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Mapping Post-Harvest Waste in Perishable Supply Chains through System Dynamics: A Sri Lankan Case Study

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ABSTRACT

Purpose : *This research focuses on gaining insights on post-harvest waste. It is based on the upstream traditional vegetable and fruit supply chains in Sri Lanka and hopes to provide a basic understanding for future research. The research focuses on Thambuththegama and Nuwara Eliya dedicated economic centers which were established to collect vegetables directly from farmers.*

Research Method : *Novel methods such as value stream mapping and system dynamics were used to map the supply chain and post-harvest waste for the first time in Sri Lanka. Value stream mapping was used to identify value-adding and nonvalue-adding activities. From the knowledge gained through literature and industry inputs a causal loop diagram was drafted.*

Findings : *The causal loop diagrams show that lack of communication platforms, poor practices in handling vegetables, weather conditions and the number of intermediaries affect more towards post-harvest waste. To reduce post-harvest waste, the government should invest more in awareness programs for the actors in the supply chain and relevant infrastructure. The research finds that inability to control the transpiration and respiration process of the harvested vegetables, unawareness of the issues among the value chain actors and operational inefficiencies are the main causes for post-harvest waste.*

Value : *Future researchers can base the drafted causal loop diagram and develop a simulation model to increase operational efficiency and reduce post-harvest waste in the system.*

Keywords: *Supply Chain, Post-Harvest Waste, Value Stream Mapping, System Dynamics, Causal Loop Diagram*

INTRODUCTION

Vegetable and fruit supply chains are critical food supply chains that have come under the scrutiny of many experts, due to its perishability. Industrial experts and researchers have contributed in many ways to increase the efficiency of perishable supply chains. Operational barriers and environmental barriers like the high perishability of products, certain activities among the value chain, and weather conditions that constrain effectiveness are critical issues. This produces waste at various stages of the supply chain, and this is defined as post-harvest waste. This is a huge loss for the economy of the country, and this directly impacts farmers and consumers, because farmers get a low revenue at the selling point while consumers have to pay a huge amount at the buying point.

This research focuses on analyzing this problem from a systems engineering perspective using methods such as value stream mapping and system dynamics to compound the value chain to a system. While preceding literature has explored this from various angles, we feel this study complements the current literature by synthesizing previous works and our findings through the mentioned methods. We hope to encourage more multidisciplinary research on this nationally important research area to build a strong data repository that can be used to develop a seamless value chain that benefits all stakeholders.

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Literature Review

With the rising income level of the middle-class, people in developing countries have placed more impetus on perishable supply chains. As a result, demand has increased between 50-70% during the 20th century Green Revolution (Prosekov and Ivanova, 2018). In order to supply the demand, vegetable and fruit production has also been increased. But globally, half of the fresh vegetables and fruits go to waste as they flow through the supply chain. This loss is known as Post-Harvest Waste (PHW). Experts in this sector define PHW as the waste that results in loss of either quality or the quantity of the vegetables or fruits while flowing from upstream to downstream in the supply chain (Kader, 2005). With the growing population, food security is a major concern and the reduction of waste is a solution for this. One issue that binds with PHW is the fact that there isn't any universally accepted scientific method to estimate or predict the exact amount of PHW. This is because of the high variability of the climates, geographical conditions and heterogeneity of crops (Kader, 2005)

When considering PHW, it can occur mainly in 3 stages of the supply chain. These are operational, ecological and socio-economic stages (Nourbakhsh *et al*, 2016). According to Murthy *et al,* (2009), major operational causes that affect PHW are inefficiencies in storage, handling and transportation. At present in most of the developing countries, farmers don't use any demand forecasting techniques like in the manufacturing, processing, or service sectors. Additionally, the current agricultural industry is more focused on how to increase production rather than optimize production (Zou *et al,* 2007). Because of previously mentioned reasons, misuse of knowledge, poor infrastructure and lack of awareness about Good Agricultural Practices (GAP), vegetables and fruits go to waste.

In the Sri Lankan context, we can see two different vegetable and fruit supply chains. According to Perera *et al*. (2011), they are traditional (through shops and fairs) and modern (supermarkets) supply chains. Still, the larger quantity of vegetable and fruit production flows through the traditional supply chain and it fulfils 67% of the total consumer demand (Perera *et al.* 2011). But the problem in this supply chain is that 35-40% of the total production goes to waste (Kodithuwakku and Weerahewa, 2014). Adding to that Minister of Primary Industries found that Sri Lanka's PHW is more than 40% of the total production in 2017. It was reported in Daily FT on the 19th of May 2017 that the estimated cost of this is Rs. 18 billion (Sri Lankan Mirror, 2018).

When it comes to the operations process, around 30-40% of the total vegetable and fruit production is wasted and from that 48% is wasted due to inefficiencies in distribution and the transportation process (Weerasinghe and Priyadarshan, 2017). Abeygunasekara, (2015) has found that improper practices of packaging such as tight packing and overpacking contribute to approximately 75% of the PHW in Sri Lanka.

Limited transparency in the perishable supply chain is a major issue that hides most of the problems from the public eye. Therefore, to get a glance at current practices of the upstream supply chain, mapping the activities of the supply chain is vital. This allows us to understand the current practices along the upstream supply chain. This study analyzes the upstream supply chain of both up-country and low-country vegetable and fruit supply chains in Sri Lanka to get a bird's eye view of these chains while identifying the current challenges, issues, opportunities, best practices and factors that affect PHW. Next, different activities and operations along the supply chain will be mapped to understand how these activities affect PHW.

