Supply Chain Reconfiguration as an Option to Mitigate Post Harvest Losses and GHGs: Simulating a Case Study from Banana Supply Chain in Sri Lanka

M. K. D. C. K. Chandrasiri[1(✉)] , U. S. S. Dharmapriya[1] , A. K. Kulatunga[1] ,
R. M. R. N. K. Ratnayake[2], W. M. C. B. Wasala[2], and W. A. P. Weerakkody[2]

[1] University of Peradeniya, Peradeniya, Sri Lanka
`chandrasirichethana@gmail.com`
[2] National Post Harvest Management of Sri Lanka, Anuradhapura, Sri Lanka

Abstract. Zero hunger is one of the top three goals of Sustainable Development Goals which is achievable by reducing the postharvest losses of the food supply chain and improving food security. In developing countries approximately 40% of fruit harvest goes to waste due to not having proper mechanisms, coordination and best practices and poor post-harvest management. A pilot study has found post-harvest losses of fresh fruits and vegetables occur in 2.29%, 1.57%, 6.22% and 7.89% at farmer, collection center, wholesaler and retailer respectively, emphasizing the need of a reconfiguration. Following good practices in handling, introducing suitable bulk packing methods, vehicle upgrades and development of different supply chain configurations are some approaches in mitigating post-harvest losses. Therefore, it is timely to change the product flow of supply chain by reconfiguration. The existing configuration of fruit and vegetable supply chain is simulated as an agent based simulation model taking banana supply chain as a case study. Short supply chain branches were introduced as suggestions to avoid the congestion and banana getting exposed to mechanical damages. The reconfigured supply chain emitted 10% less GHG than the existing banana supply chain while achieving the efficiency in distribution flow.

Keywords: Reducing PHL · Supply chain reconfiguration · Agent based simulation

1 Introduction

Sri Lanka has been ranked 66th among 113 countries in the Global Food Security Index in 2019. In Sri Lanka the annual loss of fruit during domestic production has been reported about 210,000 metric tons, worth about US$90 million [1]. Postharvest losses (PHL) frequently occurred when packing, transporting, handling, harvesting, distributing, storage, production and retailing. To mitigate PHL, experts have suggested supply chain actors following good practices in handling, using suitable bulk packing methods, vehicle upgrades such as controlling systems, and supply chain reconfigurations to mitigate PHL.

1.1 Different Supply Chain Configurations

Sri Lankan fruit and vegetable (F & V) supply chain mainly functioning as traditional and modern (supermarket) F & V supply chain channels. Commission system and periodical (fairs) system are minor operating supply chain channels [1] in Sri Lanka Table 1 provides a descriptive summary of the different supply chain channels.

**Table 1.** Existing different supply chain configurations.

Supply chain channel	Description
Traditional	• Composed with small scale farmers • Value/non-value adding activities at intermediaries • Different configurations with slight geographical and operational variations (Fig. 1)
Super market	• Includes super market collection centers and central processing warehouse • Proportion purchased is very low • Low quality products are sold to traditional supply chains • During the market gluts, purchasing from the traditional supply chain • Transportation and overhead cost is high, cost due to damage is low [2]
Commission system	• Contact commission agents in Manning market (Colombo) and supply by transport agents • Farmers get paid by the commission agents • The product ownership is not transferred to the transport agent. (They are not accountable for the PHL occurred) • The PHL is deducted from the farmer
Periodical system	• After supplying to the main distribution channels, the remainder is sold at the local fair

The different ways of product flow between the intermediaries create different supply chain channels. increased number of intermediaries makes the supply chain more complex while increasing the PHL leading to low profitability for farmers and higher prices for consumers [1]. Table 2 Provides detailed summary of the intermediaries and their characteristics.

Table 2. Intermediaries involved in the existing supply chain structures.

Intermediaries	Characteristics
Collectors (Mobile/Centers)	• Buy from small scale farmers and distribute to DECs, whole sale markets and retail fairs • Mobile collectors visit, harvest and purchase the crop or distribute to collection centers • When mobile collectors involved loss is comparatively low
Dedicated Economic Centers (DEC)	• Majority of the F & V s are distributed via 12 DECs scattered across the island • Transferred to another DECs, whole sale market or a retailer
Central Wholesale Market (Manning Market)	• Connecting the DECs all over the country [3] • Farmers, collectors and DECs supply F & V to the central wholesale market and dispatched to retail markets and fairs
Super Market Collection Center	• Only a limited number of farmers who regularly supply and who are located closer have the direct access • High buying price if meet the high quality requirement
Central Processing Warehouse	• Operated by major supermarkets • Super market collection centers transport F & V to the central processing warehouse to store • Sorting, grading, weighing and packing is done before dispatching to super markets [4]
Fairs/road side shops	• Directly supply to the consumers

