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Research Article

Design of Supply Chain Network Model for Perishable Products with Stochastic Demand: An Optimized Model

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Abstract

Supply chain network design in perishable product has become a challenging task due to its short life time, spoilage of product in degradation nature and stochastic market demand. This paper focused on designing and optimizing model for perishable product in stochastic demand, which comprises multiple levels from producer, local collector, wholesaler and retailers. The ultimate goal is to optimize availability and net profit of all members in supply chain network model for avocado fruit under stochastic demand. The network model has considered the quality deterioration rate of the product with increased order of transportation time. The validity of developed model was tested with data collected from avocado supply chain network in Ethiopian market.

Keywords: Supply Network Model; Perishable Goods; Avocado and Stochastic Demand

1. Introduction

Perishable products, such as food, fruit and vegetable, are usually deteriorate its life with time and quality during the transportation processes. The value and quality will become decrease continuously during their delivery (Hsueh & Chang, 2010). Thus product quality continuous monitoring and their transportation environment conditions becomes a very important issue in competitive market. Stochastic nature is an inherent characteristic of supply chain network (Van Landeghem & Vanmaele, 2002). Stochastic behavior of perishable rate and their network can be observed from demand side and supply nature. The material within perishable supply chain has some special characteristics that make supply chain even more vulnerable such as shelf life, material seasonality. In certain demand, producer and customer can take some redeeming action if they have awareness about products' condition before its arrival at the destination. Stochastic demand makes supply chain into more complexes. Due to time sensitive shelf life of perishable product holding in an inventory form leads a loss of quality and deterioration, in stochastic demand the case is somewhat serious. To optimize availability and net profit requires an effective network design management model in stochastic market demand. Therefore, post-harvest supply action has to be well designed the distribution network, in this paper supply chain of perishable network model was developed and considered customer demand under stochastic nature.

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2. Literature Review

Supply chain survey on perishable product became under public scrutiny. Customers with more health conscious require more and more high quality for perishable products at a fair price (Christopher, 2016). Competition among firms results in strict cost, quality and time control of perishable products in supply chain network (Cho, Fan, & Zhou, 2009). The structure of supply chain network for perishable products is increasingly complex and related to the superposition of many different types of networks (Baghalian, Rezapour, & Farahani, 2013). The design of perishable supply chain network is different from others model and consider essential parameter such as food quality and human safety (Boehlje, 1999). To achieve these requirements, it is necessary to urge an extensive method to understand, analyze and manage to serve customers in effective and safe.

In perishable supply chain network, each members engage in various activities and tasks in product realization to bring to market, for the fulfilment of end users' demand (Ahumada & Villalobos, 2009).The term perishable product has been coined to describe the product that has a fixed lifetime (Salin, 1998). Perishable supply chain network is organization network that ranges from producer to end-user in order to bring perishable products to customer and satisfy customers' demand.

Nahmias provided excellent review on deteriorating items and their inventory management (Nahmias, 2011).

Belien and Force reviewed blood supply chain and its inventory management (Beliën & Forcé, 2012). Yu and Nagurney showed that the contribution in supply chain to link more than two chain process (Yu & Nagurney, 2013). Goyal and Giri reviewed an inventory model of perishable items in a random shelf time (Goyal & Giri, 2001). Mandal and Phaujdar studied a time-dependent demand rate as a linear function at instantaneous stock level (Mandal & Phaujdar, 1989).

Many number of research papers have been proposed in supply chain network optimal model for perishable products from system-optimization perspective recently. An integrated model for quality control in production and distribution of food products was developed by (Rong, Akkerman, & Grunow, 2011). Furthermore, devised a methodology for determining the quality deterioration rate. Baghalian et al. (2013) present a stochastic model for rice supply network in uncertain nature. A two-echelon supply chain production/distribution and inventory planning for perishable product developed by (Rezaeian, Haghayegh, & Mahdavi, 2016). Furthermore, they proposed a genetic algorithm and simulated annealing to solve real life scenario.

Wang and Li reduced spoilage rate and maximize retailer's net profit under various price approach in predefined shelf life (Wang & Li, 2012). Asgari et al. (2013) evaluated the maximum wheat delivery amount from supplier province to consumer province per month across the year by using linear integer programming (LIP) model. Dabbene et al. (2008) studied a trade-off between logistic associated cost and food quality. Yiliu presented a discrete theory choice model to seek an equilibrium in supply chain network in certain market demand to optimize the profit of supply chain network (Ma & Tu, 2016).