Accordingly, the objectives of the research are;

- Finding the root causes that lead to post-harvest waste in the upstream of the vegetable and fruit supply chain
- Identifying the cause-and-effect relationship of the identified factors and their effect on post-harvest waste in the upstream supply chain

Sources, Types and Methods of Data Collection

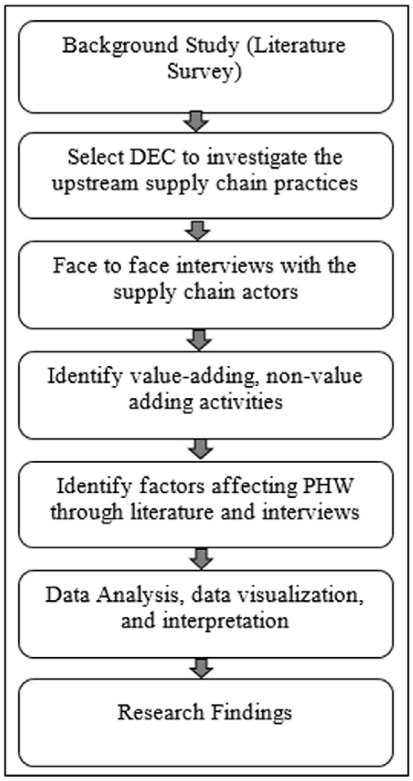

Figure 1: Conceptual Framework

MATERIALS AND METHODS

As the first step of the methodology, we have taken the case study approach and selected two main nodes of upstream vegetable supply chains in Sri Lanka. The selected two nodes were Thambuththegama Dedicated Economic Center (TDEC) and Nuwara Eliya Dedicated Economic Center (NDEC) which are the main sourcing points for low-country and up-country fruits and vegetables respectively.

Stratified sampling was implemented to identify the practitioners in the value chain. Hence, the sample includes farmers, wholesalers, transporters, helpers and retailers. The rationale behind selecting these value chain practitioners is considering their impact on post-harvest waste. We visited each Dedicated Economic Center (DEC) and had face-to-face interviews using a questionnaire with value chain actors within the premises including the manager of the respected DEC. Snowball sampling was used in connecting with the value chain actors including farmers, wholesalers, transporters, helpers and retailers. We hoped to identify the activities after harvesting the vegetables, peripheral activities in the DEC, activities after the DEC and measure the time for each activity by using a questionnaire survey. The sample size was 40 and it includes 8 respondents from each sub-category of the sample. In the study of the DEC, information was gathered such as activities after harvesting the vegetables, peripheral activities in the DEC, activities after the DEC and time consumption for such activities. Information was collected from different perspectives such as from the farmer's perspective, transport service provider's perspective, laborer's perspective, wholesaler's perspective, retailer's perspective, and the management perspective of each DEC. Additionally, opinions regarding factors that affect PHW were captured through these surveys from the value chain actors and experts in the field.

Methods of Analysis

Value Stream Analysis

When considering vegetable and fruit supply chains, there are many intermediaries along the chain which add value to the products. Until the product comes to the hand of the consumer there are several activities required to continue

the flow of the product. After identifying the activities that add value to the product, we can eliminate the waste of the independent activities of the system and re-engineer the system to optimize the system performance (Sugathadasa *et al.*, 2021).

Value Stream Mapping (VSM) is a technique that was created by the people who worked at Toyota to eliminate the waste in their production line and to make the production sustainable (Rother, 1999). This method is executed by creating a map for the flow of products in the production process. In a nutshell, it visualizes the activities which are performed in a system, the value added to the product, the processing time for each activity and the spatial relationship between the activities and the economic agents.

For this research, this method is used to identify the process of the upstream end of the vegetable and fruit supply chain of Sri Lanka. In addition to that, this method is used to identify value-adding activities, nonvalue-adding activities and necessary nonvalue-adding activities.

System Dynamics

System Dynamics is a thinking and simulation model which helps to study the changing patterns and dynamics of a complex system. This method was introduced by Jay Forrester in 1960 (Lee *et al,* 2015).

Through this method we can analyze the relationship between several variables or factors in a system, understand the feedback structure of the system variables and simulate quantitative data to understand the behavior of the system. Because of that, system dynamics is a good method to study the relationship between several variables and their cause-and-effect relationship. Through this, we can identify and understand how each process is working collaboratively in a system. When we understand the system, we can take necessary actions or create new policies to manage the system.

In system dynamics, the first stage is known as "Conceptualization". This stage contains four steps;

1.Defining the purpose

2.Define the model boundary and key variables

3.Describe the behavior of the identified key variables

4.Drafting the feedback loop of the system which is known as Causal Loop Diagram

This Causal Loop Diagram (CLD) is a diagram that helps to visualize how different variables are interconnected and interrelated in a system. Through the CLD we can gain a general overview of the system dynamic model (Paulrajan, 2015).

A CLD consists of several variables of a system, arrows are known as causal links which connect the variables and polarity for each causal link either positive or negative which denotes how the dependent variables react when the other connected independent variables change (Stermen, 2000).

There are loops in this system that are known as Feedback Loops. There are two types of feedback loops, Balancing and Reinforcing (Stermen, 2000). Furthermore, the describes the structure of the system. That implies what would happen to the system if one variable were to change. In this research, CLD is used to visualize how PHW is interconnected with several variables in the system and how it affects PHW.

RESULTS AND DISCUSSION

Value Stream Map for Inbound Process of Thambuththegama Dedicated Economic Center

When considering the activities between the farmer and the wholesaler in the value chain, we can identify harvesting vegetables, sorting the vegetables according to grade (quality or physical appearance), packaging, loading the gunny bags into the vehicle and transporting them to the TDEC as key activities. When the vehicles arrive at TDEC, due to high demand in the morning period there is high congestion at the entrance. The main reason for this congestion is

most farmers bring their harvest early morning leading to a high supply in anticipation of diversion to more populous areas. The other key reason why most farmers come to TDEC early morning or late evening is to avoid high radiation and heat from the sun during the daytime as that would reduce the quality of the product. This thinking pattern of the farmers creates unnecessary congestion at the entrance which reduces the overall operational efficiency at TDEC.

