Quality Loss Assessment and An Optimization Approach for Scheduling Fresh Fruit Exporting Operations

KAMHANGWONG Damrongpol [1], NEUBERT Gilles [2],
SEKHARI Aicha[1] , SUREEPHONG Pradorn [3]

[1] Université Lumière Lyon 2, Lyon, France
[2] EM Lyon Business School, Lyon, France
[3] Chiangmai University, Chiang Mai, Thailand
{damrongpol.kam@mfu.ac.th, gneubert@em-lyon.com, Dorn@camt.info}

Abstract. Mechanical damage to fresh fruits and vegetable during transportation is significant in logistics cost for export companies. Many global companies have tried to control the product quality throughout the food supply chain. However, the cost of quality loss due to the mechanical injuries during transportation is difficult to identify accurately and incorporate into logistics cost model. In this paper, we propose the methodology to formulate the mathematical model to maximize revenue that considered not only common logistic cost but also the physical injuries cost due to shock and vibration during transportation. The resulting model can be applied in an illustrative case study for the other FFV, and can be used to design and operate food distribution system both in term of export plan and marketing plan in each day during fruit season period.

Keywords: fresh fruit distribution, cost optimization, road profile impact

1 Introduction

The mechanical injury due to transportation is an important cause of downgrading and wastage of FFV during distribution [1] and represents a significant cost for companies. The FFV might be demonstrated the physical injuries during transportation ranging from 5 to 40% of their total market loss which the losses can vary by the relative susceptibility of the commodity to physical damage, the quality of the road, shipment distance, and the type of container in which they were packed [2]. In global FFV supply chain, it is evident that each export company must be held responsible for food quality under economic point view. Many companies try to reduce basic distribution cost based on the number of vehicle used, total distance-traveled and total lead time while the loss of quality is also reduced indirectly. Most of the models approaches regarding FFV distribution management have been considered by the vehicle routing problem with time window and improve their transportation condition to optimize the logistics and distribution cost and/or profit which indirectly delivers a better quality.

However, FFV supply chain management is more difficult and different from the distribution of other products because most FFV produces are the highly perishable products and fragile. They show continuous quality changes throughout the supply chain, all the way final consumer [3] and can be easily bruised and damaged from mechanical force: shock, vibration and compression during transportation, handling and storage [4]. These attributes have often also limited the possibilities for quality loss in supply chain integration in FFV supply chain. It also has received only little attention in literature and no researcher have specifically studied FFV which has its own special characteristics. In order to address practical real-world challenges, this paper proposed the logistics cost model that incorporated not only the common distribution cost but also the effect of transportation condition in term of vibration level on bruising of FFV.

A brief literature review is presented in section 2. In section 3, the fruits export planning and quality loss from mechanical force during exportation base on a case study of mangosteen exportation and assessment are formulated as an integer linear programming model (LP) In the section 4, the assessment of quality loss result from case study are presented. Section 5 contains concluding remark.

2 Literature review

In the field of mathematical optimization, the models for FFV supply chain planning can be divided as deterministic or stochastic, according to the certainty of the value of the parameters used [5]. The deterministic is traditional modeling approach that can be used to formulated to solve problem in many ways such as linear programming (LP), dynamic programming (DP), mixed integer programming (MIP), and goal programming (GP) while, stochastic modeling approaches are used as a framework for modeling optimization problems that involve uncertainty, these include stochastic programming (SP), stochastic dynamic programming (SDP), simulation (SIM), risk programming (RP).

Decisions variables of the models for FFV supply chain usually can be in the fields of production scheduling, harvest operation, distribution of product and inventory control, with two main objectives of minimizing costs and maximizing profitability. The researcher might be focus to study on one field or several fields simultaneously such as Itoh and et al. presented a model for crop planning with uncertain values, described with fuzziness and randomness, with the objective of maximizing value of revenue [6], Ferrer and et al proposes a plan for the optimal scheduling of the harvest of wine grapes using a LP model with the objective of minimizing operational and grape quality costs [7], Aleotti and et al developed a SP model to optimize production scheduling, harvesting and distribution by changing the capacity of food preservation facilities and considering the uncertainties in crop markets[8], and Widodo and et.al presented a DP model to integrate production, harvest and storage of perishable items with growth and loss functions for maximizing the demand satisfied [9].

