$  value is 2. Both fresh packed sausage and frozen seafood have tissue enzyme as their major cause of deterioration. Their usable shelf life or 7 days and one year also demonstrate the impacts of initial shelf life on the cost structure of product.

From the results, we can see that, for products with longer shelf life, the production costs contributes over 90% of the overall costs, and increases as shelf life increases. The holding costs also increase as initial shelf life increases. However, on the other hand, products with shorter usable life do have higher ordering costs, nutrition loss, and loss from physical senses. The results do indicate that product with higher food risk has higher potential costs from food risk. Product with longer usable life experiences more overall intangible costs. As the testing quality level is 99%, so all products have quality costs under 1%, and products with long shelf life have a relatively higher percentage of quality costs.

A sensitivity analysis has been conducted, to illustrate the impact of certain variables. The samples includes: annual demand (D), ordering quantity (Q), initial usable life (F1), weighting value for nutrition and physical senses loss (a, b), hazard severity (HS), and the decisional factors are: overall costs, duration of each ordering cycle, optimal ordering quantity, potential risks, and percentage intangible costs. Value of other variables uses the value of bread for demonstration.

#### 4.1.1 Annual demand (D)

	1	2	3	4	5
D	876000	949000	1022000	1095000	1168000
Optimal Q	1303	1362	1418	1473	1525
Total cost	1920802	2078019	2235142	2392182	2549146
Duration T	0.542917	0.523846	0.506429	0.491	0.476563
Risk	0.037762	0.035156	0.032857	0.030885	0.029096
% intangible costs	1.49%	1.43%	1.38%	1.33%	1.29%
	6	7	8	9	
D	1241000	1314000	1387000	1460000	
Optimal Q	1577	1627	1675	1723	
Total cost	2706043	2862878	3019655	3176380	
Duration T	0.463824	0.451944	0.440789	0.43075	
Risk	0.027561	0.026167	0.024892	0.023771	
% intangible costs	1.25%	1.22%	1.19%	1.16%	

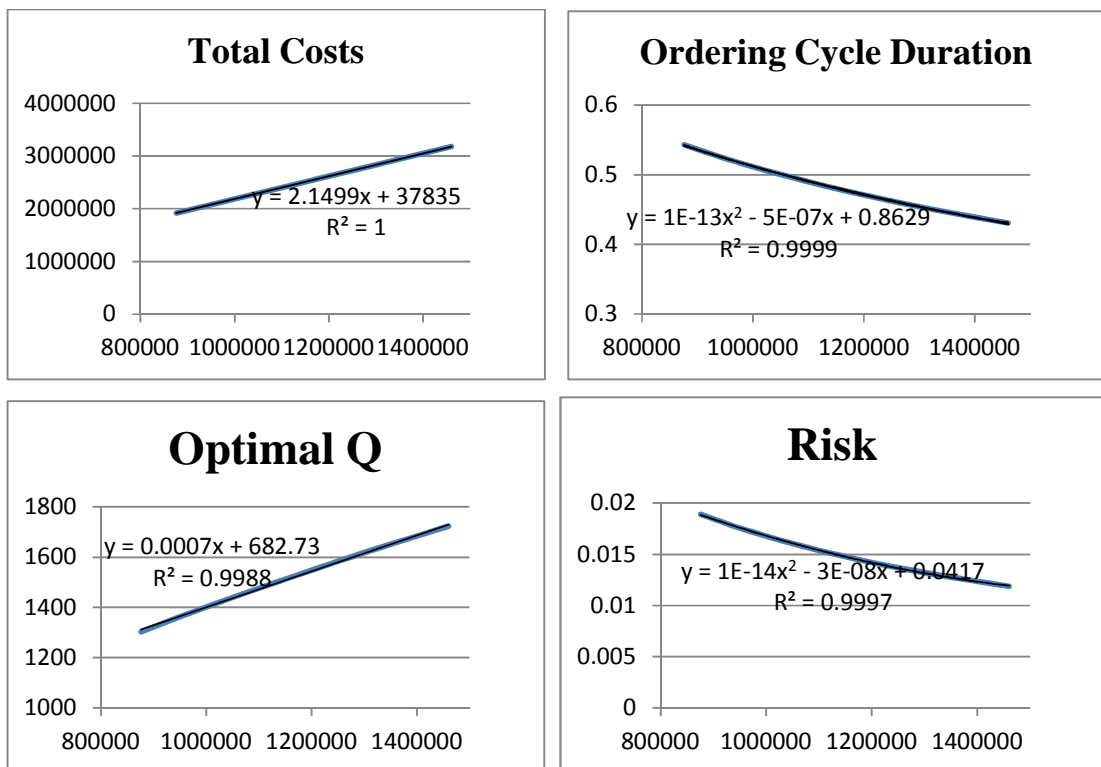


Figure 12: Sensitivity Analysis of Annual Demand on Total Costs, Ordering Cycle Duration, Optimal Ordering Quantity, and Food Risk.