Yang and Wee examined interdependency between a vendor and multi-buyer for deteriorate item in production and inventory management (P.-C. Yang & Wee, 2002). Although they are not covered deteriorating process, implicitly an exponential function employed to determine deterioration. It is only suitable when products are independent on previous deterioration history and rate such as radioactive materials. But usually perishable product fails to satisfy these conditions.

Emana and Gebremedhin conducted detail study of major actors in market value chain producers, middlemen/brokers, traders and consumers are main actors in eastern Ethiopia (Emana & Gebremedhin, 2007). A study performed by Shumeta studied avocado supply chain in southern Ethiopian. The result shows that 4.3% advance payment made before harvest and only 3.3% consider quality as impacting factor on selling price. (Shumeta, 2010). A study conducted by Tefera in northern-east of Ethiopia reviled that producer have lowest and marking has high profit share (Tefera, 2008).

Quality and its losses are the two performance measures for post-harvest losses. Loses occurs in harvesting, transportation, packing and at market places (Kader, 2004). Even though knowledge and information about equipment handling for fruit has a crucial importance in reducing loss, accessing these in developing country usually low. Cold chain plays a vital in slowing quality deterioration in transport of harsh environment (Kader, 2004). In addition to quality, the shelf space allocated to products also affect the customer demand (Desmet & Renaudin, 1998; Sajadieh, Thorstenson, & Jokar, 2010). A shelf space elasticity for various products presented by (Desmet & Renaudin, 1998). Curhan (1972) studied the quadratic correlation between demand and shelf space in supermarket.

In many studies, set to seek a minimum quality loss reduction in the chain and their by increasing revenue. Most of the studies were limited only in developed countries but there is huge loss in developing. Some of the researches were not focused directly towards minimization of losses in transportation and distribution. Quality losses need to be considered in design and optimization of perishable supply chain. It maximizes revenue and increase the availability, which mean right quantity and right quality at the customer end.

In this paper address the quality loss problem in perishable supply chain network by taking transportation time and deterioration rate from users' perspective. The designed and optimized supply network model consider the changing characteristics of perishable products with time is distinct from other literatures aspects. In order to optimize the availability of perishable product, the quality rate in transportation is captured as a function of transportation time and optimizes net profit of market channel in stochastic market demand.

3. Problem Statement

In recent years, agricultural loss ranges from 20% to 60% of total harvested product reported by Widodo et al. (2006). Perishable product is unlike to other supply chain due to fixed shelf life time. Thus, time sensitivity nature of products and stochastic in market demand makes loss in utility of fresh products. Especially in stochastic demand, the supply network of distribution of products from producer to customer requires an effective control model. In the present study a mathematical model for perishable products is constructed considering deterioration rate as a function of transportation time in order to optimize the net profit.

4. Objective of the Study

The objective of this desk review is to design perishable supply chain network model under stochastic demand and to optimize the net profit.

5. Methodology

5.1. Mathematical Modeling

To begin with consider a general network $\boldsymbol{H} = [\boldsymbol{G}, \boldsymbol{L}]$, where G denote node sets in the network and $\boldsymbol{L}$ denote directed link sets (Blackburn & Scudder, 2009). There are $\boldsymbol{S}$ producer that produce a homogeneous perishable product. There are $\boldsymbol{d}$ distributors that ship this kind of perishable product to $\boldsymbol{k}$ retailers. Consider $\boldsymbol{D_k}$ is the demand for the perishable product at retailer *k*. $\boldsymbol{\gamma(t)}$ denotes the quality rate of perishable product at time t is shown in figure 1.