At present, numerous different configurations exist as given in Fig. 1. One third of the total F & V in Sri Lanka is handled through farmer – DEC – retailer market – consumer matrix, 20% through farmer – wholesaler – retailer - consumer marketing channel, 3% via local fairs and only 1% via supermarket channels [5]. Since high portion of the fruits and vegetables are reaching the consumers through the traditional channel, high impact can be made by reconfiguring. This study ultimately proposes reconfiguration of the supply chain to change the mode of operations. Initially, the existing supply chain of a selected fruit (banana) will be modeled as an agent based simulation model. Then the identified bottlenecks will be addressed by a reconfigured supply chain model.
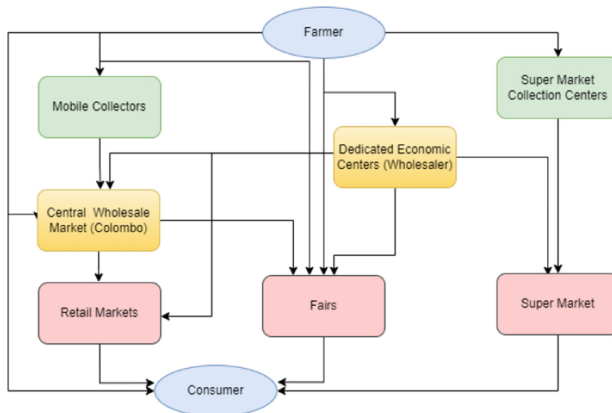
Fig. 1. Existing F & V Distribution Channels.

2 Background Study

PHL estimations, their occurrences and major influencing factors for PHL have been widely studied all over the world. In Ethiopia, banana PHL was estimated as 26.5% and out of it 56%, 27% and 17% occurred in retail, wholesale and farm levels respectively [6]. Cross-sectional analysis to determine the extent and factors influencing PHL in the cooking banana value chain in Uganda has found that 14.9% of banana suffer PHL, 7.2% completely and 7.7% partially [7]. Carbon footprint is frequently studied in related to F & V supply chain. A study of greenhouse gas emission of bananas from cradle to retailer and cradle to grave has found overseas transport and primary production are the main contributors of total GHG emissions [8]. Considering the fact that banana is one of the most important crops in the world, none of the studies have done related to banana supply chain reconfiguration in order to reduce PHL, GHG emission and achieve operational efficiency.

Even bananas are the widely cultivated and highest selling fruit crops in Sri Lanka [6], only a handful of studies have investigated different aspects of banana supply chain over last two decades [7].The long term trends in extent, production and cost of cultivation have been studied of the banana sector in Sri Lanka [8]. Value chain concept has been utilized to analyze the situation (characteristics, inefficiencies) of banana industry in 2016 [9, 10]. PHL have been quantified in sour banana supply chain and associate climate impacts have been estimated using life cycle analysis approach [7]. The waste streams and causes of waste have been identified and solution frameworks have been suggested to minimize those wastes and to improve quality and safety of banana [11]. Appropriate bulk packaging system for banana bulk transportation has been introduced to reduce PHL due to mechanical damages in Sri Lankan distribution channels [12]. None of the studies have been done reconfiguring the banana supply chain to reduce PHL and GHG emission. This study aims proposing a reconfiguration of the supply chain to change the mode of operations.

3   Methodology

3.1   Data Collection

The study covered two major banana supply chain branches; starting from farmer fields at Embilipitiya (Southern province) and Thambuttegama (North Central province) which are terminating at the retail markets of Colombo, Gampaha (Western province), Kandy (Central province), Badulla (Uva province) and Balangoda in (Sabaragamuwa province). For this study, randomly selected farmers were given questionnaires and finally, 20 and 10 farmers were selected from Embilipitiya and Thambuththegama respectively due to the complete information provided. From these farmers data regarding their production, collection, distribution, mode of transportation and quantity, wastages, storage capacity, selling price, buying price, waiting time at each stakeholder, number of routes, vehicle capacity and travelling distance at each stake holder were collected through field surveys, observations and personal interviews. According to the data obtained, Embilipitiya and Thambuththegama banana supply chains were simulated.