FFV can be easily bruised and damaged from mechanical force: shock, vibration and compression during transportation, handling and storage because most fruits contain a lot of water about 65 to 95 percentage of water. FFV mechanical damage represents a serious hazard to quality and has the potential to significantly reduce the value of product [10]. Among different causes of damage to fruits, vibration generated by vehicles during road transport has an important role on the damage process to the agricultural products, particularly soft fruits.

Most of literature regarding fruits supply chain management focuses on different distribution problems in fields of decisions variables of the models but without considering explicitly the fruit bruising during distribution while there are a few papers comprehensive reviews of fruit considering the loss of quality during transportation. For example, Osvald and Stirn is the first group of researcher in a previous work that proposes the perishability as a critical factor incorporated a heuristic proposed to solve the problem of distributing fresh vegetables [11]. Peiqing Li and et.al developed a nonlinear mathematical model that considered not only the routing problem with time window but also the effect of road irregularities on the bruising of the FFV to obtain the optimal distribution routes for fresh product considering different road class with the least amount of logistic cost [12]. In practice, the cost of FFV quality loss due to transportation is difficult to identify accurately because the degree of FFV bruising due to transportation is non-deterministic value which cannot be fixed and depends on two parameters: the magnitude of the force and the number of times the fruits received an impact during transportation, storing and handling. Some papers have proposed to estimate the cost of quality loss of fruit during transportation by using surface class of road (high type: asphalt concrete and cement concrete, sub high type: bituminous penetration, asphalt macadam and bituminous surface treatment, intermediate type: graded aggregate, half tidy stones and other aggregates, and low type: aggregate strengthen soil and others together with a mathematical model. However, the surface road class cannot be used to predict the cost of the quality loss due to transportation accurately because it is a lot of difference for surface roughness of road when compare at the same road class. In order to be able to estimate the cost correctly, this research proposes a model of net profit estimation for fruit exporter which considers the cost of quality loss due to real vibration level of transportation in term of average root mean square acceleration level (Grm level).

3. Fruit export planning

This section presents the development of LP model which take into account the cost of quality due transportation in each export route which are relevant for the mangosteen exportation from a collecting center in the east of Thailand (Chantaburi) to main distribution center in China, as a case study. The model considers an objective of revenue maximization of the exported fruit which was divided into 2 parts: 1) representing fruit quality loss during exportation, 2) building the net profit model. In phase 1, we studied and analyzed the relation of transportation vibration level, the percentage of fruit bruising in term of the mechanical damage evaluation coefficient of fruit (δ_{ij}). After that, the results from phase 1were considered as a part of the total revenue model in phase 2.

3.1 Representing fruit quality loss during exportation

To study the real vibration level of mangosteen each of transit routes from Thailand to China, three piezoelectric tri-axial accelerometers were mounted to the floor of the refrigerator truck container, at rear floor position. This location produces the highest vertical vibration measurement. Vibration data was recorded in real time for 3 s for every 1 min of road travel. The total recording time was 43,200 s for about 10 days driving. The case study concerns transportation from the collecting center in Chantaburee, to three main fruit distribution center of China: Kunming, Nanning and Guangzhou, by nine exporting routes as shown the detail in table1.

Table 1: The details of the fruit shipments studied.