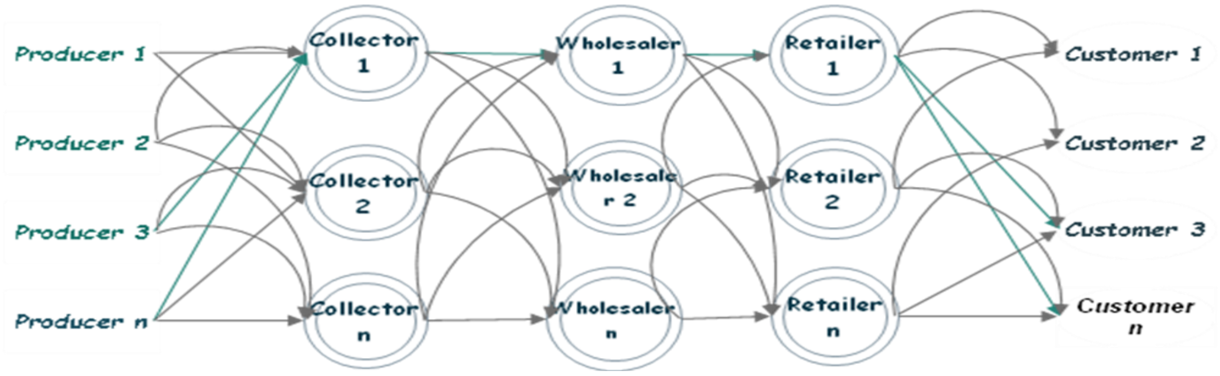

Fig. 1. Supply chain network

5.2. *Assumption and notation*

a) Basic assumption

Consider a supply chain network in Figure 1 defined by the following assumption:

- A multi-producer, local collector, wholesaler and retailer are considered
- Customer demand and supply are stochastic

b) Notations

The notations used in this study are as shown below:

Symbol	Denotation
s	Number of producer
l	Number of local collector
i	Typical transportation way
j	Transportation mode
$\gamma(t)$	Quality deterioration at time t
c	Unit transportation cost (USD)
p	Price per unit product (USD)
λ	Degradation rate
For Producer	Denotation
Q_s	Quantity of perishable products at producer
P_s	Selling price per unit product at producer (USD)
For local collector	Denotation
Q_{sl}	Quantity of perishable products b/n producer & local collector
C_{sl}	Unit transportation cost of product b/n producer & local collector (USD)
TC_{sl}	Transaction cost b/n producer & local collector
P_l	Selling price per unit product at collector (USD)
T_{sl}	Transportation time b/n producer & collector
For wholesaler	Denotation

Q_{ld}	Quantity of perishable products b/n collector & wholesaler
C_{ld}	Unit transportation cost of product b/n local collector & wholesaler (USD)
TC_{ld}	Transaction cost b/n local collector & wholesaler
P_d	Selling price per unit product at wholesaler (USD)
T_{ld}	Transportation time b/n collector & wholesaler
For retailer	Denotation
Q_{dr}	Quantity of perishable products b/n wholesaler & retailer
C_{dr}	Unit transportation cost of product b/n wholesaler & retailer (USD)
TC_{dr}	Transaction cost b/n wholesaler &retailer
P_r	Selling price per unit product at retailer (USD)
T_{dr}	Transportation time b/n wholesaler & retailer

Local Collector

Local collector is those people who purchase avocado form farmers (producer) in the nearby village market and sell to the wholesalers. Q_{sl}, Quantity of perishable products between producer ^{s} and local collector ^{l}. The total amount of product at local collector is equivalent to total shipped products to collector, $Q_{l,}$ through a mode of transportation **j** are given in the equation (1).

$$Q_l = \sum_{s=1}^{n}\sum_{i=1}^{j} \mathrm{Q_{sl}} \tag{1}$$

The total transaction cost between producer ^{s} and collector ^{l} include transportation cost and discarding cost of perishable products, TC_{sl}, are given in the equation (2)

$$TC_{sl} = C_{sl}{}^{i}(Q_{sl}.\gamma(t)) \tag{2}$$

Transportation time between producer and collector, $T_{sl,}$ is related to the volume of product flow is given in the equation (3).

$$T_{sl} = \gamma(t).Q_{sl} \tag{3}$$

The total spoiled volume of product between producer and collector, $Q_{sl}{}^{s}$, can be given as a time function given in the equation (4)

$$Q_{sl}{}^{s} = \gamma(t).Q_l \tag{4}$$

The profit gained by local collector is equal to the unit selling price of product times the total number of items distributed to wholesaler minus transaction cost and discarding cost of perishable product given in the equation (5).

$$\text{Max} \sum_{d}^{n}\sum_{i=1}^{j} P_l[1-\gamma(t)]Q_{ld} - \sum_{s}^{n}\sum_{i=1}^{j}(TC_{sl} + [Q_{sl}{}^{s}.P_s]) \tag{5}$$

Wholesaler

Wholesalers purchase products from local collector markets. Q_{ld}, Quantity of perishable products between local collector ^{l} and wholesaler ^{d}. The total product amount at wholesaler is equivalent to shipped products to distributor, Q_d are given in the equation (6).

