Losses in the Transportation of Fruits and Vegetables: A Brazilian Case Study

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ABSTRACT *Transportation modelling approaches have not necessarily taken into consideration the eventual losses incurred during the transportation of agricultural products. A normative mathematical programming model was developed to deal with transportation losses and was applied to a typical cross section of the movement of selected fresh fruits and vegetables in Brazil. Despite the barriers to be overcome, results indicate that implementation of new technological options for diminishing losses would first benefit the consumer at the wholesale market. Additional benefits from diminishing losses are related to changes in the marketing structure of the business.*

Introduction

A transportation model that includes loss events would enable the evaluation of technologies for reducing losses. Several modelling applications have been developed for the trade in agricultural products; however, they have not considered potential transportation losses.

Transport models can take into account the occurrence of losses during the transportation activity itself. In view of that, this study presents in the first section a review of the main concepts that can be associated with transportation losses. In the following section, a Brazilian case study is explored through the development of a mathematical model, as a means of evaluating the interaction between transportation losses and the behaviour of producers, wholesalers and consumers, in a representative city market for tomatoes and pineapples. In the final sections, the main results are discussed and some recommendations are suggested.

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Losses Attributed to Transportation Conditions

Transportation is certainly a very important activity within the post-harvest system. Throughout history, as Baumel & Hayenga (1984) mention, there have been documented a great number of cases of people migrating to where food was more adequate. In today's world, food is moved to the people, which makes transportation a necessary condition for contemporary specialisation and urbanisation. Gallimore (1981) also emphasises that while world demand for food outstrips world food production, as important as the ability to produce is the ability to transport food from the farm to the port. That capacity depends largely on the existing transportation system, the amount and location of new land to be brought under cultivation, and the adequacy (or existence) of transportation services to those new lands. Yet, as the Food and Agricultural Organisation of the United Nations (FAO) (1989) points out, the goal of every person concerned with transport should be that the produce be kept in the best possible condition during transport and that the haulage of produce be quick and efficient.

Davis (1980) gives an example of the importance of the transport conditions, mentioning an article published in the *Wall Street Journal* (26 June 1980). It was reported that production conditions in Zaire ranged from good to ideal, with the country having the potential to feed much of the population on the continent of Africa. However, it does not even feed its own people due to a basic reason: Zaire has a primitive transportation system, a decrepit railroad system and virtually no modern highways. The article told of farmers who are giving up, because they simply cannot get their crops to market. Certainly, this is not unique to Zaire, but common to a great number of countries.

The task of transporting food from producers to consumers typically consists of moving the raw food products relatively short distances from farms to processing or storage facilities, and then moving the processed products from the processing and storage facilities to storage or trading facilities in consuming regions. Therefore, almost all food products must be transported at least twice and, in some cases, more often. Few consumers carry more than a few days' inventories of many perishable products, so interruptions of food shipments could have a rapid impact. In addition, long-distance transportation requires time, which creates the possibilities of food deterioration, shrinkage, and loss during transport.

Hence, for agribusiness activities, benefits may arise not only from an increase in production but also from an avoided loss. More specifically, better feeder roads or highways, for instance, besides reducing the cost of moving produce from the farm to the consumer, may also minimise the eventual losses due to bad road conditions. The resulting benefit may be distributed among farmers, truckers and consumers.

Indeed, as Ndulu (1980) reminds us, in many developing countries a poor transportation system means major restrictions to the movement of ideas and information necessary for the improvement of agricultural productivity. Information on weather, new methods, seeds and implements is not easily diffused without frequent contacts between farmers and agricultural extension workers, who find it too time consuming to visit and help farmers in inaccessible areas.

There are a few case studies documented in the literature, but only some of them treat the post-harvest losses in a more detailed form (this does not

TABLE 1. Major Hazards of a Journey

Hazards	Examples
Impact, vertical	Package dropped when unloading truck
Impact, horizontal	Shunting rail truck
Vibration	Engine and transmission vibration from the truck
Compression, static	Stack in warehouse or vehicle
Compression, transient	Packages stacked in rolling, pitching ship
Racking or deformation	Uneven support due to poor floor or uneven lifting
Puncturing, snagging	Projection on vehicles
Temperature, high	Sun, ships' boilers
Temperature, low	Cold store
Water, liquid	Rain, spray, condensation
Water, vapour	Humidity of atmosphere, natural or artificial
Biological	Insects, rodents, moulds
Human	Pilferage, inspection

Source: New *et al.* (1978).

necessarily mean that all of the figures are effectively reliable). Moreover, none of these studies strictly defines the different aspects that could be considered in transportation losses. For instance, there is a pioneering study developed by the FAO (1977) that contains a good quantity of information, reported by Country Representatives. The quality of these estimates varies according to the primary source, and only a few of them are supported by evidence from systematic surveys.

Grains, roots, fruits and vegetables are all important for the human diet, and any effort to minimise losses related to their required transportation activities are certainly appreciated. However, in order to focus this study on a more specific category of food, fruits and vegetables were selected. It must be noted, following comments reported by the FAO (1989), that the words "fruits" and "vegetables" have no real botanical meaning but are terms of convenience used for horticultural and domestic purposes. In this study, the "fruits" and "vegetables" group includes the food originating from: edible flowers (e.g. broccoli, cauliflower, pineapple etc.); vegetative growthğleaves, stems and shoots (e.g. cabbage, lettuce, spinach, onions, leeks etc.); and reproductive structures (e.g. mango, avocado, plum, tomato, citrus, cucumber, pepper, aubergine, banana, green beans, okra, pigeon pea etc.).

Fruits and vegetables are more easily perishable than cereals and root crops. Due to their soft texture, most vegetables and fruits can be easily damaged after harvest, making the product unsaleable. In a normal journey, for instance, horticultural produce could be subject to a series of hazards, as summarised in Table 1.