No.	Exporting routes	Distribution center	transportation time (day)	distance (km)	Vehicle
1	R3A Road: Bangkok – Chiang Rai – Mohan –Kunming	Kunming	3	1,863	• Refrigerator truck, 24-wheel, 2.26mx 13.14mx 2.25m, 55,000 kg of capacity.
2	R3B Road: Bangkok – Chiang Rai – Muangla –Kunming	Kunming	3	1,817	
3	Road and River shipment: Bangkok - Chiang Rai – Lan Chang River - Jing Hong- Kunming	Kunming	5	1,768	• Refrigerator truck, 24-wheel, 2.26mx 13.14mx 2.25m, 55,000 kg of capacity. • Unrefrigerator cargo ship, 150-ton dry cargo ship, 150TEU of capacity.
4	R12 Road: Bangkok- Nakhon Phanom – Vung Ang- Guangzhou	Guangzhou	5	2,669	• Refrigerator truck, 24-wheel, 2.26mx 13.14mx 2.25m, 55,000 kg of capacity.
5	R9 Road: Mukdahan – Vung Ang - Guangzhou	Guangzhou	5	2,751	
6	Road and Ocean shipment, Mukdahan -Vung Ang- Nanning	Nanning	10	1,674	• Refrigerator truck, 24-wheel, 2.26mx 13.14mx 2.25m, 55,000 kg of capacity. • Refrigerator cargo ship, 520-foot dry cargo ship
7	Ocean shipment, Laemchabang – Hong Kong- Guang Zhou-Nanning	Nanning	10	4,367	
8	Ocean shipment, Laemchabang – Singapore- Guang Zhou-Nanning	Nanning	15	5,944	
9	Ocean shipment, Singapore-Nanning	Nanning	15	4,825	

All 10 Kg of fruit were packed in packaging system: non-returnable polypropylene box with internal dimension (33x44.5x16 cm) supported in both bottom and top with sponge (polyurethane), as a cushion system, and loaded into 40 foots shipping containers (column stacking) at about 21,460 kg/container, as show in figure . The fruits were shipped at about 14 – 15 °C and the distance in range 1,674-5,944 km. On arrival to the Chinese distribution center, the data were transferred to a computer to calculate the magnitude of the force in term of acceleration value at various frequencies (Hz) by using the SaverXware software. Three sampling per village were collected and analyzed. The average Power Density Spectrum (*PSD*, G^2/Hz) within a narrow band of frequencies of the spectrum (*BW*) at various frequencies were calculated and plotted against the frequency of the bandwidth to develop the PSD-BW curve. The transportation vibration level in term of the root mean square acceleration value or Grm level measured in specific gravity unit (g) was determined by integration area under the PSD-frequency curve in the frequency range 1-5 Hz. The relation of Grm level and *PSD* are represented as the following [13]:

$$\sum_{i=1}^{n}(Grm_i^2) = \left(\frac{PSD}{BW}\right) * N \qquad (1)$$

Where Grm_i^2 = root mean square acceleration value measured in specific gravity unit (g) within a BW of frequencies.
BW = frequencies of the spectrum
N = number of instants sampled

To study the relationship between Grm level and the amount of fruit damage, The mangosteen were packed in packaging system for mangosteen exportation and were simulated transportation condition with 7 treatments: 0.5, 1.0, 1.5, 2.0,2.5 and 3.0 of Grm level (0 Grm level control treatment and eight repetitions) by the vibrator. All treatments were stored at room temperature for 3 days and then, they were monitored the percentage of fruit damage each treatment by visual inspection at more than 0.5 centimeter of the bruising diameter. The bruising diameter (*BD*) was determined as the following in figure1 and equation (2), and the percentage of fruit damage was determined as the following in equation (3). The relationship between Grm level and the percentage of fruit damage were plotted as a Grm level-%fruit damage graph and formulated in term of the linear equation to determine the percentage of fruit damage each export routs.

$$BD = \left[\frac{(a+b)}{2}\right] \tag{2}$$

$$\%Fruit \quad damage = \left[\frac{ND}{NF}\right] * 100 \tag{3}$$

Where BD = bruising diameter (cm.)
a = maximum fruit diameter (cm.)
b = minimum fruit diameter (cm.)
ND = the number of fruit damage at BD > 0.5cm.
NF = the total tested fruit

Figure 1: The mangosteen bruising and the bruising diameter of mangosteen, a: the maximum fruit diameter, and b: the minimum fruit diameter