$$Q_d = \sum_{l}^{n}\sum_{i=1}^{j} \mathrm{Q_{ld}} \tag{6}$$

The total transaction cost between collector and wholesaler include transportation cost and discarding cost of perishable products, TC_{ld} are given in the equation (7).

$$TC_{ld} = C_{ld}{}^{i}(Q_{ld}.\gamma(t)) \tag{7}$$

Transportation time between collector & wholesaler is related to the volume of product flow, T_{ld} are given in the equation (8).

$$T_{ld} = \gamma(t).Q_{ld} \tag{8}$$

The total spoiled volume of product between collector and wholesaler, $Q_{ld}{}^{s}$ can be given as a time function given in the equation (9).

$$Q_{ld}{}^{s} = \gamma(t).Q_d \tag{9}$$

The profit gained by wholesaler is equal to the unit selling price of shipped products times the total number of products distributed to retailer, then minus transaction cost and discarded cost of perishable product given in the equation (10).

$$\text{Max } \sum_{r}^{n}\sum_{i=1}^{j} P_d \, x \, [(1-\gamma(t)]Q_{dr} - \sum_{l}^{n}\sum_{i=1}^{j}(\mathrm{TC_{ld}} + [\mathrm{Q}_{ld}{}^{s}.P_l]) \tag{10}$$

Retailer

The retailer demand based on factors that relate to sales revenue that affect the consumption rate of perishable product; market ^{a}, price ^{p} and quality rate at given time **t**, to model the relationships between retail demand and factors. The model has been adopted from literature (Swami & Shah, 2013). The demand characterized is given in the equation (11).

$$\mathrm{D_1(t)} = \mathrm{a - bp + d\gamma(t) + \varepsilon} \quad , 0 \le t \le t_o \tag{11}$$

Where, ***b*** denotes price elasticity and ***d*** denotes product quality. **ε** denotes demand fluctuation and it is follows uniform distribution **ε** ∈ U[−L, L]. As quality rate decrease, demand at retailer will go down accordingly. In many conditions, retailer will give discount rate (θ) with attractive price (***f***) based on quality loss function as mention in figure 3. The demand rate after discount offer given in the equation (12).

$$\mathrm{D_2(t)} = \{\mathrm{a - bp + d\gamma(t)} + f + \varepsilon \quad , t_o \le t \le T \tag{12}$$

By applying the limits $\mathrm{D_1(t)}$ demand at non-discount period and $\mathrm{D_2(t)}$ discount period as given in the equation (13, 14).

$$\int_0^{\mathrm{to}} \mathrm{D_1(t)}\, dt = (a-bp)t_o + dq_o\left(\frac{1-e^{-\lambda \mathrm{t_o}}}{\lambda}\right) + \varepsilon \mathrm{t_o} \tag{13}$$

$$\int_{t0}^{T} D_2(t)dt = (a - b\theta p + f)(T-t_o) + dq_o\left(\frac{e^{-\lambda \mathrm{t_o}} - e^{-\lambda \mathrm{T}}}{\lambda}\right) + \varepsilon(\mathrm{T - t_o}) \tag{14}$$

Therefore, retailer profit margin at $\mathrm{D_1(t)}$ and $\mathrm{D_2(t)}$ is given in the equation (15, 16).

$$\mathrm{E}\,[p\int_0^{\mathrm{to}} \mathrm{D_1(t)}\, dt] = p\,(a-bp)t_o + pdq_o(\frac{1-e^{-\lambda \mathrm{t_o}}}{\lambda}) \tag{15}$$

$$\mathrm{E}\,[\theta p\int_{t0}^{T} D_2(t)dt] = \theta p\,(a - b\theta p + f)(T-t_o) + \theta p d q_o(\frac{e^{-\lambda \mathrm{t_o}} - e^{-\lambda \mathrm{T}}}{\lambda}) \tag{16}$$

6. Numerical Example

In this paper, avocado supply chain is taken for analysis as shown in figure 2. Avocados quality rate $\gamma(t)$ is predicted using an exponential distribution. Quality rate has been adopted from literature (S. Yang, Xiao, & Kuo, 2017), as given in the equation (17).