3.2   Selection of Simulation Technique

To observe the impact of each supply chain entities, the existing operations and where the improvements are required the agent based simulation method can be adopted by taking farmers, collectors, DECs centers, wholesalers and retailers as agents.

3.3   Banana Supply Chain Case Study

Initially, the existing banana supply chain is simulated as an agent based simulation model on "Simio 14" for a week and the performance measures in terms of the PHL, GHG emission (kgCo2eq) and lead time of the current banana supply chain are discussed. Then to mitigate GHG emission and PHLs them the existing banana supply chain is reconfigured and the performance measures of the new configuration are compared with the existing banana supply chain.

A kilogram of banana is considered as one entity which is traversing through the simulation model. Cultivation areas have been taken as sources, and farmers, collection centers, DECs, wholesalers and retailers have been taken as servers. From the retailer markets, the entities are passing to the sinks which are referred to the consumers. Sources, servers and sinks are connected by paths drawn according to the actual distance scale. EF_i, F_i, ECC, TCC, EW, TW, EFV_i and TFV_i were referred to, Embilipitiya i^{th} farmers, i^{th} farmer, Embilipitiya collection center, Thambuttegama Collection Center, Embilipitiya wholesaler, Thambuttegam wholesaler, Embilipitiya farmer's i^{th} vehicle, Thambuttegama farmer's i^{th} vehicle respectively.

4   Results and Discussion

When the farmers delivering banana to the collection centers/DEC, the payment is made for the total banana weight. Therefore, they overload the vehicle and try to deliver

maximum at once, eventually increasing PHL. According to the pilot study conducted it was found that, the second most banana PHL is occurring at the wholesale point followed by the collection center [9]. Since most of the farmers and mobile collectors deliver banana lots to the collection centers/DECs in the morning, there is a huge congestion. In the existing banana supply chain, entire amount of banana is going through collection center, wholesaler and then to different retailers while exposing to PHL at each point.

To overcome these issues,

- The small scale farmers are encouraged to use the collection center vehicle or a mobile collector rather than taking individual vehicles.
- Large scale farmers are encouraged to supply their ripen banana directly to the wholesaler.
- Collection centers are encouraged to supply the over-ripen banana directly to the retailers.

When mobile collectors involve, who follow the good post-harvest handling practices the PHL are comparatively low. The large scale farmers supplying the over ripen bananas directly to the wholesaler to avoid the congestion at collection center. Letting the collection centers directly supply the over ripen banana to retailer market is another strategy to reduce congestion and PHLs at wholesale. Here, in the improved version, all the banana lots are not traversed through the same route. Yellow color demarcated vehicles are used to collect banana in a defined route. Figure 3 contains direct paths from the Embilipitiya and Thambuttegama collection centers to Colombo retail market. Other than that, large scale farmers are directly supplying the wholesale markets. Since the loading and unloading is lesser, the probability of banana exposing to PHLs can be reduced (Fig. 3).
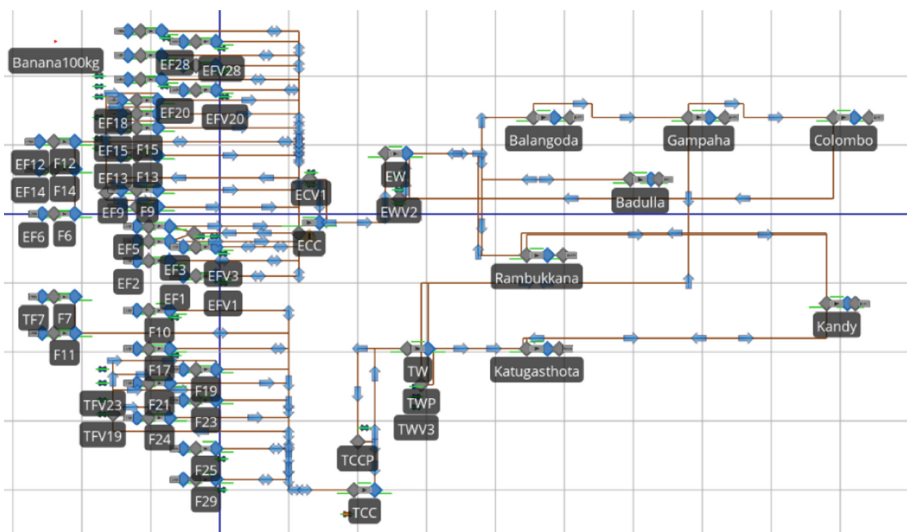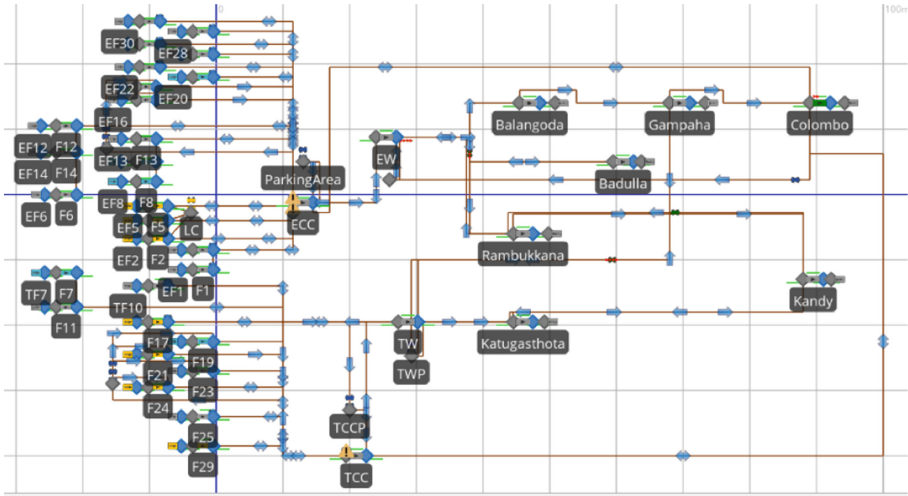