To analyze the mechanical damage evaluation coefficient each export route, the percentage of fruit damage each export routs was used to calculate the mechanical damage evaluation coefficient (δ_j) of each route, as show in equation 4. This coefficient was used to adjust the cost per ton that was paid to the producer. If the original cost at the producer is *PDi* ,the raw material cost at collector, after taking into account the loss of product will be $PDi*\delta_j$. The objective is to integrate the mechanical damage evaluation coefficient as a parameter in the cost to exporting model to evaluate the net profit for fresh mangosteen exportation.

$$\delta_k = \left| \frac{1}{1 - \left[\frac{\%Fruit\ damage}{100}\right]} \right| * 100 \tag{4}$$

A completely randomized design was used with all treatments. Vibration data and the percentage of fruit damage at various Grm levels were subjected to analysis of variance (ANOVA) and mean comparisons were carried out by Duncan's multiple range testing and the correlation coefficient between the vibration factor and the fruit damage factor were analyzed by Pearson's correlation. Analysis was performed using the SPSS package (SPSS 11.0 for windows, SPSS Inc., Chicago, IL, USA). The statistical significance was considered to be p<0.05. [10].

3.2 Building the net profit model

The revenue of fruit export depends on the difference of raw material price at the local orchard and selling price fruit at the distribution center. Theses parameters are determined by the quantity of goods supplied by orchard and fruits demanded by consumers at various periods. From case study, mangosteen plants in Chantaburee can fruit a total of two times during their season in period from May to July which the optimal time fruit harvesting may be slightly different due to weather and cultivated area. Most mangosteen has the optimal harvesting date for the first time and second time at about the third week of May and the third week of June which it is also effect on the raw price material reduction at the same time. The raw material prices change every day as a direct result of the changes in the amount of harvested fruits from orchard each day while the purchasing raw material need of exporter is very high and doesn't not effect on the reduction of the fruit price [14].

The sell price of the mangosteen can be predicted by two major factors. The first factor is the total quantity of mangosteen and the seasonal fruits of China released on market at that time. In the figure 2, we found that the sell price of mangosteen in Chineses market is most expensive during the first three weeks of May at about 170-200 baht / kg because the domestic market demand for fresh mangosteen in Chinese market is huge while there are a very few mangosteen and the other seasonal fruits of China on market during the same period. During the second period, form B-C, the fruit price tends to dropped significantly because of the impact of the increase in both amount of mangosteen imported from Thailand and the seasonal Chinese fruit on market, as the result it made consumers more choice to buying decision. The second factor affected on sell mangosteen price is fruit buying behavior of Chinese consumers during the holiday season. Chinese consumers pay more attention to the family and prefer to buy a health product for adult which they respect. During the periods from C-D, the sell fruit price slightly increases due to the result of the increase of consumer demand during Chinese festival.

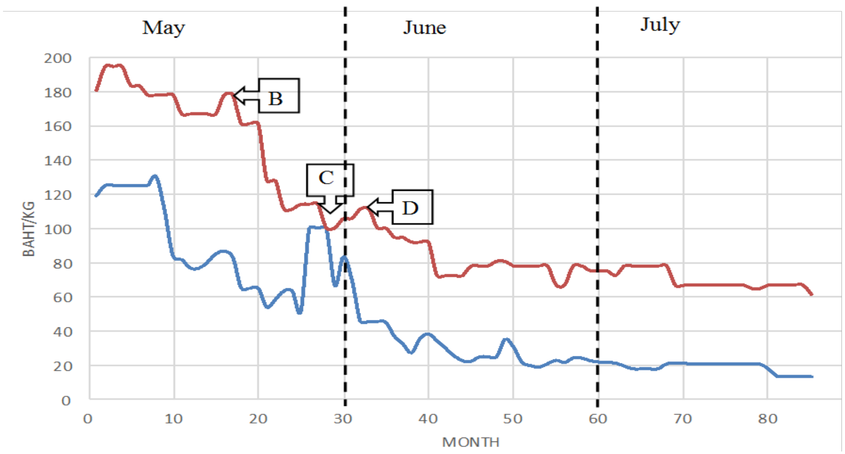

Figure 2: the sell price of mangosteen fruit at destination market and the raw material price at Chinese collecting center from May to July in 2006.