According to Bourne (1977), the majority of organisations that conduct activities in the area of post-harvest food loss reduction devote their efforts largely or wholly to reducing losses in grains and dry legumes. This attitude is probably based upon the fact that the cereals and dry legumes are staple foods and contribute the major part of the calorie and protein intake of populations in developing countries.

However, as Bourne (1977) reminds us, some of the major nutritional deficiencies in developing countries, especially of vitamins and minerals, can only be remedied through greater intake of fruits and vegetables. Deficiencies of these minor nutrients require a longer period of time to produce obvious clinical symptoms than do deficiencies in calories and proteins, but deficiencies in minor nutrients can increase mortality rates just a surely as calorific and protein deficiencies.

Finally, as Spensley (1982) points out, even if fruits and vegetables were, on aggregate, only half the value of the grains to the developing countries, the losses in them could well be many times as great as is now being found in cereals, so the economic benefit could be considerable.

In view of this, some aspects of the transportation of fruits and vegetables, significant for the consideration of eventual losses, were selected and are described in the following sections. For the purpose of this study, the definitions given by the FAO (1989) are assumed, which means that losses in the transport of agricultural products are basically caused by mechanical damage or overheating.[1] In the case of fruits and vegetables, they can be due to the following:

(a) the mode of transport utilised, which can provoke vibration of the vehicle, especially on bad tracks;
(b) lack of specialised transport equipment (e.g. closed vehicles without ventilation);
(c) inadequate packaging (with lack of adequate ventilation of the packages themselves, and which fails to prevent the occurrence of accidents during loading and unloading).

Transportation Mode Utilised

One of the aspects neglected in the measurement of transportation losses is the one related to the kind of energy to be utilised. Polopolus (1982) reminds us that there is a great need to improve energy and labour productivity in food transportation, particularly for fruits and vegetables.

Therefore, the mode of transport to be utilised will imply a pattern of energy consumption, which may or may not be well suited for shipments of certain products or commodities. Trucks, because of their speed and flexibility, have inherent advantages over rail and barges for certain products, while the low cost of barge shipment makes it attractive to bulk commodities where time is not particularly important. If the transportation mode selected is not the most adequate one, a series of losses can occur. The Council for Agricultural Science and Technology (1974) outlines some of the main problems, common to all transportation modes, that could make the losses worse. Among these are the following:

(a) unavailability of adequate capital for necessary expansion because of inadequate earnings of the carriers;
(b) inadequate coordination of interchanges among railroads, trucks and barges which may result in double handling of the produce and other inefficiencies, including idling of equipment due to bunching;

(c) insufficient communication and trust among carriers, shippers and receivers to develop required improvements in planning and efficient utilisation of equipment; e.g. deficient back-haul scheduling and inadequate information on location of freight to be hauled usually result in inefficient use of equipment;
(d) inadequate supply of transportation equipment.

In the case of most developing countries, priority has been given to road transport. Rail and river transport are theoretically gaining in relative importance with the increase in energy costs. They require not only a lower energy input per tonne-km, but also a lower maintenance cost. Nevertheless, as Reusse (1976) comments, they can rarely deliver produce to the final wholesale destination, and are therefore not competitive with road transport in short and medium hauls.

The development of river transport has been restricted by the substantial investments required to make some rivers navigable. In addition, problems may arise related to the fluctuations in river levels, which affect the utilisation of equipment, and to the eventual dependency of the turn-around time of barges on the availability and arrivals of ocean vessels.

Rail transport has faced the problem of deteriorating equipment and services. The poor condition of much rail equipment is responsible for excessive loss of products during transit, increased loading time, and decreased effective annual carrying capacity for a given rail car. Some state-owned transport is unable to compete without subsidies.

Air transport could also be explored. Although it yields short journey times, favouring the maintenance of produce quality, it is very unlikely to be used within developing countries due to its high costs.

In terms of empirical evidence to support the relationship between the transportation mode utilised and the resulting losses in the load, Jones *et al.* (1991) give an interesting contribution to the matter through the development of a simulation model to predict the damage to horticultural produce during transportation by trucks. The basic input data used for the model were: the road profile; the tyres; the suspension and chassis of the vehicle; and the produce, packaging and cushioning which constitute the load itself. Using then a force-characteristic description of the vehicle and load elements to calculate the energy absorbed by the produce, it was assumed that this energy would be directly related to the physical damage that could occur to that load. Applying the methodology to assess the impact upon transport of apples, information about bruise volume for different loads could be generated, as well the effects due to the variation in the velocity of the vehicle, height of road bumps and the position of the load on the truck tray.

Lack of Specialised Transport Equipment

New *et al.* (1978) comment that, as far as the produce itself is concerned, the main advantage of land transport is the possibility of temperature control, even though the journey may take two or three weeks. The demands placed upon the package by surface transport are generally greater than those by air owing to the longer time for the journey, higher humidity, and usually greater stack heights.

The Food and Agricultural Organisation (FAO) of the United Nations (FAO, 1989) comments that most agricultural fresh produce cannot be stored without refrigeration, and that the possibilities for extending storage lives under ambient conditions are limited. Therefore, another way of avoiding potential transportation loss relates to the utilisation of specialised transport equipment, according to the level of perishability of the agricultural product. Reusse (1976) observes that the advantages of specialised transport equipment are better load protection, savings on time and labour in loading and unloading etc., which basically means reduction of the potential losses. The disadvantages, according to Reusse, are higher investments and maintenance costs and reduced suitability for general transport use.

Harvey (1981), commenting about the biological features of individual commodities, notes that the time during which many fresh fruits and vegetables are in transit may constitute a major portion of their total post-harvest life. In view of that, the author recommends that optimum environments must be addressed when designing and operating new transport equipment for specific products, taking into consideration the eventual reactions from those products to different levels of temperature, relative humidity, modified oxygen and carbon dioxide levels, and ethylene.