If we categorize these activities into value-adding activities, nonvalue-adding activities and necessary nonvalue-adding activities it will be easy to understand how important these activities are for the value chain.

Farming is the source of activity in the value chain. Sorting is an important value-adding activity because farmers categorize the harvested vegetable into different grades according to the physical appearance. This adds value to their product as different grades have different buying prices. The other value-adding activity is cleaning. Cleaned vegetables and fruits increase the visibility of the physical appearance. Thus, it attracts customers and adds value to the product. Additionally, when sorting, farmers can reduce harmful pests or diseases spreading to other vegetables which are in good condition. Through this, farmers hope to reduce their PHW (Deliya *et al,* 2012).

We can identify packaging the vegetables into gunny bags and loading the gunny bags into the vehicle as main nonvalue-adding activities. However, the most time-consuming nonvalue-adding activity of this value chain is the high waiting time at the entrance due to congestion. This is a waste of time for both farmers and collectors who bring vegetables to the TDEC. Due to this, if there isn't a radiation shield in the vehicle that transports the vegetables, it will be a reason to increase PHW.

Transporting vegetables from the farm gate to TDEC can be identified as a necessary nonvalue-adding activity. According to the literature the distance, transit time, vehicle condition and several other factors affect PHW. Hence, farmers should think twice before they bring their harvest to a DEC. Since the transportation process incurs a cost for the farmer and if there is a high percentage of PHW generated during transportation, it will be an additional loss for the farmer. Additionally, if the farmers are transporting their harvest from a long distance to TDEC and if they were not able to sell the vegetables which they brought to the DEC within the day, it will incur a huge loss for the farmer since transport consumes a higher cost compared with other activities. That is the reason many farmers give their harvest to a collector for transportation. In that way, they can reduce their cost and optimize transport operations.

Figure 2 represents the value stream map for the inbound process of TDEC. This figure illustrates the time consumption for cycle time (T) and lead time (T′) between two activities.

Value Stream Map for Outbound Process of Thambuththegama Dedicated Economic Center

There are several activities that happen inside the TDEC that are directly affecting the efficiency of the DEC and supply chain. These activities are the negotiation of prices between the farmer and the wholesaler, naming and unloading of gunny bags from the vehicle, weighing the gunny bags or harvest in plastic crates, deconsolidation, selling vegetables for the buyer and billing for the farmer, loading the gunny bags to another vehicle and outbound transportation.

From the above activities, there isn't any value addition to the product. Therefore, negotiation between farmer and wholesaler, naming and unloading, weighing, deconsolidation, selling and billing and loading to another vehicle are nonvalue-adding activities since the end customer has limited value addition from these activities. But the major point is there isn't any intermediate holding in TDEC. This is because the wholesaler sells the vegetables and fruits which are bought by the farmer to another buyer within the day. This implies that the turnaround time at the DEC is a matter of hours. Intermediate holding only occurs when there is a seasonal product like pumpkin or

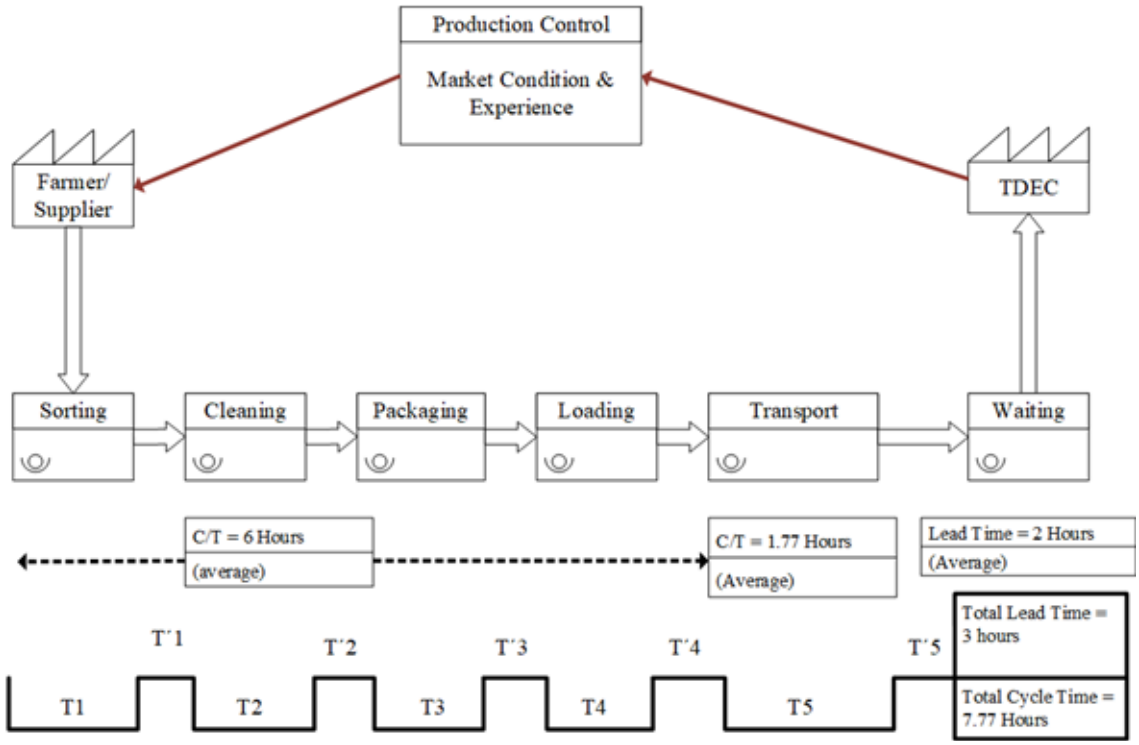

Figure 2: Value Stream Map for Inbound Process of Thambuththegama Dedicated Economic Center

cooking melon. Therefore, practitioners and the management have taken steps to eliminate this nonvalue-adding activity from the system.