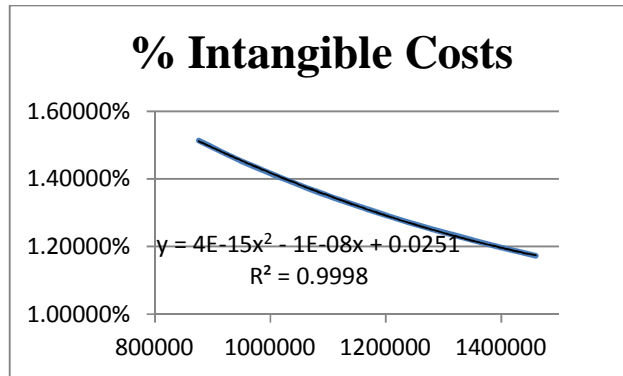


Figure 13: Sensitivity Analysis of Annual Demand on Percentage Intangible Costs.

According to the data list above, we can conclude that, optimal ordering quantity increases as demand increase. The duration of ordering cycle also reduced, from 0.549 days to 0.43 days. And with the time for duration reduce, food deterioration process before customer receive it has been limited, and results in a reduction in food risk. Overall intangible costs also have decreases. This also proves that, mass production system also benefits in the control of intangible costs.

#### 4.1.2 Ordering Quantity (Q)

	1	2	3	4	5
D	120450	120450	120450	120450	120450
Q	250	300	350	400	424
Total cost	285483.2	282908.1	281559.3	281006.4	280949.3
Duration T	0.757576	0.909091	1.060606	1.212121	1.284848
Risk	0.073526	0.105878	0.144112	0.188227	0.211492
% intangible costs	0.0202	0.0253	0.0306	0.0362	0.0389
	6	7	8	9	
D	120450	120450	120450	120450	
Q	450	500	550	600	
Total cost	281010.5	281428.2	282168.3	283169.8	
Duration T	1.363636	1.515152	1.666667	1.818182	
Risk	0.238225	0.294105	0.355867	0.423512	
% intangible costs	0.0419	0.0479	0.0541	0.0605	

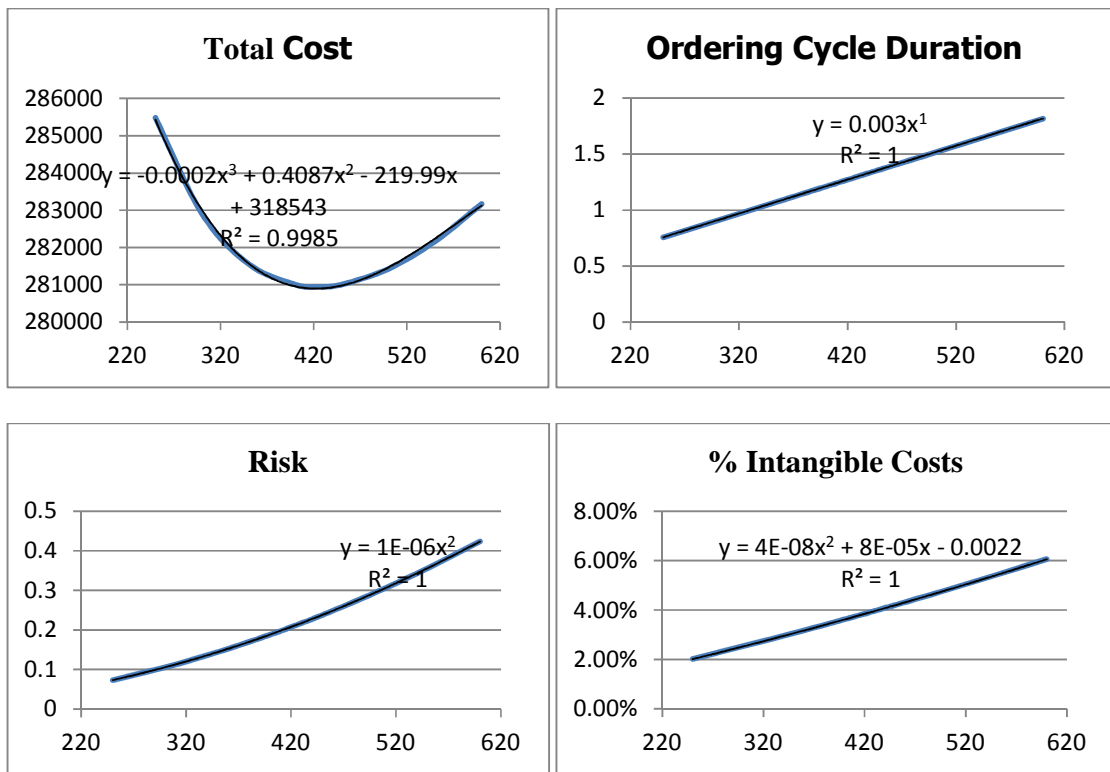


Figure 14: Sensitivity Analysis of Ordering Quantity on Total Costs, Ordering Cycle Duration, Food Risk and Percentage Intangible Costs.

According to our sample, the optimal ordering quantity is 424 unit. From the data listed, we can see that, the overall intangible costs could be double by increasing the ordering quantity, and results in high potential unknown loss.