In developing countries, where the cost of labour is low but investment and maintenance costs are high, the case for imported specialised transport equipment must be well founded in order to justify the costly investment involved. Owing to the specialised nature of the equipment, it is usually difficult to find regular and suitable return loads, or an alternative use if the original one does not develop as expected.

Empirical evidence on the importance of utilising specialised transport equipment has been presented in reported cases; they assume that the eventual losses during transportation are mainly due to transit time from the supply region to the demand region. In view of that, the effects of longer transit times will be felt by the products according to their specific characteristics, which can be approximated by their respective storage lives. Indeed, the storage life is highly influenced by the temperature and humidity characteristics of the pertinent ambient. The eventual benefits of using "controlled atmosphere" or "modified atmosphere", reported in some studies (e.g. Salunkhe *et al.*, 1991), produce an increase of at least 100% in the storage life of fruits and vegetables.

Kader *et al.* (1985) point out that temperature is the most important environmental factor that influences the deterioration rate of harvest commodities. As is shown in Figure 1, for each increase of 10°C, the rate of deterioration increases two- to three-fold.

It should also be noted (Hutchinson *et al.*, 1974) that one must be careful when interpreting such data as only a portion of the storage life is taken up by transportation activities. Both retailers and buyers wish to store the commodity, at least for a short time, and typically under less than ideal conditions. The transportation system must, therefore, make delivery before the storage life is exhausted.

Inadequate Packaging Patterns

Packaging procedures and transportation as a whole are closely related activities. Austin (1992) gives as an example the situation where markets are distant,

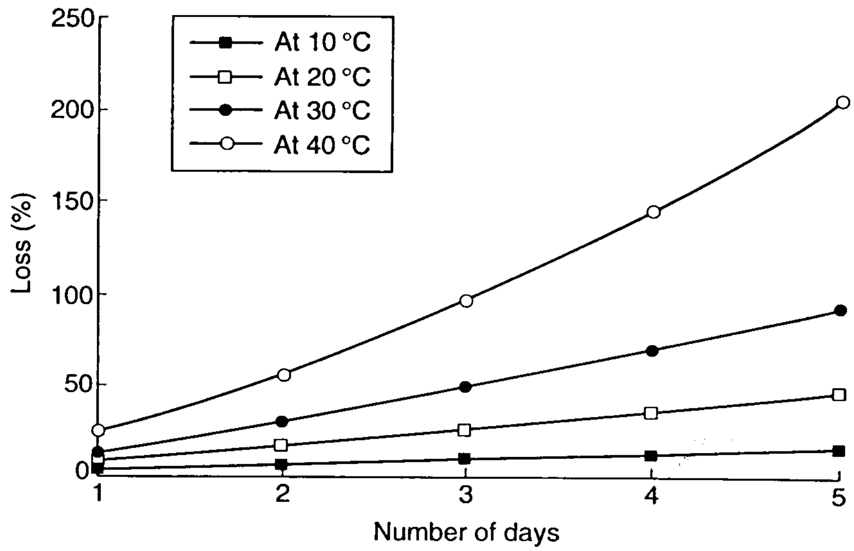

FIGURE 1. Effect of Temperature on Deterioration Rate of Non-Chilling Sensitive Commodities (Based on Kadar *et al.*, 1985).

roads rough, or transport services unreliable: the demands placed on the packaging's durability and its ability to preserve the product will certainly be increased. Therefore, the correct choice of types of packages to be used can influence the eventual loss during the transportation of agricultural products.

There are wasteful inefficiencies and a lack of adequate standards in the packaging of food products, particularly fresh fruits and vegetables. Polopolus (1982) suggests that through an improved unitization, an increase in the efficiency of intermodal shipments of food products can be achieved, facilitating the shipments that move across truck, rail, barge and ocean freighter modes.

Mazaud (1994, pers. comm.) cites that many losses result from unsuitable packaging and from loading in packages which are far too large, both for ease of handling and for protection of the produce inside the package. Some projects conducted recently by the FAO have endeavoured to reduce transportation losses by designing improved packaging materials, mostly for perishables. Although quality was better, quantities of produce transported were lower, and adoption rates were not high.

If the introduction of new packaging does not result in increased returns, it cannot be economically feasible. The FAO (1989) reminds us that the use of packaging represents an added cost in marketing and the price of the marketed product must take account of the capital outlay and unit packaging cost as well as expected profit. New *et al.* (1978) consider that the cost of packaging is an important factor. However, the aim should be to select a package which will minimise the total cost of transporting the produce to the consumer, not simply to select the cheapest package.

A study in Thailand, reported by the FAO (1989), tells of a plastic crate that, while costing five times as much as a traditional bamboo basket of similar capacity, was still useful after 20 times the number of journeys, putting the cost per journey of the plastic crate at about one-quarter of that of the bamboo basket. However, in many similar cases, as the FAO (1989) notes, it is more important