Going into further detail regarding these activities, we can understand how important this is to the system behavior and we can take necessary actions to reduce or eliminate these activities to make the system more efficient. Without negotiating a price inside the DEC if there is a platform such as a telephone conversation or SMS service to give the information about the price and negotiate between wholesaler and farmer, we can optimize this activity. When developing these platforms developers should discern the transparency of the information about the quality and physical appearance of the products. This will ultimately reduce the congestion inside the DEC. However, this needs to be transparent. Otherwise, there will be higher prices and higher margins from the wholesalers. Therefore, officials must take necessary actions for this, like implementing an online platform that will provide market information to the farmers.

We can't eliminate the second activity known to be naming and weighing. Because naming (labeling) the gunny bag is important when they sell that gunny bag to another buyer. Weighing and deconsolidation are also very hard to eliminate. Deconsolidation is not a very popular practice inside the DEC. This only happens to the upcountry vegetables which are brought by the collectors.

In the selling and billing process, the current practice is getting the vegetable gunny bags from the farmer and directly selling them to another buyer by the wholesaler. Therefore, intermediaries take a 5% commission from the selling price for this service. For outbound transportation, loading is done by a laborer of the wholesaler. He also takes additional charge for this service.

After arrival before unloading and until the wholesaler sells the vegetables to the buyer, the farmer must wait inside the DEC. Therefore, these waiting times can be eliminated if there is a platform for providing information like giving a certain time slot for each farmer. In conclusion, if there is a platform to negotiate prices in real time and allocate a time slot for a farmer by the wholesaler or by the management of TDEC, it will reduce the waiting time of the farmer and the congestion inside the DEC.

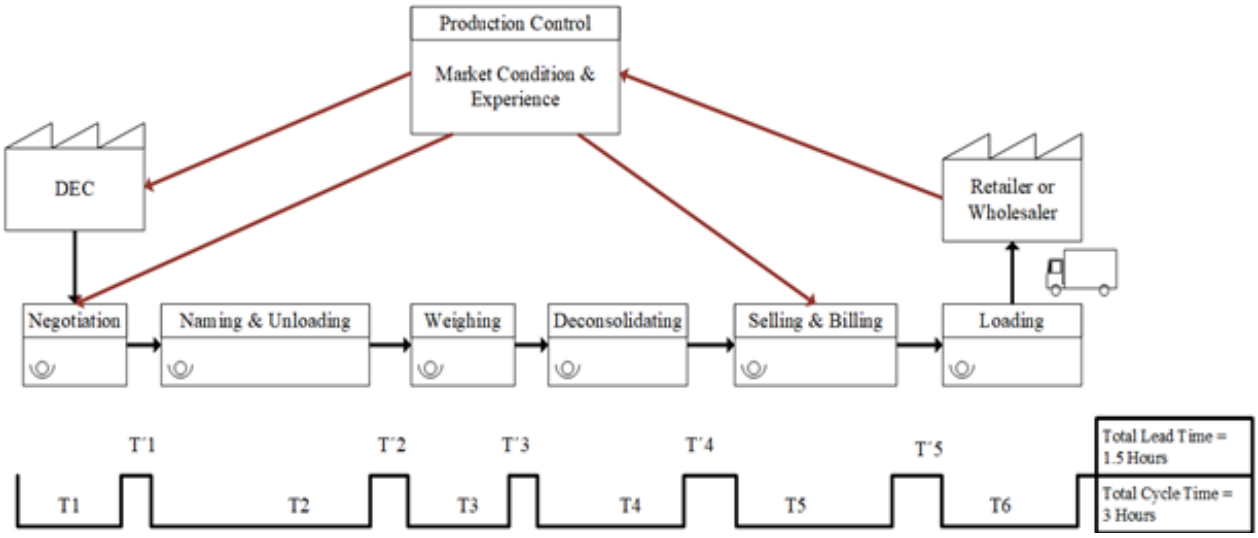

Figure 3: Value Stream Map for Outbound Process of Thambuththegama Dedicated Economic Center

Value Stream Map for Inbound Process of Nuwara Eliya Dedicated Economic Center

Nuwara Eliya Dedicated Center (NDEC) is based on up-country vegetables. Rather than low-country vegetables, up-country vegetables are far more sensitive to temperature changes. Therefore, each activity should be more concerned about the physical appearance of the vegetables.

Practices that bind with DEC is mainly rely on the associated wholesaler. This is because the wholesaler is the dominant player in procuring vegetables to DEC and distributing them to demand nodes in Sri Lanka. Therefore, if we consider the activities, sorting and cleaning or washing are the major value-adding activities occurring before the DEC. Other than that, similar to TDEC practices NDEC also has several nonvalue-adding activities. These include packing vegetables into gunny bags, weighing before loading, loading vegetables into a truck or lorry. Apart from that, we can see order placing and wholesalers' laborers going to farmers' land. As a necessary nonvalue-adding activity we can see inbound transportation of harvested vegetables to NDEC.

In sum, this inbound process of procuring vegetables from the farmers happens in a very short period. This is mainly due to the short shelf life associated with some of the up-country crops. Therefore, every actor of this supply chain puts their effort to reduce the transit times and limit the time that is consumed for each activity. Figure 4 visualizes the approximate timeline of the inbound process of the NDEC.