#### 4.1.3 Initial usable life (F1)

Table 8: Sensitivity Test for Initial Usable Life under Model 1					
	1	2	3	4	5
F1	3	7	14	30	60
D	120450	120450	120450	120450	120450
Q	258.7	424	623	923	1259
Total cost	296187.6	280941.8	273158.4	267693.5	264601.7
Duration T	0.783939	1.284848	1.887879	2.79697	3.815152
Risk	0.428656	0.211492	0.114151	0.054566	0.025381
% intangible costs	0.0583	0.0389	0.0273	0.0181	0.0119

Table 8 Con't					
	6	7	8	9	
F1	90	120	180	360	
D	120450	120450	120450	120450	
Q	1468	1612	1801	2056	
Total cost	263378.1	262710	261993.5	261216.8	
Duration T	4.448485	4.884848	5.457576	6.230303	
Risk	0.015336	0.010402	0.005771	0.00188	
% intangible costs	0.009	0.0074	0.0054	0.003	

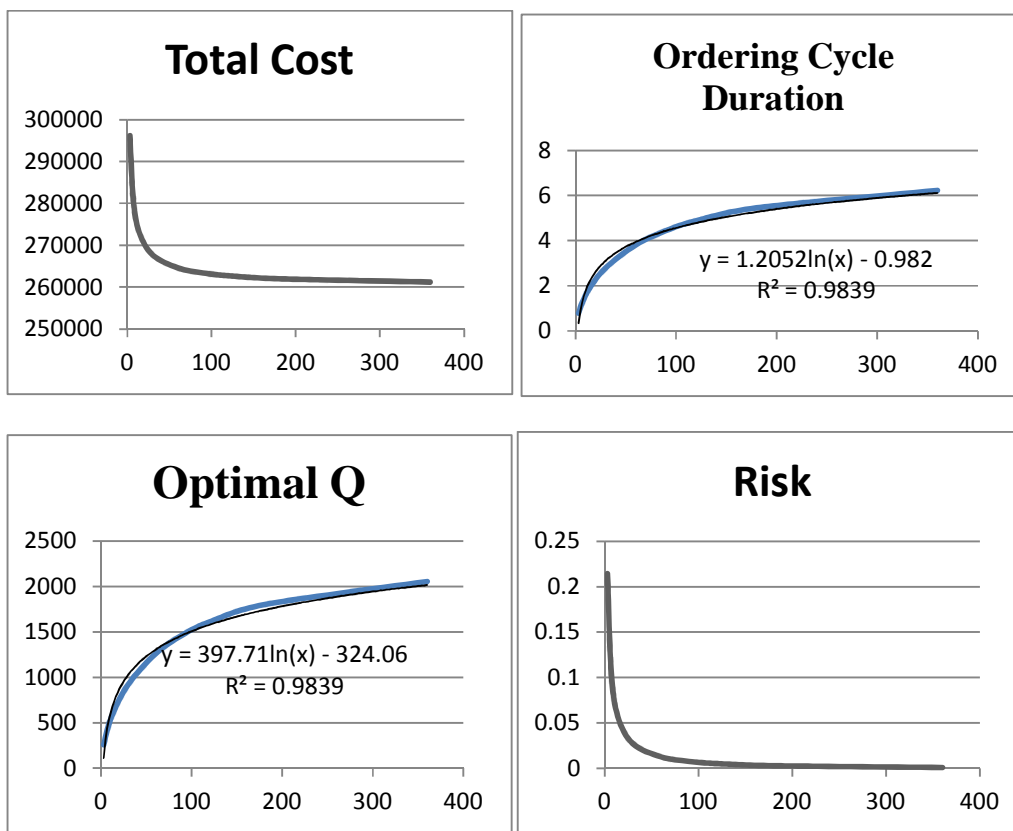


Figure 15: Sensitivity Analysis of Initial Usable Life on Total Costs, Ordering Cycle Duration, Optimal Ordering Quantity, and Food Risk.



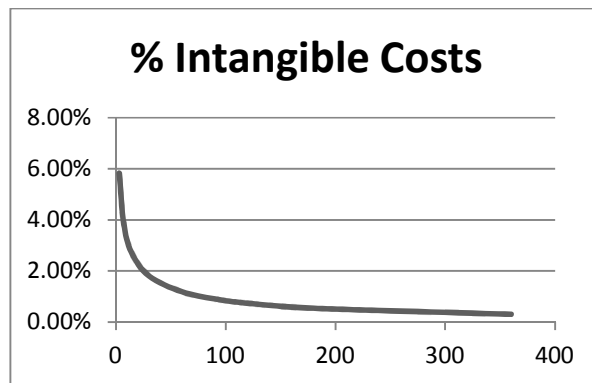


Figure 16: Sensitivity Analysis of Initial Usable Life on Percentage Intangible Costs.

For products with longer initial usable life, the duration of ordering cycle could be increased. And the amount of intangible costs could reach as low as 0.30% when usable shelf life increased.