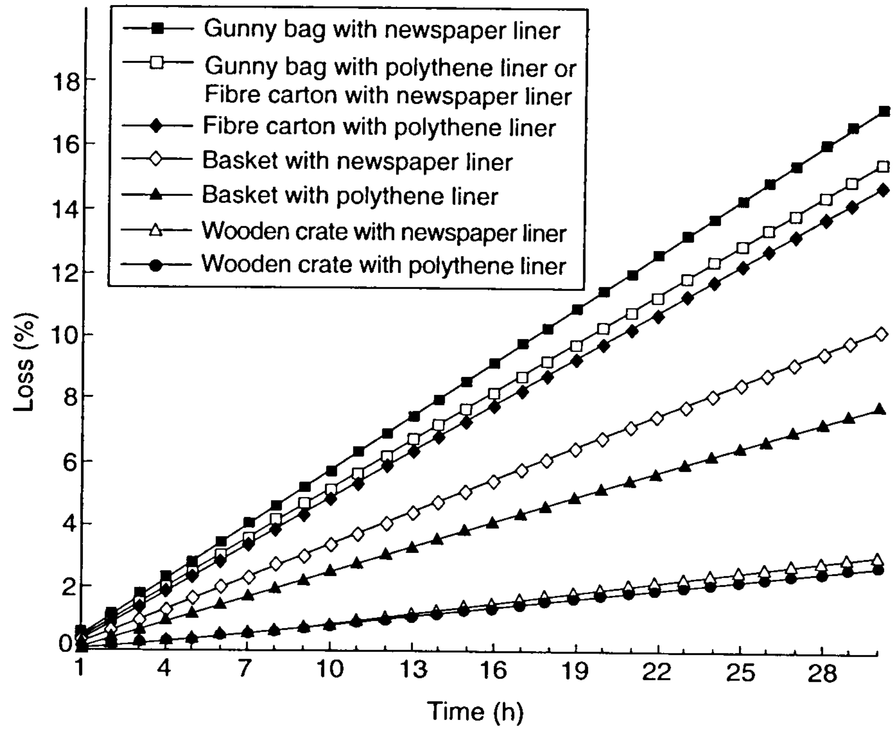

FIGURE 2. Effect of Packing Containers on Losses of Aonla Fruits (*Phyllanthus emblica*), During Transportation in India (Based on Data by Pathak *et al.*, 1989).

for the pertinent actors to change their attitudes toward reducing post-harvest losses than it is for them to think of buying costly packaging.

Some studies have provided empirical evidence about the reduction of losses through the use of appropriate packaging conditions. For instance, Siddiqui *et al.* (1990) showed that wire-bound boxes were more convenient than traditional boxes for the transportation of mandarin fruits in India. Along the same line, Pathak *et al.* (1989) investigated the effect of packing containers on losses of aonla fruits (*Phyllanthus emblica*) during the transportation to two different cities in India. The main results of that work are reproduced in Figure 2. Basically, packaging of fruits in wooden crates with a polythene liner showed minimum weight loss and bruising during transportation. This finding was in accordance with a similar study conducted for mangoes by Subramanham *et al.* (1972).

Another study, conducted by Ketsa (1989), analysing the benefits of prepackaging head lettuce at production sites in Thailand, showed that least physical damage occurred with the use of stretch film in collapsible plastic crates. More detailed results are reproduced in Table 2.

There is also an interesting study (Crucefix, 1990) that, besides assessing the physical losses by themselves, investigates the viability of using adequate packaging. The case involved an evaluation of alternative methods of inter-island shipment of plantains (*Musa sp.*) in the Commonwealth of Dominica. A commercial trial demonstrated that packaging was economically feasible (see Table 3) and reduced losses by 25%. In addition, indications were that the dealers could both improve quality and improve profitability of the system even

TABLE 2. Post-harvest Losses of Head Lettuce Shipped in Different Wrapping Materials and Shipping Containers in Thailand

Condition	Physical Damage (%)
Trimmed and wrapped with stretch film in collapsible plastic crates	19.5
Trimmed and wrapped with newspaper in collapsible plastic crates	23.1
Non-trimmed and wrapped with newspaper in bamboo baskets	28.1

Source: Ketsa (1989).

in the absence of a quality-related price premium. However, according to the same author, despite further extension using these data, no dealers have been persuaded to take up the ideas.

Fruit and Vegetable Commercialisation in Brazil

More than 80% of Brazilian agricultural production is transported by trucks. This can be explained by the difficulties that the other modes of transportation have in the interior areas, which are not well served by railways or waterways. However, the Brazilian road transport system is not necessarily of a good standard.

It was shown (Farina, 1992) that the road transportation time to bring melons from the north to São Paulo State had doubled in five years, attesting to the bad conditions of Brazilian roads. This can be considered a development of the same problem as identified by the World Bank (Harral & Faiz, 1988), through

TABLE 3. Comparison of Costs Incurred in Two Handling Systems for Plantain in Dominica

Item	Bunch	Carton (EC$/kg)
Price from farmers	110.0	110.0
Cost of rejected material	0.0	12.5
Packing costs	0.0	3.4
Cost of carton	0.0	20.7
Wharfage	0.0	0.5
Freight	14.5	13.8
Unloading	2.4	3.4
Customs charge	2.8	2.8
Cost of weight loss	27.7	4.0
Cost of bruising	15.4	0.0
Cost of small rejection	12.5	0.0
Total	185.3	171.0
Price obtained	220.0	220.0
Residue	34.7	48.9

Source: Crucefix (1990).

TABLE 4. Post-harvest Loss Estimates for Fruits and Vegetables in Brazil, 1992

	Production		Losses				
Product	Quantity (1.000 t)	Value (US$ million)	Quantity (1.000 t)	% of Production	Value (US$ million)	% of Loss Total Value	Cumulative % of Loss Total Value
Banana	10,195	3,445	4,079	40.0	1,378	38.52	38.52
Orange	18,806	4,485	4,137	22.0	987	27.58	66.11
Grape	786	1,851	204	26.0	481	13.45	79.56
Pineapple	1,086	627	258	23.7	149	4.16	83.72
Tomato	1,971	346	788	40.0	139	3.87	87.59
Mango	542	395	149	27.4	108	3.03	90.63
Others	4,955	1,239	1,435	29.0	335	9.37	100.00
Total	38,341	12,388	11,050	—	3,577	100.00	—

Source: Secretaria da Agricultura e Abastecimento de São Paulo (1993).

analysis of a survey conducted by Brazil's Federal Highway Network Authority in 1984, in which 70% of the Brazilian federal highways (more than 32,000 km) were rated as being of between fair and poor condition, with an estimated US$2.4 billion needed for maintenance and reconstruction work. As a consequence of road conditions, the losses during a longer journey tend to increase.