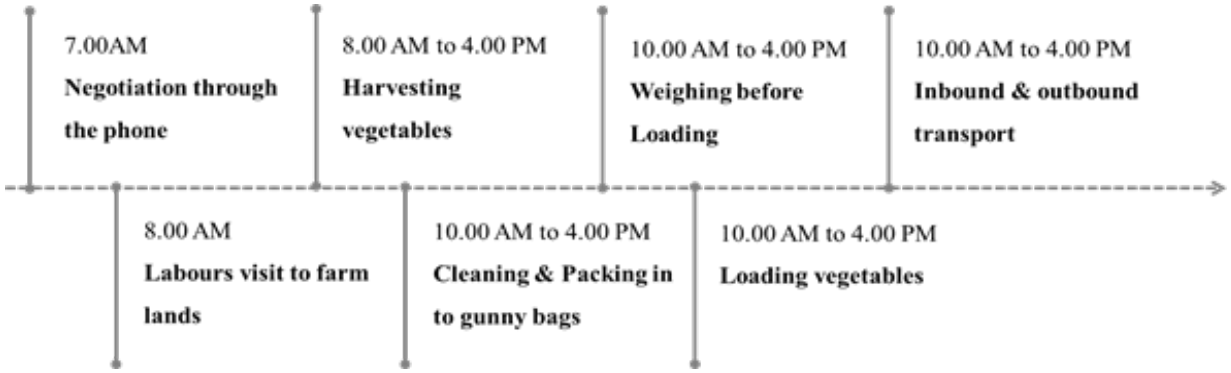

Figure 4: Approximate timeline of the Inbound Process of NDEC

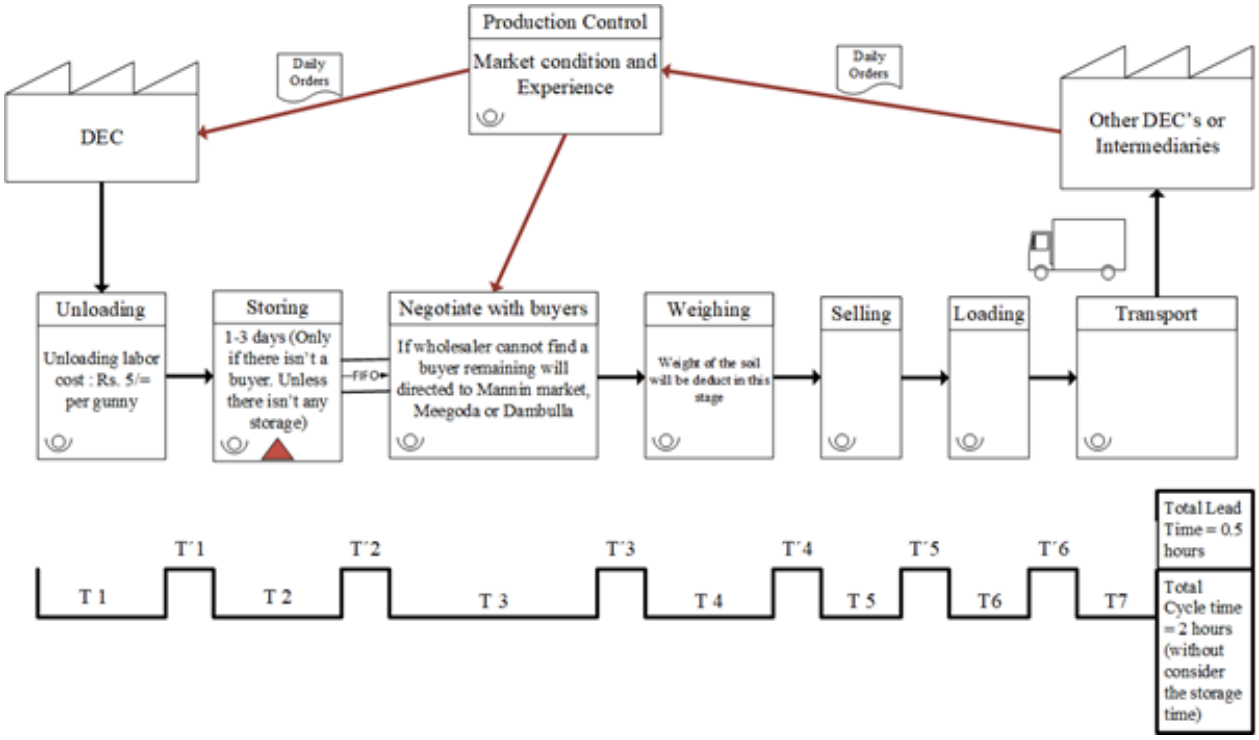

Figure 5: Value Stream Map for Inbound Process of Nuwara Eliya Dedicated Economic Center

Value Stream Map for Outbound Process of Nuwara Eliya Dedicated Economic Center

After bringing the vegetables and fruits to NDEC, we didn't observe any value-adding activity. However, several activities are similar to the practices at TDEC. Unloading, negotiating, weighing, selling, loading the vegetables into the vehicle can be identified as nonvalue-adding activities. Apart from these activities, we can see a storing process in this DEC. Most of the time, the portion of the harvest which was unable to be sold is stored in such a way due to issues with the quality or with the buyer. Therefore, if the wholesaler couldn't contact another buyer to sell this remaining portion, it is sent to a DEC through a transport service provider which regularly travels to those kinds of DECs. Most of the time this is Dambulla DEC.