#### 4.1.4 Weighting value for loss

Table 9: Sensitivity Test for Weighting Value for Nutrition Loss and Physical Senses Loss under Model 1					
	1	2	3	4	5
a	0	0.1	0.2	0.3	0.4
b	1	0.9	0.8	0.7	0.6
D	876000	876000	876000	876000	876000
Q	1865	1630	1446	1303	1190
Total cost	1893503	1903637	1912662	1920802	1928237
Duration T	0.777083	0.679167	0.6025	0.542917	0.495833
Risk	0.077362	0.059094	0.046506	0.037762	0.031496
% intangible costs	0.005701	0.009344	0.012329	0.014861	0.017065
	6	7	8	9	
a	0.5	0.6	0.7	0.8	
b	0.5	0.4	0.3	0.2	
D	876000	876000	876000	876000	
Q	1099	1024	961	908	
Total cost	1935102	1941498	1947502	1953175	
Duration T	0.457917	0.426667	0.400417	0.378333	
Risk	0.026864	0.023322	0.020541	0.018337	
% intangible costs	0.019026	0.020794	0.022406	0.023911	

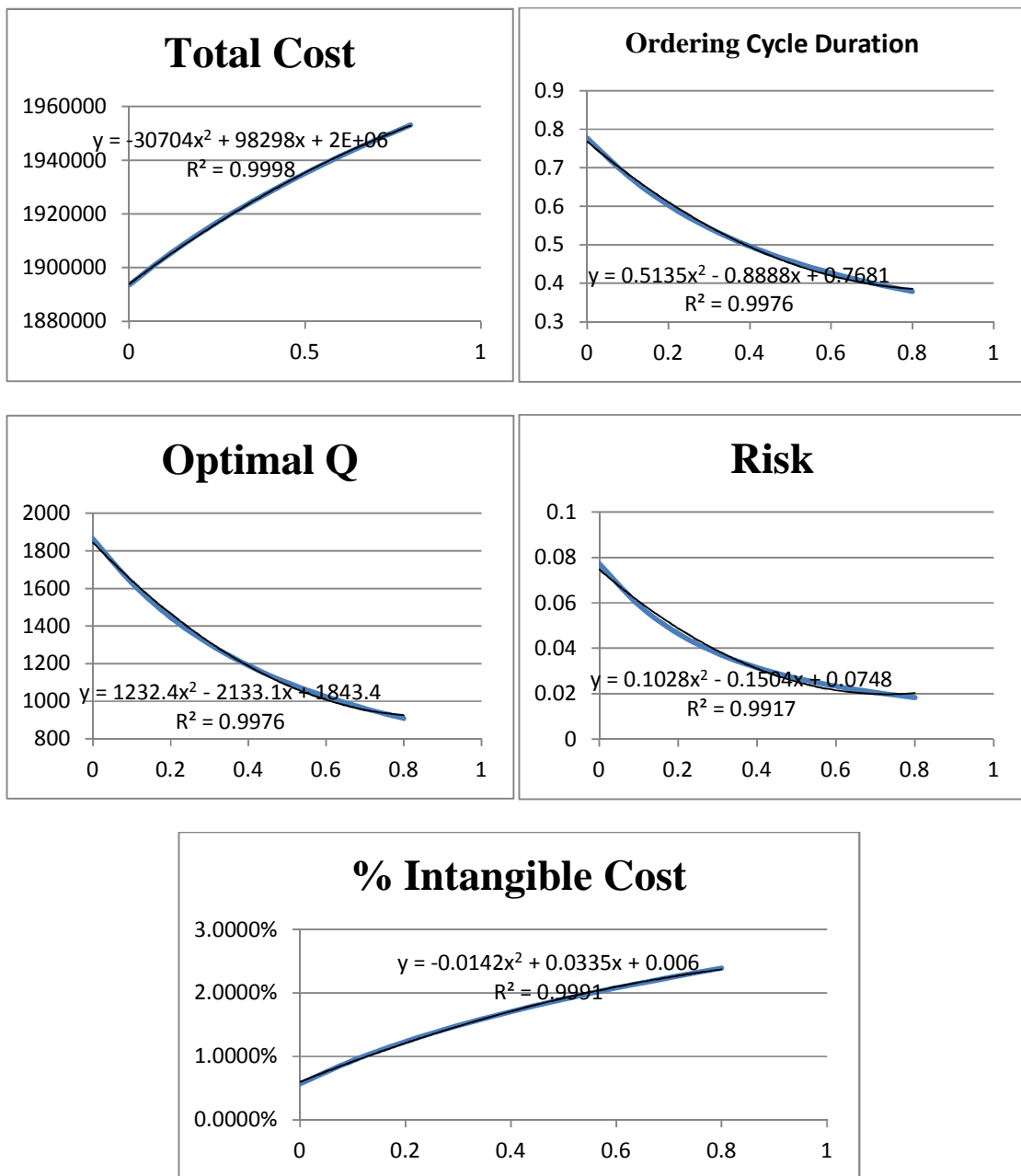


Figure 17: Sensitivity Analysis of Annual Demand on Total Costs, Ordering Cycle Duration, Optimal Ordering Quantity, Food Risk, and Percentage Intangible Costs..

One of the decision making factor is the weighting value of nutrition loss and physical senses loss. Since most of the customers make their purchasing decision based on the appearance of product rather than the actual nutrition value of product, so 4.1.4 section is used to test for the

result of that factor. It turns out to be, as the weighting of nutrition loss increase, optimal ordering quantity decrease, and overall costs increased. Duration of cycle decreased from 0.78 days to 0.38 days. However, the food risk do decreased from 0.077 to 0.018.