Losses during transportation are often related to seasonal conditions (Mazaud, 1994, pers. comm.). For instance, during rainy seasons, it is difficult to move produce out of the field and, when it is eventually transported, many difficulties may be encountered (delays, accidents, etc.). Therefore, the neglect of road maintenance not only raises transport charges and discourages market production, but also can raise consumer prices for speciality products, such as fresh produce. In addition, the high ambient temperature during the transport of fruit and vegetables in tropical countries such as Brazil accelerates the deterioration of those products.

According to Borges (1991), the Brazilian situation, in terms of losses, is no different from that of other developing or less developed countries. Losses account, in general terms, for around 30%, and reach between 80 and 100% for the more perishable products, such as some fruits and vegetables.

In the 1992 season, according to evaluations conducted by the Agriculture Department of São Paulo State, 11 million tonnes out of the national production of 38.3 million tonnes of fruits were wasted within the post-harvest system, implying a loss of US$3.3 billion (see Table 4). In terms of the total loss value, banana, orange, grape, pineapple, tomato and mango are responsible for more than 90% of the losses occurring in 1992.

The trade in two of these commoditiesĝpineapple and tomato[2]—kin the São Paulo State was investigated using data taken from a cross section of the trade that occurred during 1993[3] in the Ceagesp (*Companhia de Entrepostos e Armazéns Gerais de São Paulo*), the main wholesale market in São Paulo city, in Brazil. The conditions for the trade of these selected commodities are briefly summarised in Figure 3.

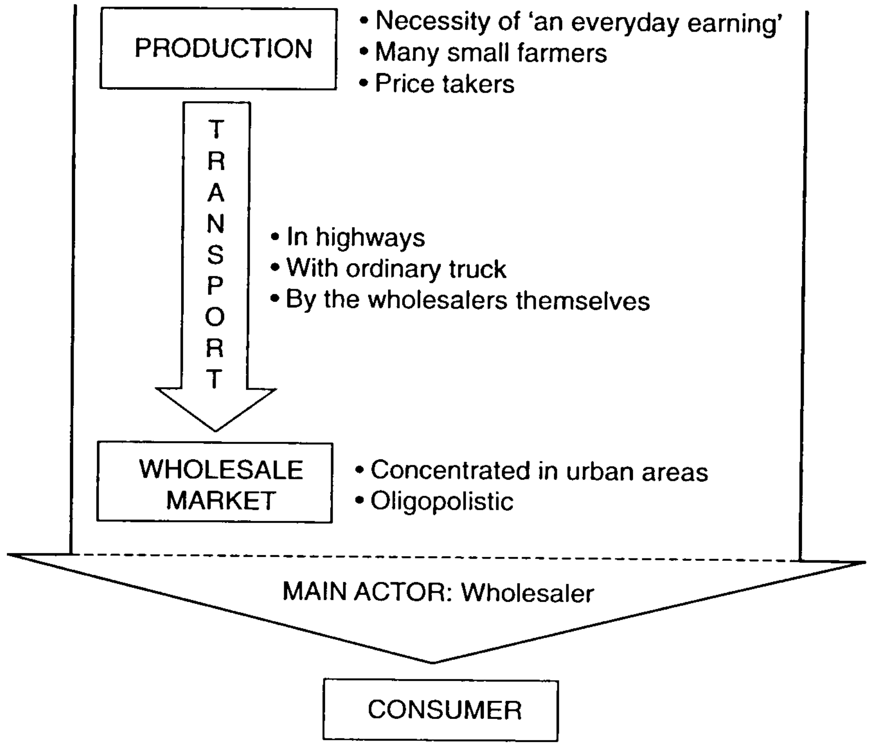

FIGURE 3. Basic Logistics Operating Environment of Trade of Fruits and Vegetables sold in São Paulo city, Brazil.

The wholesaler, the main actor in the entire process, is responsible for selling the produce from the farmers. According to Barros (1990), the wholesalers lead other market levels in terms of price variation, and these variations are transmitted less than proportionally to consumers and almost proportionally to producers.

From the final price obtained in the market, and over the total volume delivered by the producers, the wholesalers subtract their fixed proportional commission, as well as the transport expenses. The remaining value is the amount paid to the farmers.

The producers are usually great in number, with small properties, and with little bargaining power over the wholesalers. Also, as Khan (1992) reminds us, farmers want to be paid immediately after they deliver their products to the wholesaler. The small farmers usually have need of "an everyday earning" and do not have the capacity or interest to store their produce.

The wholesalers, as carriers, have an interest in the storage of the products, to at least preserve the highest possible percentage of the products to be sold in the market. However, they are normally reluctant to incorporate some type of more advanced technology (e.g. refrigerated trucks, modified atmosphere etc.) due to the investment costs involved, as well to a lack of information regarding the extra returns to be obtained through the use of that type of technology. Currently, most of the fruits and vegetables are still loaded in bulk, into normal trucks.

The Proposed Model

In order to model the problem of losses during the transportation of fruits and vegetables, taking into consideration the main aspects associated with losses (described in the previous sections), the following were assumed.

(a) Road conditions are fundamental when considering the distance to be driven. Therefore, adjustment factors are assumed as a means of homogenising distance values for different types of road surface, by vehicle type. For instance, taking empirical evidence given by Whitman (1968), for a diesel truck (10 t), to drive 1 km on a gravel road is "equal" to driving 1.510 km on a paved road, and so on.
(b) The level of losses varies according to the transport option to be utilised. This means that distinct loss levels will be observed if the product is, for instance, transported in bulk by normal trucks or by refrigerated cars with adequate packaging.