$$\gamma(t) = q_o e^{-\lambda \mathrm{t}} \tag{17}$$

Where qo and λ representing initial quality and deterioration rate respectively

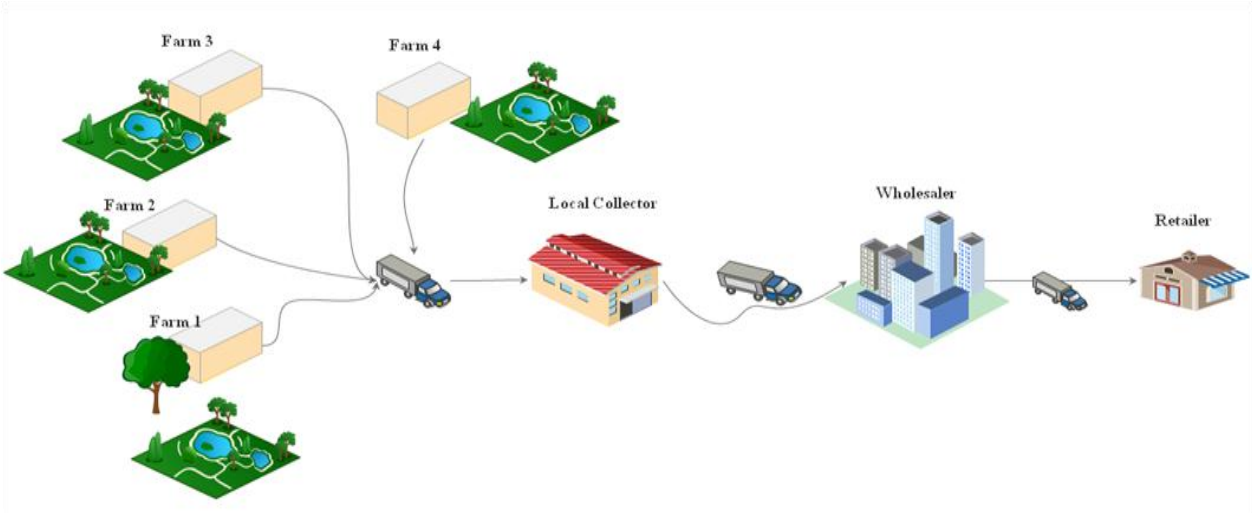

Fig. 2. Avocado supply chain network

Table 1
Parameters

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
a	7	T	30	P_s	1.6	$C_{sl}{}^{i}$, $C_{ld}{}^{i}$	4
b	4.42	θ	0.65	P_l	3.125	Q	100
d	4.42	f	2	P_d	5.125	P_r	6

Supply chain network net profit is given in the equation (18),

$$\mathbf{Max\ P} = ((\mathbf{A} + \mathbf{B} + \mathbf{C}) - (\mathbf{D} + \mathbf{E})) \tag{18}$$

$$\boldsymbol{A} = \sum_{s}^{n}\sum_{i=1}^{j} P_l x\,[(1-\gamma(t))]Q_{sl} \tag{19}$$

$$\boldsymbol{B} = \sum_{d}^{n}\sum_{i=1}^{j} P_d x\,[(1-\gamma(t))]Q_{ld} \tag{20}$$

$$\boldsymbol{C} = [\theta p(a - b\theta p + f)(T - t_o)] + \theta p d q_o \frac{(e^{-}\lambda t_o - e^{-}\lambda T)}{\lambda} \tag{21}$$

$$\boldsymbol{D} = \sum_{l}^{n}\sum_{i=1}^{j} (TC_{sl} + [Q_{sl}{}^{s}.P_s] \tag{22}$$

.

$$\boldsymbol{E} = \sum_{l}^{n}\sum_{i=1}^{j} (\mathrm{TC_{ld}} + [\mathrm{Q}_{ld}{}^{s}.P_l\,]) \tag{23}$$

In the objective function (18) where A, B, C represents sales revenue at collector, wholesaler and retailer in the equation (19, 20, 21) respectively. Equation (22) state the transaction cost between producer & collector and Equation (23) state transaction cost between collector & wholesaler.