#### 4.1.5 Hazard severity (HS)

	1	2	3	4	5
Hazard severity	0.01	0.05	0.1	0.2	0.3
D	876000	876000	876000	876000	876000
Q	1303	1303	1303	1303	1303
Total cost	1920802	1920802	1920802	1920803	1920803
Duration T	0.542917	0.542917	0.542917	0.542917	0.542917
Risk	0.037762	0.188811	0.377622	0.755243	1.132865
% intangible costs	0.014861	0.014861	0.014861	0.014862	0.014862
	6	7	8	9	
Hazard severity	0.5	0.6	0.8	1	
D	876000	876000	876000	876000	
Q	1303	1303	1303	1303	
Total cost	1920804	1920804	1920805	1920806	
Duration T	0.542917	0.542917	0.542917	0.542917	
Risk	1.888109	2.26573	3.020974	3.776217	
% intangible costs	0.014862	0.014862	0.014863	0.014863	

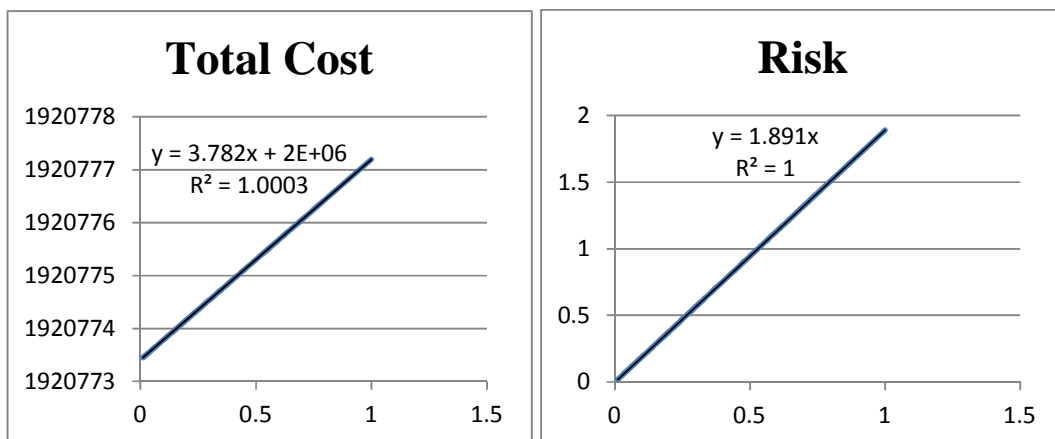


Figure 18: Sensitivity Analysis of Hazard Severity on Total Costs, and Food Risk.

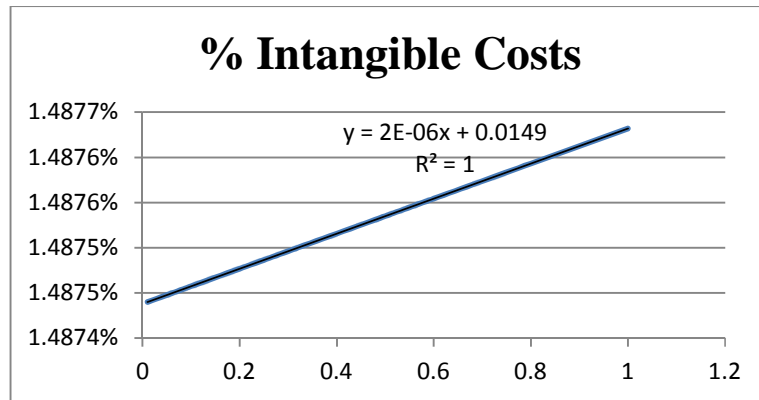


Figure 19: Sensitivity Analysis of Hazard Severity on Percentage Intangible Costs.

Results above indicate that product with high risk and low risk do not experience much difference in overall costs (less than 0.01%). Optimal ordering quantity, duration of cycle, overall intangible costs for different risk level maintain similar with less than 0.01% variation.

4.2 Model 2: Organization only performs as producer. No functions of distributor.

By using all the same variables in model 1, and following the objective function of producer only case of model 2, the results are showing below: (food risk is assumed to be shared equally between producer and retailer)

	Bread		Milk		Seafood		Sausage	
Optimal Q	429		1800		3828		468	
Production Cost	2920000	85.868750%	2190000	92.676647%	1825000	95.194065%	2190000	88.168756%
Set-up Cost	433.3333	0.012743%	7272.727	0.307768%	3866.667	0.201690%	472.7273	0.019032%
Quality Cost	29494.95	0.867361%	22121.21	0.936128%	18434.34	0.961556%	22121.21	0.890593%
Transportation Cost	146000	4.293437%	73000	3.089222%	36500	1.903881%	73000	2.938959%
Ordering Cost	170163.2	5.004006%	40555.56	1.716234%	19070.01	0.994713%	77991.45	3.139913%
Holding Cost	99198.61	2.917144%	26977.09	1.141619%	13384.62	0.698157%	85324.68	3.435146%
Nutrition Loss	35248.57	1.036558%	3128.252	0.132382%	860.2009	0.044869%	34957.26	1.407369%
Physical senses Loss	0.001474	0.000000%	0.001569	0.000000%	20.4934	0.001069%	5.765683	0.000232%
Food Risk Loss								
	3400539		2363055		1917136		2483873	
Total Cost	3.95%		1.27%		0.74%		4.84%	

Similar results has been obtained in model 2, compare with model 1.