When weighing before selling the vegetable, the soil is excluded from the weight. As the soil has dried up by that time, it can be easily removed by washing and it is a usual practice to control the field heat as well. The turnaround happens within the day and transactions between the wholesaler and customer are credit-based. These transactions are not documented in any book. It was noted that the actual value of the perishables that transfer per day by a particular wholesaler is very high in volume and value. As a result, if they document that they may have to pay considerable amounts of taxes to the government. Thus, the transactions based at NDEC are more focused on trust. Despite this, there have been several incidents in the past that businessmen or customers who buy vegetables from the wholesalers at NDEC on a credit basis didn't honor the transaction and skipped the due payment. In such cases, the wholesaler must bear the total loss. Sometimes wholesalers don't keep any track of their customers. Adding to that, they can't take any legal actions against the culprit due to the unavailability of any legal documents.

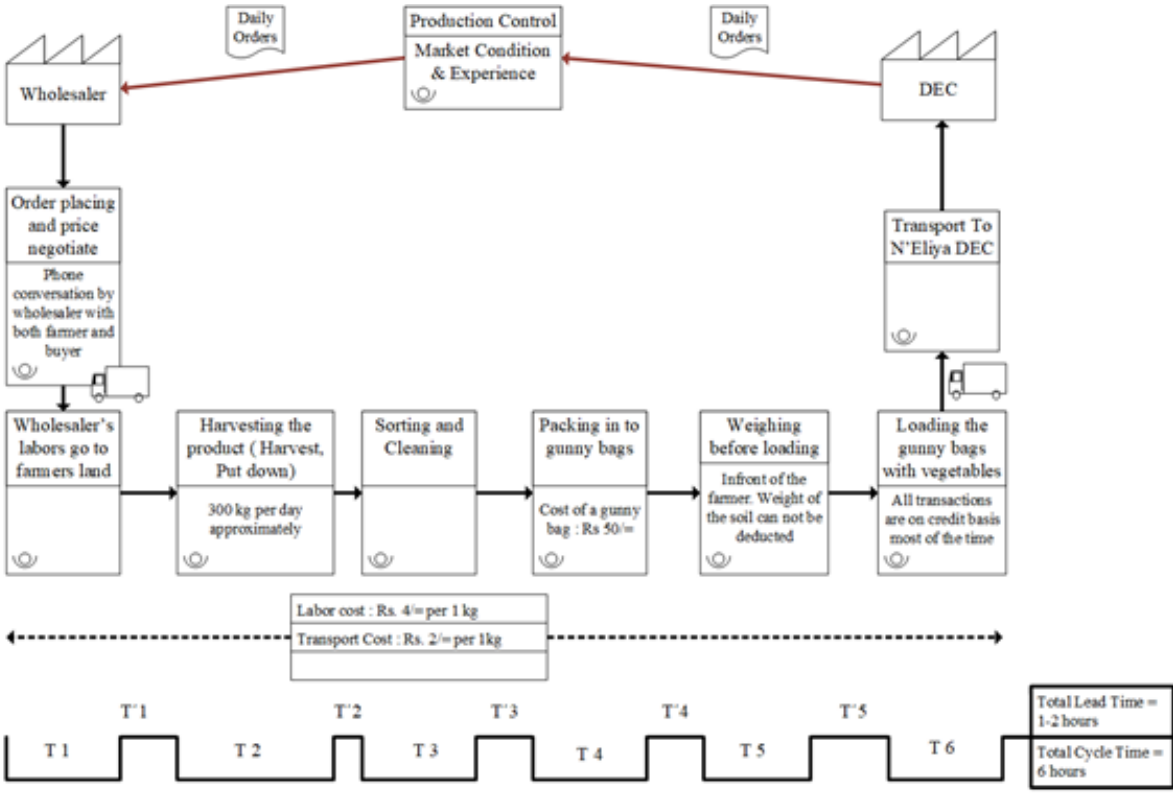

Figure 6: Value Stream Map for Outbound Process of Nuwara Eliya Dedicated Economic Center

Comparison of Practices Between Thambuththegama DEC & Nuwara Eliya DEC

Transparency of the Transactions

When considering the transactions between farmer- wholesaler and wholesaler- customer, transactions are very different between each DEC due to several reasons. Transparency of the transactions is very high at TDEC since the farmer is active until the end of the transaction. Farmer has the visibility of the wholesalers' selling price and the buying price. Additionally, the wholesaler is only keeping a commission of 5% from the selling price.

The practice at NDEC is much different. The wholesaler plays a vital role in every transaction and the farmer is not aware of the monetary value of the transaction at some points. Hence, the farmer might be unable to get a reasonable price for their product due to a lack of awareness about the market condition and the demanding power of the wholesaler. In this transaction, the laborers for harvesting, packaging materials and transporting the harvest to the market are facilitated by the wholesaler as per the information gathered through the interviews with the supply chain actors in this study.

The main objective of the Sri Lankan government establishing these DECs is to provide higher profit to the farmers by reducing the intermediaries between the farmer and the consumer. Still, the thinking pattern of the people, generational practices, and strategies of intermediaries have been impediments to achieving the government objective. The study carried out by Sugathadasa *et al.*, (2021) can be useful to identify the attributes of the actors in DEC to improve productivity.

Post-Harvest Waste

NDEC has a low percentage of PHW when comparing with other DECs. Agricultural experts state that NDEC only incurs 2% PHW per annum in a workshop about feasibility study findings of cold chain in Sri Lanka held in 2019 at Colombo.

The reason behind this is that the activities are performed by wholesalers and their awareness about preserving the quality of the vegetable throughout the inbound process. They know that

up-country vegetables have more tendency to go to waste. Therefore, they follow precautions to reduce PHW. Vegetables are handled by laborers who are under the supervision of the wholesaler from farm gate until it passes to another customer at the DEC. A wholesaler in the NDEC has expressed that, they follow different safety measures in packaging and transporting certain vegetables. The best example is leeks. According to one of the wholesalers, if they store gunny bags with leeks horizontally while transporting, 5-10 kg goes to waste per one gunny bag which has 50 kg of leeks. But they can reduce that to 1-4 kg by just changing the storing pattern from horizontal to vertical.