There are also distinct costs associated with each of the transport options. These functions and the respective costs for them are therefore incorporated in this analysis. In view of this, a normative approach is appropriate and mathematical programming techniques are utilised for the treatment of the problem.

The problem can be formulated as one of maximising the wholesaler's profit observed in the trade of each specific product, taking into consideration the possibility of having available technological options for diminishing losses. This would imply the determination of the following: shipment patterns between supply and demand regions for agricultural products; prices to be paid to the producers; pertinent consumer's prices; and damage prediction during the transportation of each type of product. The required data are basically associated with the following: supply and demand functions; transport cost functions; loss levels; and the distances between the regions.

The mathematical structure of the model as well as the data used can be found in Caixeta-Filho (1994), while a detailed output for the tomato situation is presented by Caixeta-Filho (1995). A basic scheme for the model is presented in Figure 4, where it is assumed that the traditional behaviour of the wholesaler is related to the maximisation of total profit observed for each specific product, under supply, demand and "price transmission" constraints. An alternative behaviour would include in this framework the supply of technological options (wooden boxes for pineapples and refrigerated trucks for tomatoes), as a means of reducing the losses during transportation activity. The mathematical model proposed was built for both cases, and processed with the General Algebraic Modelling System (GAMS), developed by Brooke *et al.* (1992).

Simulated Scenarios: Results and Discussion

The market for fruits and vegetables in Brazil, in both supply and demand sides, cannot yet be divided according to a preference for a logistic option. For instance, there is no specific demand equation for pineapples transported in wooden boxes. In this case, the consumer is mainly interested in the product itself, with a reasonable quality (roughly measured by visual inspection), and

PRESENT BEHAVIOUR	ALTERNATIVE BEHAVIOUR
Maximisation of the total profit subject to supply and demand functions	Maximisation of the total profit subject to supply and demand functions (incorporating losses) **+ supply of technology options for diminishing losses**

GENERAL RESULTS
Demand price Price paid to the producer Shipments patterns Damage prediction Total revenue for the producer Profit of the wholesaler

POLICY EXPERIMENTS
Economic assessment of the implementation of the technological options for diminishing losses

FIGURE 4. Basic Structure of the Simulated Scenarios.

with the lowest possible price. Hence, the behavioural equations are the same, independent of the scenario that is tested.

The differences between the scenarios to be run are related to the different levels of losses as well as to the different transport costs involved. In order to compare the performance of refrigerated trucks over open trucks, each of these transportation options was considered separately, in an individual scenario, with the different results being compared, according to the perspectives of the actors involved in the process. In view of this, the following decision rules were considered:

(a) the wholesalers (the main actors) would be willing to adopt an alternative logistic option if their aggregated commission was increased;
(b) the consumer at the wholesale market would only be impressed by smaller unit prices;
(c) the producers would be better off if their total revenue was increased.

Two basic types of scenarios were tested under the validated modelling structure. In the first one, the level of losses associated with the alternative transportation option was parameterised, as a means of evaluating the main implications on the variables of the model. In the second category of experiment, the price elasticitiesĝused to formulate the supply and demand functionsĝwere altered, with the eventual changes on the trade of the products being assessed.

It is observed that the demand side involved in the trade of pineapples and tomatoes is much more sensitive to a decrease in losses than the supply side. It is also interesting to confirm that, for both products, the only variable that has its value clearly increased, after a decrease in the level of losses, is the "demand volume".

The introduction of wooden boxes makes the pineapple more attractive for the consumer, since the increased supply of that fruit pressures the price downward. In terms of the production side, there is almost no alteration in the behaviour of the supplied volume and supply price, or in the producer's revenue.

With a continuous decrease per unit of loss avoided, the wholesalers are better off only until the stage at which the losses with wooden boxes are at a minimum level of 18%. Therefore, if the losses are lower than that level, even considering that this would benefit the consumers, it is unlikely that such an option would be established.

The grounds for the viability of the utilisation of refrigerated trucks are still more questionable with respect to the tomato. Transport in refrigerated trucks seems to be more attractive than transport in open trucks, at least in terms of final demand price, when the observed level of losses is lower than 38%. However, both wholesaler's commission and producer's revenue diminish continuously after the introduction of this alternative transportation option. Therefore, it appears that both wholesaler and producer would have to undergo a decrease in their incomes in order to pay for the increase of the benefits of the consumers.

Figure 5 shows that situation "1" (greater amount of losses) can be changed to situation "2" (smaller amount of losses) if losses incurred through transportation by refrigerated cars are diminished. The possibility of having more produce available at the wholesale market (DV2 > DV1) pressures the price down (DP1 → DP2). The new price to be paid to the producer (SP2) is lower than the original one (SP1), which is mainly a result of the "price transmission" constraint, that searches for the best combination for the difference between the demand price (DP) and the supply price (SP). The supplied volume in the improved situation (SV2), which is also lower than the previous value (SV1), can then be calculated directly in the pertinent supply function.

The data utilised can be considered reliable, but when aggregated to represent the actual situation for the trade of pineapples and tomatoes, some doubts are raised, especially with respect to the values of the price elasticities used in the supply and demand functions. In view of this, the sensitivity analysis conducted on these values can give some explanation for some of the assumptions incorporated into the model. The results show that groups of variables had similar behaviour—the same relative change—after the variation in the values of the elasticities: demand and supply prices; demanded and supplied volumes; and wholesaler's commission and producer's revenue. Also, due to its lower demand elasticity (in absolute value),[4] the changes in the tomato results were much more significant than those of the pineapple results.