However, most exported mangosteen have quality loss due to mechanical injury at about 10%-30% of total magosteen exportation which is objectionable to fresh market consumers, and can result in a lower grade for any mangosteen and sell price of mangosteen. The degree of fruit bruise is vary depending on packaging system, transportation routes and storage time. As mention above, to plan and choose the appropriate distribution scheme under the various demand, supply in each day, export route, revenue and inventory level. The model requires introducing the following variables into the model:

- x_i: is the quantity of fruit (in ton) exported in day (i)
- y_i: is the quantity of fruit (in ton) exported in day (i) and immediately sold in arrived
- day ($i+d$)
- z_i: is the quantity of fruit (in ton) exported in day (i) and sold after storage for ($i+d+k$) day
- s_i: is the quantity of fruit sold immediately in day (i) by without storage
- w_i: is the quantity of fruit from inventory sold in day (i) after storage

The LP model considering both revenue and quality losses in term of damage coefficient were formulated to optimize the scheduling fresh fruit exporting operations under maximize the net profit for fruit exporter (r_i) which can be shown as the follow.

$$Maximize\ revenue = \sum_{i=1}^{n} r_i \ ; i \geq d+1 \tag{5}$$

Subject to:

$$r_i = [s_i + w_i] * PS_i * [1 - \delta_j] \tag{6}$$

$$x_i = y_i + \sum_{k=1}^{m} z_{ik} \tag{7}$$

$$s_i = \begin{cases} 0 & : i < d+1 \\ y_{i-2} & : i \geq d+1 \end{cases} \tag{8}$$

$$w_i = \begin{cases} 0 & : i < d+r \\ \sum_{k=1}^{m} z_{(i-d-k-1)} & : i \geq d+r \end{cases} \tag{9}$$

$$x_i = SR_i \tag{10}$$

$$y_i \geq 0 \tag{11}$$

$$z_{ik} \geq 0 \tag{12}$$

Where PS_i = sell price of fruit in day i
δ_j = mechanical damage evaluation coefficient of export route j
Si = mangosteen supply from orchard in day i

To maximize revenue of mangosteen export, the model was developed by using the time delay balancing from suppliers to final customers. Time the fruits spend in the logistics process which was considered in the model comprised of transportation time (*d*) and storage time (*k*), as show in the relation of parameters in formulation (5) to (10).

In constraint (5) and (6), the revenue model is comprised of the revenue of fruit that was sold immediately at arrive time by without storage and the revenue of fruit from inventory sold after storage at various time. In (7), the total quantity of exported fruit in day *i* cannot be greater than the combination of quantity of fruit sold immediately by without storage in day *i* and quantity of fruit in inventory sold in day i after stored in room cooling for *k* day. Constraint (8) ensures the exported fruit will be not sold before they arrive to distribution center. Constraint (9) ensures the fruit in inventory will be not sold before storage date. Constraint (10) ensures that total amount of mangosteen exported at day *i* cannot be greater than the maximum mangosteen supply from orchard (*St*) in each day. For this model, we assume that there is ultimate capacity of room cooling at distribution center.

4 Case study analysis

Studying the relation of vibration level and the percentage of fruit damage during handling and transportation is presented in figure 3. To combine the cost of fruit bruising as a part of model, we assume that any mangosteen after transportation has a limited degree of bruising under Grm level which can be divided into two stages. The first period from 0 to 1.000 of Grm level (0-A), the mangosteen is bruised by mechanical force but there are no discernible changes and the apparent quality stability. The second period, at Grm level more than 1.0 (A-B), the bruising of the fruit can be noticed and fruit quality is not acceptable by consumers (BD > 0.5 cm.). In real-life the mangosteen distribution, after fruit harvesting, the quality of most fruits is in the first period. The fruits begin to visibly degrade after this period due to impact force during delivery.