Sensitivity analysis of certain variables has also been tested, and the results are showing below:

4.2.1 Annual Demand:

	1	2	3	4	5
D	876000	949000	1022000	1095000	1168000
Optimal Q	1304	1362	1419	1473	1526
Total cost	1887213	2043180	2199131	2355013	2510876
Duration T	0.543333	0.523846	0.506786	0.491	0.476875
Risk	0.01891	0.017578	0.016452	0.015443	0.014567
% intangible costs	0.015139	0.014538	0.014014	0.013533	0.013105

Table 12: Con't					
	6	7	8	9	
D	1241000	1314000	1387000	1460000	
Optimal Q	1577	1627	1676	1723	
Total cost	2666696	2822497	2978277	3134012	
Duration T	0.463824	0.451944	0.441053	0.43075	
Risk	0.013781	0.013084	0.012461	0.011885	
% intangible costs	0.012712	0.012355	0.012029	0.011723	

#### 4.2.2 Optimal Q

Table 13: Sensitivity Test for Optimal Ordering Quantity under Model 2					
	1	2	3	4	5
D	120450	120450	120450	120450	120450
Q	250	300	350	400	424
Total cost	285477.7	282901.5	281551.6	280997.6	280940
T	0.757576	0.909091	1.060606	1.212121	1.284848
Risk	0.036763	0.052939	0.072056	0.094114	0.105746
% intangible costs	0.0202	0.0253	0.0306	0.0362	0.0389
	6	7	8	9	
D	120450	120450	120450	120450	
Q	450	500	550	600	
Total cost	281000.6	281417.2	282156.2	283156.6	
T	1.363636	1.515152	1.666667	1.818182	
Risk	0.119113	0.147053	0.177934	0.211756	
% intangible costs	0.0419	0.0479	0.0541	0.0605	

#### 4.2.3 Initial usable life

Table 14: Sensitivity Test for Initial Usable Life under Model 2					
	1	2	3	4	5
F1	3	7	14	30	60
D	120450	120450	120450	120450	120450
Q	258.7	424	623	923	1259
Total cost	296181.9	280932.4	273144.7	267673.2	264574

Table 14: Con't					
T	0.783939	1.284848	1.887879	2.79697	3.815152
Risk	0.214328	0.105746	0.057075	0.027283	0.01269
% intangible costs	0.0583	0.0389	0.0273	0.0181	0.0119
	6	7	8	9	
F1	90	120	180	360	
D	120450	120450	120450	120450	
Q	1468	1612	1801	2056	
Total cost	263345.8	262674.6	261953.9	261171.5	
T	4.448485	4.884848	5.457576	6.230303	
Risk	0.007668	0.005201	0.002885	0.00094	
% intangible costs	0.009	0.0074	0.0054	0.003	

#### 4.2.4 Weighting variable for nutrition and physical senses loss

Table 15: Sensitivity Test for Weighting Variable under Model 2					
	1	2	3	4	5
a	0	0.1	0.2	0.3	0.4
b	1	0.9	0.8	0.7	0.6
D	876000	876000	876000	876000	876000
Q	1865	1630	1446	1303	1190
Total cost	1893462	1903601	1912630	1920773	1928211
T	0.777083	0.679167	0.6025	0.542917	0.495833
Risk	0.077362	0.059094	0.046506	0.037762	0.031496
% intangible costs	0.005702	0.009344	0.012329	0.014862	0.017065
	6	7	8	9	
a	0.5	0.6	0.7	0.8	
b	0.5	0.4	0.3	0.2	
D	876000	876000	876000	876000	
Q	1099	1024	961	908	
Total cost	1935078	1941476	1947481	1953155	
T	0.457917	0.426667	0.400417	0.378333	
Risk	0.026864	0.023322	0.020541	0.018337	
% intangible costs	0.019026	0.020794	0.022406	0.023911	

#### 4.2.5 Risk hazard severity

Table 16: Sensitivity Test for Hazard Severity under Model 2					
	1	2	3	4	5
Hazard severity	0.01	0.05	0.1	0.2	0.3
D	876000	876000	876000	876000	876000
Q	1304	1304	1304	1304	1304
Total cost	1920773	1920774	1920774	1920774	1920775
Duration T	0.543333	0.543333	0.543333	0.543333	0.543333
Risk	0.01891	0.09455	0.189101	0.378202	0.567302
% intangible costs	0.014874	0.014874	0.014875	0.014875	0.014875
	6	7	8	9	
Hazard severity	0.5	0.6	0.8	1	
D	876000	876000	876000	876000	
Q	1304	1304	1304	1304	
Total cost	1920775	1920776	1920776	1920777	
Duration T	0.543333	0.543333	0.543333	0.543333	
Risk	0.945504	1.134605	1.512806	1.891008	
% intangible costs	0.014875	0.014876	0.014876	0.014876	

#### 4.2.6 Conclusion of model 2:

For model 2, based on the results, we can see that model 2 has similar results from model

1. All data has variation within 1% between each other. Major different is the percentage of overall intangible costs. This is because of the producers don't consider the holding costs of product, and results in a lower level of tangible cost, compare with case 1.