Concluding Remarks

This study proposes a normative transportation model that incorporates the possibility of assessing transportation losses. An application was developed for a cross section of the trade of pineapples and tomatoes at a representative wholesale market from São Paulo city in Brazil. Apart from some limitations on

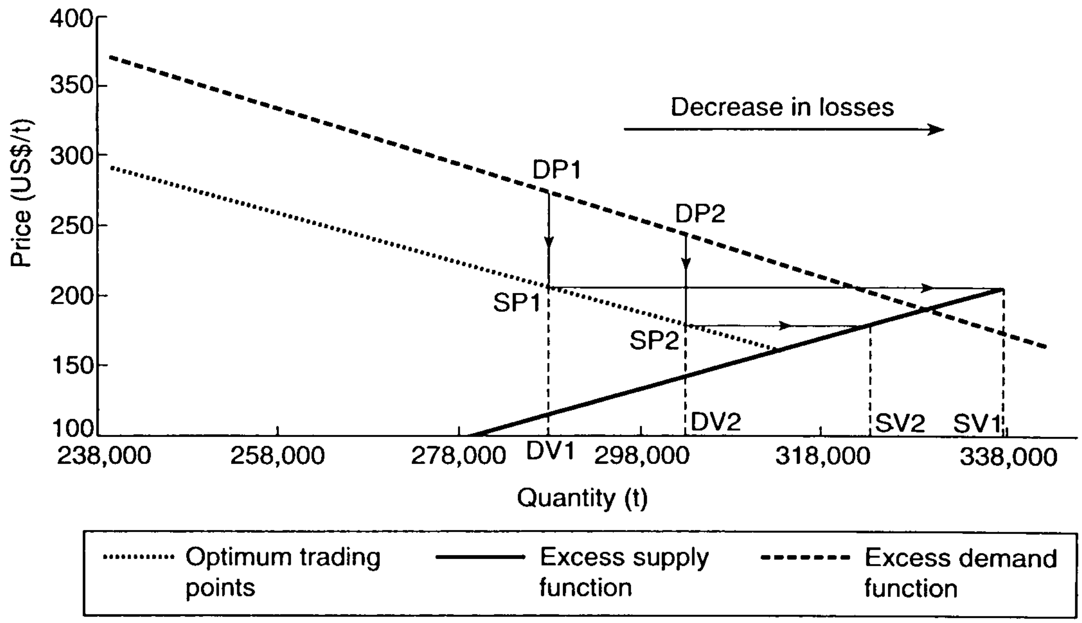

FIGURE 5. Dynamics of Change in the Market, After a Decrease in the Level of Losses in the Transportation of Fresh Produce.

the data utilised, it could be observed that in an oligopolistic environment such as this, the appeal of diminishing the level of losses, via use of alternative technological options, did not appear to be viable. There would be a clear benefit for the consumers from an increase in the availability of those products, at a lower unit price.

On the other hand, due to their price elasticity characteristics, the producers seemed to be more sensitive to the decrease in the unit price than to the increase in the volume traded, diminishing their deliveries. The wholesalers, on their side, if keeping a fixed proportional commission on that volume received, would not be greatly encouraged to invest in alternative technological options.

Specifically in relation to the tomato case, it must also be remembered that the utilisation of refrigerated trucks is only one of the activities that has to be carefully planned if an effective cold chain is to be established. Moreover, it would require a totally different concept for planting, harvesting and storing of the product, which was not investigated in this study.

In summary, it can be said that it is possible to model a typical interface problem such as the one regarding losses in the transportation. However, the benefits from diminishing losses seem to be more related to changes in the marketing structure of the business than solely to the use of new technological options. Besides, as one player pays the costs and another gains the benefits, there would only be a potential solution for this logistics chain problem if both costs and benefitsĝincluding the environmental savings from technological improvementsĝwere shared among the different players.

NOTES

[1] Certainly, there are some other direct and indirect causes and effects of losses in the

transportation of agricultural products. Also, the factors that cause losses in transport are not necessarily related to the transportation activity itself.

[2] The reasons for the choice of these two products are related to obtaining pertinent data to be used in the mathematical model. Nevertheless, the methodology developed can be applied to products with any level of losses.

[3] Of the 1990s, 1993 can be considered as a representative year in terms of trade of fruits and vegetables in Brazil.

[4] The values for price elasticities were obtained from Thomas *et al.* (1991).

REFERENCES

AUSTIN, J.E. (1992) *Agroindustrial Project Analysis: critical design factors.* EDI Series in Economic Development, 2nd edn (Baltimore, MD, Johns Hopkins University Press).

BARROS, G.S.C. (1990) Transmissão de preços pela Central de Abastecimento de São Paulo, *Revista Brasileira de Economia,* 44, (1), pp. 5–20.

BAUMEL, C.P. & HAYENGA, M. (1984) Domestic food security: transportation and marketing issues, in: BUSCH, L. & LACY, W.B. (Eds) *Food Security in the United States,* pp. 278–288 (Boulder, CO, Westview Press).

BORGES, R.F. (1991) *Panela furada: o incrível desperdício de alimentos no Brasil,* Vol. 7 (São Paulo, Columbus, Coleção Cardápio).

BOURNE, M.C. (1977) *Post Harvest Food Losses: the neglected dimension in increasing the world food supply* (Ithaca, NY, Cornell International Agriculture Mimeograph 53).

BROOKE, A., KENDRICK, D. & MEERAUS, A. (1992) *GAMS: a user's guide, Release 2.25* (Redwood City, CA, The Scientific Press).

CAIXETA-FILHO, J.V. (1994) *Modeling Losses in the Transportation of Agricultural Products,* Research report (Kiel, Institut fur Agrarökonomie, Christian-Albrechts-Universität zu Kiel).

CAIXETA-FILHO, J.V. (1995) Transportation models: the treatment of losses in a tropical fruit and vegetables case study, in: KUSHWAHA, L., SERWATOWSKI, R. & BROOK, R. (Eds) *Proceedings of the International Conference "Harvest and Postharvest Technologies for Fruits and Vegetables",* ASAE Publication 1–95, pp. 645–652.