Sensitivity analysis

Sensitivity analysis was taken in this study by changing important parameters such as transportation time and deterioration rate and evaluates quality rate and supply chain net profit margin. Quality rate trend is shown in figure 3

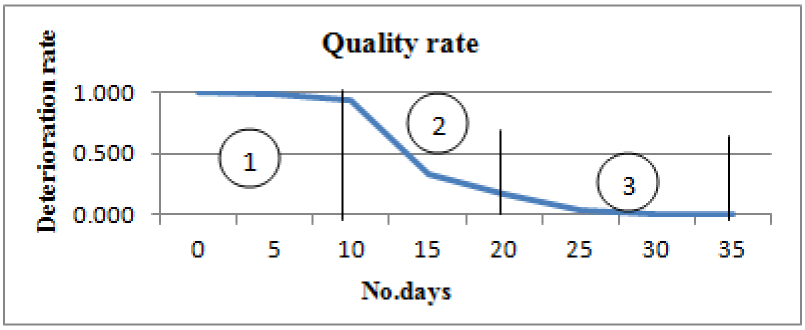

Fig. 3. Quality loss

The quality rate of avocado investigated under different time (1-stable, 2-visible change and 3- no longer acceptable) (Chen & Zhong, 2013). The probability of quality rate ranges from 1(fresh) to 0 (spoiled) and probability of deterioration rate (λ) ranges from 0.0005 to 0.08. As one of the changeable parameter called deterioration rate increase, quality rate will go down accordingly as shown in Table 2.

Table 2
γ(t) Computational analysis at various λ values

λ	0.0005	0.003	0.005	0.04	0.06	0.07	0.076	0.08
t	0	5	10	15	20	25	30	35
γ(t)	1.000	0.98117	0.9436196	0.334226	0.16295	0.03493	0.0136	0.0

The total quality loss and net profit margin of the supply chain network with respect to transportation time is shown in table 3 and table 4 respectively. The time t has taken in number of days.

Table 3
Computational analysis of quantity loss with different values of time t in days

t	0	5	10	15	20	25	30	35
${Q_{sl}}^s$	0	2	6	67	84	97	99	100
${Q_{ld}}^s$	0	2	5	22	14	3	1	0
${Q_r}^s$	0	2	5	52	72	93	97	100

Table 4
Net profit computational result of the model

t	0	5	10	15	20	25	30	35
A	313	307	295	104	51	11	4	0
B	513	503	484	171	84	18	7	0
C	1124	1124	803	932	484	322	162	0
D	400	395	386	240	199	168	163	0
E	400	402	405	248	135	31	12	0
Max P	1149	1137	791	720	284	152	0	0

The market margin can be profit or loss for the retailer which depends on selling price. But the profit margin of retailer depends on selling price at market which is proportional to the quality rate of avocado and stochastic demand. Table 5 shows the effect of θ and f on the net profit of retailer.

Table 5
Retailer sales revenue at different discount rate (θ)

t	f	***0.5***	***0.55***	***0.6***	***0.65***	***0.7***	***0.75***
10	1	237	326	427	540	666	803
15		300	413	541	685	843	1017
20		79	109	143	180	222	268
10	2	192	277	373	482	603	735
15		243	350	473	610	763	931
20		64	92	125	161	201	245
10	3	147	227	319	423	540	668
15		186	288	404	536	683	846
20		49	76	107	141	180	223

7. Results and Discussion

The availability of perishable product and supply chain network net profit was investigated. The quality rate of perishable product is negatively related to transportation time and deterioration rate as shown in table 2. At varies time the quality rate and net profit also various. As transportation time increase, the total quantity loss through the supply chain network from producer to retailer become more and more as shown in table 3. Due to the quantity loss increases through supply chain network the net profit was reduced as shown in table 4. The profit margin of the retailer is based on quality rate of avocado and stochastic demand. In highly visible quality rate changes the retailer might impose an attractive rate by setting various discount rates in order to minimize the regret loss as shown in table 5.

8. Conclusion

This paper developed a perishable product supply chain network model under stochastic market demand. The model expresses quality loss of perishable products by using quality deterioration rate as a function of transportation time as shown in figure 3. Total quantity loss associated with product deteriorating nature with time at various stages of supply chain network was considered as shown in table 3. The paper enables great potential in fresh product availability and supply chain net profit improvement for perishable supply chain management as shown in table 4. The developed mathematical model result showed that quality rate was negative with respect to key parameters (transportation time and deterioration rate) and the optimal value can be obtained through numerical analysis. The total quantity loss is positively related to transportation time and deterioration rate. Due to quality rate and stochastic market demand the retailer profit varies at different time as shown in table 5. As time goes, the perishable items become decay. Therefore in order to minimize the regret loss the retailer imposed a discount rate with attractive price. The results showed that the retailer sales revenue at certain transportation time with various discount rates was increased. But at varies transportation time with certain discount rate the profit was reduced. Future studies may find the impact of varies transportation mode, transport network and real-time quality control using internet of things.

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