Fig. 2. Existing Banana Supply Chain.

Fig. 3. Suggested Banana Supply Chain.

Table 4. GHG emission comparison of the existing and suggested banana supply chains.

Stage	Existing Banana SC				Proposed Banana SC			
	PHL (kg)	Net GWP (kgCo$_{2eq}$)			PHL (kg)	Net GWP (kgCo$_{2eq}$)		
		Production	PHL	Transport		Production	PHL	Transport
Farmer	31.5	272.79	8.82		31.5	272.79	8.82	
Farmer to Collector				16.3				10.43
Collector	21.6		6.04		21.5		6.01	
Collector to Wholesale				9.10				59.00
Wholesale	85.6		23.97		42.28		11.84	
Wholesale to Retailer				149.94				73.63
Total		**486.96**				**442.52**		

Here, GWP when transporting and at each supply chain intermediate point as PHL were calculated as bellows [9];

GWP (transporting) = ton-kilometers x emission factor
GWP (Organic waste) = 0.28 kgCo$_{2(eq)}$kg^{-1} x Organic waste
GWP (Production) = 0.206 kgCo$_{2(eq)}$kg^{-1} x Production quantity

Table 4 summarizes the variability of the GHG emission and PHLs between the existing and the suggested banana supply chain configurations. The proposed configuration emits 10% of GHG less than the existing structure. Only when transporting banana from collection center to wholesale, as the over ripen banana portion is suggested to directly supply to the retailers, the distance has increased and proportionally the GHG emission has been increased. As the pilot study [9], reported high percentage of PHL at wholesaler and while transporting from wholesale to retailer points and to reduce the high congestion there, the short supply chain branches are introduced. The average traverse time has reduced by 24.27% in the proposed solution. Since the GHG emission is proportional to travel distance and the travel distance is higher in the suggested configuration, altering this scenario encouraging each stake holder to supply to the nearest location, merging with other high capacitated transport modes rather than limiting to own transport modes with less capacity will further reduce the GHG emission being cost effective at the same time.

5   Conclusion

Operational efficiency has been achieved by re-configuring supply chain with less PHL and GHG emission. Introducing the short supply chain branches for ripen and over-ripen banana, adding transport capacity to wholesaler and optimum vehicle utilization were the suggested improvements. Reducing possibility of banana lots exposing to PHL while transporting and processing, the GHG has been reduced by 10% increasing the banana distribution flow and the flow efficiency of reaching the retailer markets.

This simulation is only based on static routing behaviors which can be pointed out as a limitation. This can be further extended by introducing dynamic routing behaviors in different scenarios. The simulation model can be integrated with the consumption rate at each retail market and by adding emission at each supply chain stage and vehicles incorporated. Path optimizing where the GHG, PHL and efficiency is optimized is yet to study. Vehicle capacity optimization methods for banana can be introduced to minimize the waste during transportation as a future study.

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