Another reason is most of the transactions are credit-based. To maintain the trust with each stakeholder, the wholesaler tries to provide quality vegetables that don't have issues concerning the physical appearance or quality.

The scenario at TDEC is very different. Here, farmers are the persons who harvest, pack, store the vegetables in the vehicle and transport the harvested vegetables to the market. Therefore, they are more focused on getting a higher revenue for their produce. Therefore, some farmers don't care about the packaging or handling of the vegetables before the DEC and even inside. Additionally, the farmers bring all the vegetables which were harvested by their farm at once to reduce the transport cost. Ultimately it only creates a loss for the farmer. Since most of the harvest is left at TDEC due to high supply. Wholesalers don't even bother about the quality of the product which is inside the gunny bags because their customers don't check what is inside in the gunny bags when they purchase. The wholesaler is only focusing on selling a larger volume because his income relies on the number of sales during the day. Therefore, the main reason behind high wastage at TDEC is the poor attitudes and thought processes of actors in the value chain compared to the NDEC

Market Platform

Both TDEC and NDEC focus on wholesale business. Yet, the farmer is not an active stakeholder at NDEC. The wholesaler and only his customer meet at the NDEC as the farmer has no role there. Therefore, the farmer is unaware of the customer of the wholesaler. Hence, the wholesaler plays an intermediary role. The wholesaler is the price setter for vegetables and the price can vary from one wholesaler to another. This leads to price discrepancies faced by farmers as well as customers when all other conditions may stay constant. Price mainly relies on the market price at Dambulla DEC, Manning Market of Pettah, number of orders coming per day, number of farmers who can fulfill the order, and the climate condition. Additionally, most of the transactions between farmer- wholesaler and wholesaler- buyer are credit-based.

But when it comes to TDEC, the farmer is playing a central and significant role. Farmer has the access to both wholesaler and the buyer. Hence, the farmer has more influence on the price since he is aware of the market demand and prices of the products. Wholesalers are the persons who decide the price at TDEC, but it is influenced by all the wholesalers and the average price for a certain vegetable is displayed at the market. The farmer can sell their harvest to any wholesaler which gives them the best price. All the transactions are cash-based, and the farmer receives the full payment after the transaction with the cash receipt giving all the information. Unlike NDEC, TDEC is a commission-based market platform that is more influenced by government policies and regulations.

Identified Factors that Affect PHW in Vegetable and Fruit Supply Chain in Sri Lanka

Poor harvesting practices, poor packaging practices, poor loading practices, poor storing practices, poor unloading practices, number of intermediaries, transit time, number of processed and value-added products and bad weather conditions are the major issues towards PHW which were identified through the background study of previous literature. There are several root causes that lead to these identified factors in the system. Poor harvesting practices such as incorrect identification of maturity indices and incorrect methods of harvesting lead to PHW according to Shukla & Jharkharia (2013). A salient concern that affects this problem is

the education level and the experience of the farmers (Garcia-Herrero *et al*., 2018).

Incorrect methods of packaging are also key reasons for PHW (Negi & Anand, 2015). The time difference between harvesting vegetables and packaging also leads to spoilage. This is expedited by the field heat and weather conditions. Vegetables exposed to the sun tend to increase respiration and transpiration. Therefore, farmers ought to pack it quickly in anticipation of transportation (FAO, 2013).

Poor loading and unloading practices cause physical damages to vegetables and fruit when handling. When vegetables get damaged they are infected by different bacteria and fungi very quickly which are harmful to the vegetable (Negi & Anand, 2015). Therefore, handlers should have sufficient knowledge about good handling practices and the damage which can be caused by rough handling when loading and unloading. To encourage good handling, laborers should be offered incentives (Sudharshan *et al,* 2013). According to Negi & Anand (2016), we can reduce mishandling by introducing new packaging materials such as corrugated fiberboard boxes which can be palletized. Then it can be handled mechanically using a fork-lift truck. In this way, practitioners can reduce mishandling when loading and unloading vegetables. However, the capital intensiveness of such solutions may not be well accepted by the farmers and wholesalers. The government can provide incentives to acquire such technologies through lenient financing schemes.

Due to poor storing practices, there may be high stacks in the vehicle when transporting or storing. This may lead to collapsed stacks which will damage the vegetables. Without good storage practices, there may be internal movements in the packaged vegetable according to the vehicle movements (FAO, 1989). According to Raut & Gardas (2018) tight storing practices aimed at space optimization lead to reduced ventilation that increases the accumulation of carbon dioxide which is harmful to the vegetables. New applications can be taken such as cooling with dehumidification process to improve the quality of storage and extend the quality of the products. (Uthpala *et al*, 2020)

Many intermediaries prefer high stacked storing patterns in vehicles that optimize space utilization. If there are a high number of intermediaries along the supply chain, there may be several handling operations. Hence, there is a high probability of vegetables getting spoiled (Parajuli *et al*, 2019). According to the value stream maps that are presented earlier, even though there are several intermediaries, there isn't any value addition to the vegetable and fruit products in most cases other than moving the product from one point to another. That creates a value loss for the overall chain. Therefore, minimizing intermediaries is an important measure to build a resilient perishable supply chain in Sri Lanka.

Transit time is another major issue that causes PHW. Transportation is a necessary nonvalue-adding operation. But without transportation, the product cannot be delivered to the consumer. When there are delays due to road congestions, road conditions exacerbate transit times. That will deteriorate the freshness of the product (Sharma and Singh, 2011). Dome and Prusty, (2017) have found that in addition to road conditions, irresponsible driving also affects PHW. When using open trucks without any roof, the vibration of the vehicle also causes PHW (Raut and Gardas, 2018).