#### 4.3 Model 3: Organization only performs functions of retailer.

Similar test for retailer only model 3 has also been conducted. Also, to evaluate the result, the output for this section has been used to compare with Fujiwara and Huang's EOQ model.

	Bread		Milk		Seafood		Sausage	
Purchasing Cost	4380000	0.934974	3650000	0.981078	3650000	0.99087	3650000	0.951099
Optimal Q	429		1970		4469		351	
Ordering Cost	170163.2	0.036324	37055.84	0.00996	16334.75	0.004434	103988.6	0.027097
Holding Cost	9.438	2.01E-06	68.95	1.85E-05	469.245	0.000127	18.4275	4.8E-06
Nutrition Loss	99198.61	0.021175	29524.92	0.007936	15625.87	0.004242	63993.51	0.016675
Physical Senses Loss	35248.57	0.007524	3747.048	0.001007	1172.403	0.000318	19663.46	0.005124
Risk Loss	0.000737	1.57E-10	0.00188	5.05E-10	27.93129	7.58E-06	3.243197	8.45E-07
<b>TOTAL COSTS</b>	<b>4684620</b>		<b>3720397</b>		<b>3683630</b>		<b>3837667</b>	

Total cost								
Proposed Model 3	4684619.8	Saving	3720397	Saving	3683630	Saving	3837667	Saving
Fujiwara's model	65615536	92.86%	5018807	25.87%	3756313	1.93%	18812905	79.60%
Huang's model	135319825	96.54%	32165453	88.43%	11516781	68.02%	32034520	88.02%
% intangible costs								
Proposed model 3	2.87%	Reduced	0.89%	Reduced	0.46%	Reduced	2.18%	Reduced
Fujiwara's model	93.32%	96.92%	27.20%	96.71%	2.68%	82.95%	80.57%	97.29%
Huang's model	96.76%	97.03%	88.63%	98.99%	68.00%	99.33%	88.60%	97.54%

#### 4.3.1 Annual Demand

	1	2	3	4	5
Q	1327	1387	1444	1500	1554
Total cost	2690177	2911558	3132849	3354059	3575195
T	0.552917	0.533462	0.515714	0.5	0.485625
Risk	0.019583	0.018229	0.017036	0.016014	0.015106
% intangible costs	0.010832	0.010413	0.010032	0.009697	0.009393

	6	7	8	9	
Q	1606	1658	1707	1755	
Total cost	3796264	4017273	4238227	4459129	
T	0.472353	0.460556	0.449211	0.43875	
Risk	0.014292	0.013587	0.012926	0.012331	
% intangible costs	0.009112	0.008864	0.008627	0.008409	

#### 4.3.2 Optimal Q

	1	2	3	4	5
D	120450	120450	120450	120450	120450
Q	250	300	350	400	424
Total cost	391202.3	388576.7	387177.4	386573.9	386492.6
T	0.757576	0.909091	1.060606	1.212121	1.284848
Risk	0.036763	0.052939	0.072056	0.094114	0.105746
% intangible costs	0.0147	0.0184	0.0222	0.0263	0.0283
	6	7	8	9	
D	120450	120450	120450	120450	
Q	450	500	550	600	
Total cost	386527.5	386894.7	387584.2	388535.2	
T	1.363636	1.515152	1.666667	1.818182	
Risk	0.119113	0.147053	0.177934	0.211756	
% intangible costs	0.0305	0.0349	0.0394	0.0441	

#### 4.3.3 Initial usable life

	1	2	3	4	5
F1	3	7	14	30	60
D	120450	120450	120450	120450	120450
Q	260	429	642	988	1448
Total cost	401897.2	386482.3	378491.1	372700.9	369211.7
T	0.787879	1.3	1.945455	2.993939	4.387879
Risk	0.216488	0.108255	0.06061	0.031261	0.016787
% intangible costs	0.0432	0.0287	0.0205	0.014	0.0099

	6	7	8	9	
F1	90	120	180	360	
D	120450	120450	120450	120450	
Q	1806	2115	2609	3712	
Total cost	367713.4	366836	365812.2	364512.1	
T	5.472727	6.409091	7.906061	11.24848	
Risk	0.011606	0.008953	0.006055	0.003064	
% intangible costs	0.0081	0.0071	0.0057	0.004	

#### 4.3.4 Weighting variable for nutrition and physical senses loss

	1	2	3	4	5
a	0	0.1	0.2	0.3	0.4
b	1	0.9	0.8	0.7	0.6
D	876000	876000	876000	876000	876000
Q	1917	1670	1477	1327	1209
Total cost	2662296	2672674	2681888	2690177	2697728
T	0.79875	0.695833	0.615417	0.552917	0.50375
Risk	0.040868	0.031015	0.02426	0.019583	0.016255
% intangible costs	0.004284	0.006888	0.009024	0.010832	0.012408
	6	7	8	9	
a	0.5	0.6	0.7	0.8	
b	0.5	0.4	0.3	0.2	
D	876000	876000	876000	876000	
Q	1114	1037	972	917	
Total cost	2704687	2711160	2717229	2722955	
T	0.464167	0.432083	0.405	0.382083	
Risk	0.013801	0.011959	0.010507	0.009351	
% intangible costs	0.013807	0.015086	0.016247	0.017323	