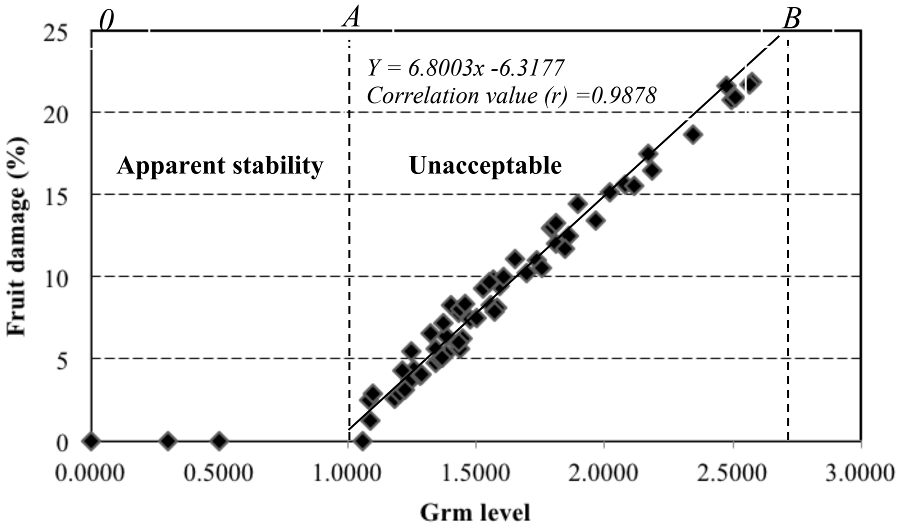

Figure 3: The relation of vibration level and the percentage of fruit damage during handling and transportation

During the period *A-B,* the damage of fruits is directly proportional to the Grm level which fruits are received during transportation. It can be considered as a linear function which was confirmed by the positive correlation coefficient value of 0.9878, then we can estimate the mechanical damage evaluation coefficient by using equation 4 reported in Table 2.

Table 2: The overview of road profile, Grm level, the percentage of bruised fruit and the mechanical damage evaluation coefficient for mangosteen delivery from each orchard zone to a collecting center in Chantaburee province

Route	Distribution center	Transportation mode	Grm level (at freuency 1-5 Hz)	Fruit damage (%)	Mechanical damage evaluation coefficient (δij)
1	Kunming	Truck	4.012d	26.97	1.3693
2	Kunming	Truck	5.047b	34.01	1.5153
3	Kunming	Truck and cargo ship	5.423a	36.56	1.5764
4	Guangzhou	Truck	4.588c	30.89	1.4469
5	Guangzhou	Truck	4.632c	31.19	1.4532
6	Nanning	Truck and cargo ship	2.912e	19.49	1.2421
7	Nanning	Truck and cargo ship	3.140e	21.04	1.2665
8	Nanning	Truck and cargo ship	3.711d	24.92	1.3320

*For Grm level, a, b different letters within a column indicate significantly different ($P < 0.05$, N=27).

However, in case of long time transportation or storage, the fruit will change the maturity stage from pink to dark purple which may be affected on the correlation value of the Grm level and the percentage of fruit damage because the bruising of dark purple mangosteen is much more susceptible occurrence than the pink mangosteen.

6 Conclusion

This paper shows that the road profile and time to delivery have an impact on the logistics costs and the efficiency of the distribution process of fresh mangosteen. The magnitude of the force and number of times this force given road roughness in term of Grm level are proposed as a part of a cost model to determine and to optimize profit for mangosteen for exporter.

The net profit model can help the logistics exporter in part of export planning and choosing the appropriate distribution scheme, depending on the demand from Chinese market and supply from local farm in Thailand. The efficiency of the distribution process highly depends on the delay from suppliers to final customers. Time the fruits spend in the logistics process represents an important problem in fresh fruit distribution, cost and quality loss during delivery.

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