COUNCIL FOR AGRICULTURAL SCIENCE and TECHNOLOGY (1974) An approach to evaluation of rural transportation needs and problems in the United States, in: *Report on a Field Study of Problems in Agricultural Transportation and Marketing,* compiled for the Subcommittee on Agricultural Production, Marketing, and Stabilization of Prices of the Committee on Agriculture and Forestry United States Senate, pp. 9–27 (Washington, DC, US Government Printing Office).

CRUCEFIX, D.N. (1990) Plantain (*Musa* sp) handling improvements in the Eastern Caribbean: the technology is only half of the battle, *Acta Horticulture,* 269, pp. 401–407.

DAVIS, J.C. (1980) Agriculture and transportation: a positive impact, in: *Increasing Understanding of Public Problems and Policies: 1980,* pp. 51–58 (IL, Farm Foundation, Oak Brood).

FARINA, E. (1992) *Frunorte: frutas brasileiras no mercado europeu,* EC.005.92 (São Paulo, FEA-PENSA/USP).

FOOD and AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS (1977) *An Analysis of an FAO Survey of Post-Harvest Food Losses in Developing Countries,* AGPP: MISC/27 (Rome, Food and Agricultural Organisation of the United Nations).

FOOD and AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS (1989) *Prevention of Post-Harvest Food Losses: fruits, vegetables and root crops: a training manual,* No. 17/2 (Rome, Food and Agricultural Organisation Training Series).

GALLIMORE, W.W. (1981) Transporting food and agricultural products, in: *Agricultural-Food Policy Review: perspectives for the 1980's,* pp. 82–93 (Washington, DC, Economics and Statistics Service, US Department of Agriculture).

HARRAL, C.G. & FAIZ, A. (1988) *Road Deterioration in Developing Countries: causes and remedies* (Washington, DC, The World Bank).

HARVEY, J.M. (1981) Optimum environments for the transport of fresh fruits and vegetables, *International Journal of Refrigeration*, 4, (5), pp. 293–298.

HUTCHINSON, T.Q., HOFFMANN, L.A. & PARLETT, R.L. (1974) *Improving the Export Distribution System for Fresh Fruits and Vegetables*, Marketing Research Report no. 1027 (Washington, DC, United States Department of Agriculture, Economic Research Service).

JONES, C.S., HOLT, J.E. & SCHOORL, D. (1991) A model to predict damage to horticultural produce during transport, *Journal of Agricultural Engineering Research*, 50, (4), pp. 259–272.

KADER, A.A., KASMIRE, R.F., MITCHELL, F.G., REID, M.S., SOMMER, N.F. & THOMPSON, J.F. (1985) *Postharvest Technology of Horticultural Crops*, Cooperative Extension, Special Publication 3311 (California, University of California, Division of Agriculture and Natural Resources).

KAHAN, R.A.R. (1992) How to save growers against losses of perishables?, *Journal of Rural Development & Administration*, XXIV, (2), pp. 43–50.

KETSA, S. (1989) Prepackaging of head lettuce at production site, *The Journal of Agricultural Science*, 22, (4), pp. 323–328.

NDULU, B.J. (1980) *The Role of Transportation in Agricultural Production Decisions: theory and empirical evidence in the case of Tanzania*, Paper 80.7 (University of Dar Es Salaam, Economic Research Bureau).

NEW, J.H., PROCTOR, F.J. & HEWITT, V.J. (1978) Packaging of horticultural produce for export, *Tropical Science*, 20, (1), pp. 21–34.

PATHAK, S., PATHAK, R.K. & SINGH, I.S. (1989) Effect of packing containers on losses of aonla fruits during transportation, *Indian Journal of Horticulture*, 46, (4), pp. 468–469.

POLOPOLUS, L. (1982) Agricultural economics beyond the farm gate, *American Journal of Agricultural Economics*, 64, (5), pp. 803–810.

REUSSE, E. (1976) Economics and marketing aspects of post-harvest systems in small farmer economies, Parts 1 and 2, *Monthly Bulletin of Agricultural Economics and Statistics*, 25, (9), pp. 1–7; 25, (10), pp. 1–10.

SALUNKHE, D.K., BOLIN, H.R. & REDDY, N.R. (1991) *Storage, Processing and Nutritional Quality of Fruits and Vegetables*, Vol. I, 2nd edn (Boca Raton, FL, CRC Press).

SECRETARIA DA AGRICULTURA E ABASTECIMENTO DE SÃO PAULO (1993) *Estimativas das perdas agrícolas no Brasil*, Coordenadoria DE ABASTECIMENTO.

SIDDIQUI, S., KUMAR, J., SINGH, K. & SHARMA, R.K. (1990) Comparison of modified wire bound boxes over traditional wooden boxes for transportation of fruits, *Progressive Horticulture*, 22, (1–4), pp. 154–155.

SPENSLEY, P.C. (1982) Whither the post-harvest sector?, in: SCHULTEN, G.G.M. (Ed.) *Post-Harvest Improvements for the Eighties and Nineties*, pp. 111–130, Communication 72 (Amsterdam, Department of Agricultural Research, Royal Institute Amsterdam).

SUBRAMANHAM, H., MOORTHY, N.V.N., LAKSHMINARAYANA, S. & KRISHNAMURTHY, S. (1972) Studies on harvesting, transport and storage of mango, *Acta Horticulturae*, 24, pp. 260–264.

THOMAS, D., STRAUSS, J. & BARBOSA, M.M.T.L. (1991) Estimativas do impacto de mudanças de renda e de preços no consumo no Brasil, *Pesquisa e Planejamento Econômico*, 21, (2), pp. 305–354.

WHITMAN, D. (1968) *A Computerized Transportation Planning Model with Application to Brazil* (Los Altos, CA, SYSTAN, Inc., SPR68–6).