#### 4.3.5 Risk hazard Severity

Table 23: Sensitivity Test for Hazard Severity under Model 3					
	1	2	3	4	5
Hazard severity	0.01	0.05	0.1	0.2	0.3
D	876000	876000	876000	876000	876000
Q	1327	1327	1327	1327	1327
Total cost	2690177	2690177	2690177	2690177	2690177
Duration T	0.552917	0.552917	0.552917	0.552917	0.552917
Risk	0.019583	0.097915	0.19583	0.391661	0.587491
% intangible costs	0.010832	0.010832	0.010832	0.010832	0.010832
	6	7	8	9	
Hazard severity	0.5	0.6	0.8	1	
D	876000	876000	876000	876000	
Q	1327	1327	1327	1327	
Total cost	2690178	2690178	2690178	2690178	
Duration T	0.552917	0.552917	0.552917	0.552917	
Risk	0.979152	1.174982	1.566643	1.958304	
% intangible costs	0.010833	0.010833	0.010833	0.010833	

#### 4.3.6 Conclusion of model 3:

For model 3, similar patterns from both model 1 and model 2 could be obtained. While annual demand increases, cycle duration decreases. Risk and percentage of overall intangible costs also reduced. Optimal ordering quantity might not achieve optimal risk or lost level, but the minimization of the overall costs. Product with long initial usable shelf life has longer ordering cycle, low risk, and less overall intangible costs in percentage. With no consideration of nutrition loss, optimal ordering quantity could increase. The overall risk, and overall intangible costs also been reduced.

To evaluate the performance of the proposed model, as shown in table 18, the proposed model saved 1.93-92.86% from Fujiwara's model, and saved 68.02-96.54% from Huang's model

in overall total costs. In terms of the percentage of intangible costs, proposed model 3 saved 2.68-97.29% from Fujiwara's model, and 97.03-99.33% from Huang's model.

Please note that, all the previous results from the comparison in Model 3 is obtained by applying optimal Q from Fujiwara and Huang's model into the proposed model 3. If simply consider the system or the cost structure proposed by Fujiwara and Huang's model, the proposed model 3 will have more costs, due to the new costs that has been identified and included.

## CHAPTER V

### CONCLUSIONS AND RECOMMENDATIONS

This thesis proposed a numerical model to evaluate the performance of food supply chain system, with the aid of cost of quality and quality loss function concept. To ensure the applicability of model, three cases was modeled, as the first model that producer also performs the retailing function, the second model concerns the producer only, while model three focus on the retailer only. To evaluate the performance of the proposed model, model three was used to compare the results with Fujiwara and Huang's perishable goods EOQ model.

In this thesis, all tangible and intangible costs in food supply chain system have been identified and modeled. The intangible costs are classified as the nutrition loss cost, physical senses loss cost, and the food risk. Quantification method has been developed according to previous literature results, and the characteristics of food industry and food product. Food risk has been modeled and considered all the major factors within the supply chain system, during and after the production, retailing, and consumption stages.

To fully demonstrate the application of the proposed models, four types of food products has been used to represent different key characteristics for food product modeling. Bread and milk is used to represent the impact of duration of initial usable shelf life. Frozen seafood and fresh packed sausage are used to demonstrate the difference of high risk and low risk food products. Due to the complexity of food deterioration process, these samples are also used to illustrate the difference between products that has food enzyme as their main source for deterioration and the products that has microorganisms as the major source.

A full sensitivity analysis has also been conducted, and based on the results; the impact of certain changing variables in the model has been discovered, and studied. The results indicate that, products with shorter usable shelf life are more sensitive to the time customer receive product. Producers and retailers for such product also suffer more intangible costs. However, producers with longer usable shelf life, the overall intangible costs is limited to less than 1% of all tangible and intangible costs in the supply chain system. The food product risk is also relatively low over the entire production.

This thesis only concerns the simplified scenario of one producer, one retailer, and one customer. The transportation cost is assumed to be a constant, and has no deterioration occurred in this stage. So, the more complex system with multiple producers, multiple retailers and multiple customers, could be studied in the future. The deterioration during transportation, off-shelf storage, is other potential topics for study.

Classification of intangible costs in food industry is one of the most difficult topics in research. In this thesis, the classification is conducted by using certain existing and popular feasible tools such as cost of quality and quality loss function. In future study, other classification methods could be developed, and produces more accurate estimation of the intangible costs.

All models in this thesis are using linear programming method, and by using spread sheet, the application could be conducted with ease in use. The model could be used to evaluate the performance of company, and could be used as a decision making supportive tool. All values used in this thesis are the recommended values found in literature. In actual application, detail number of variable could be obtained from common literature sources or historical data from company.

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