With a focus on the export market, there is a high demand for quality vegetables and fruits in Sri Lanka as per the findings of the cold chain feasibility study funded by the Europe Union (Rodrigo, 2019). By introducing a cold chain, the shelf life of vegetables and fruit will be elongated. Using refrigerated vehicles will impact the quality level of the vegetables which will ultimately reduce the PHW (Gardas *et al* 2019). Bad weather conditions such as long periods of heavy rain will cause higher PHW. This is because vegetables are caught up in the rain while packaging, handling, transporting, or selling deteriorating their shelf life (Regmi, 2013).

Causal Loop Diagram

Figure 7 is used to visualize how identified factors are contributing towards PHW in the Sri Lankan vegetable and fruit supply chain using a CLD. Vensim PLE software is used to draft the CLD. This will help to visualize how each identified factor is connected to each variable shedding light on the cause-and-effect relationship between these factors. The factors which were contributing toward PHW were identified through the literature and the discussions with the different stakeholders who we met at the DECs during the research. Several other factors in the system were identified which have a relationship with the above-mentioned factors.

The blue arrows represent the positive relationship (growth in one cause increases the effect or vice versa) between two factors while red arrows represent the negative relationship (growth in the cause decreases the effect or vice versa) between two factors. This CLD will help future researchers, policymakers and several organizations in the industry to understand how each factor connects with another factor that ultimately affects PHW.

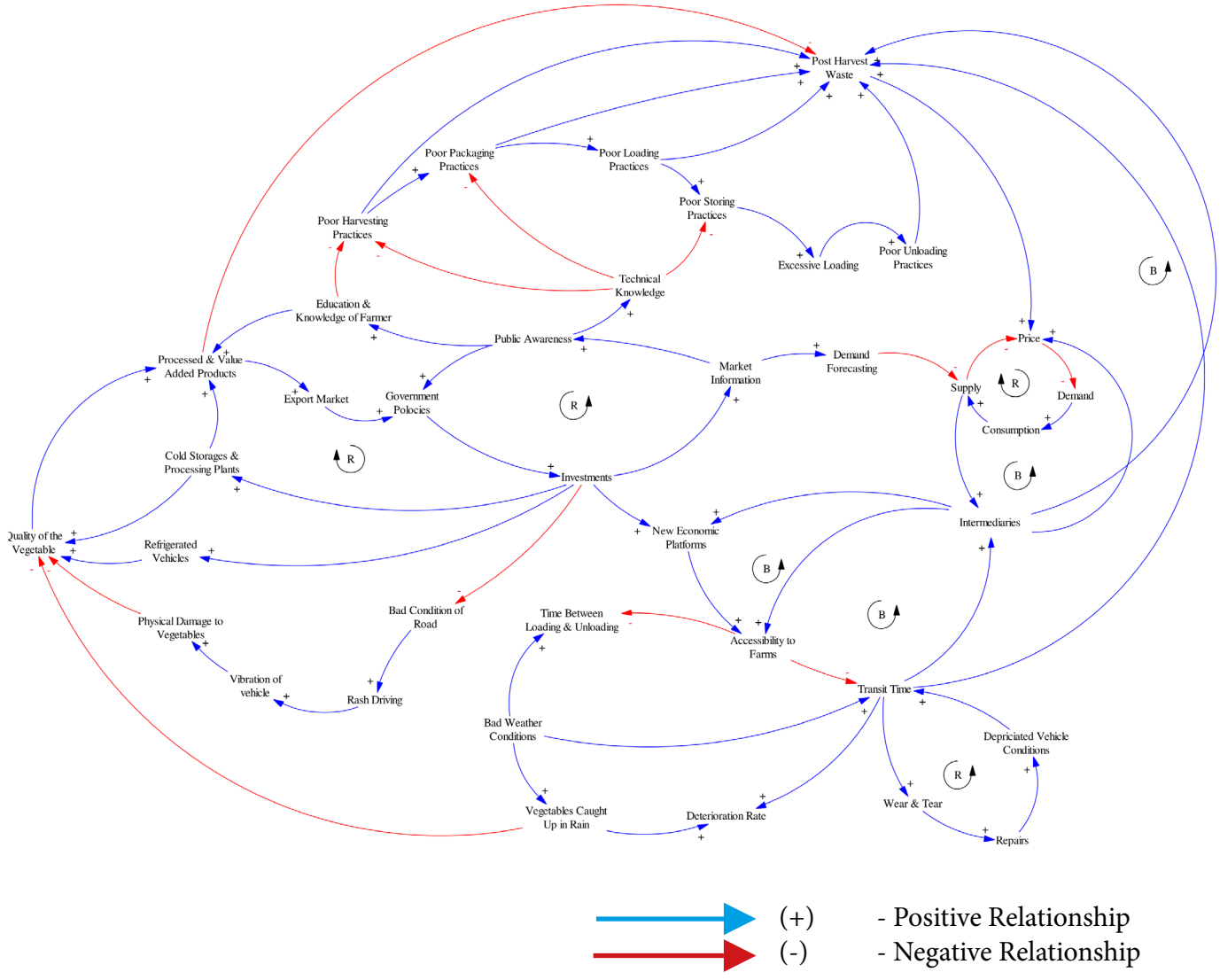

Figure 7: Causal Loop Diagram

Loop Behavior of the System

If we consider the behavior of the system which is in Figure 7, we can see 8 different feedback loops. This implies that there are variables that are interconnected with each other and behaving as a loop in the system. In this diagram, we can see four balancing loops which are represented with a "B" and four reinforcing loops which are represented with an "R".

We observe a reinforcing loop that connects supply, price, demand, and consumption. This looping behavior can be seen in most of the systems and if we begin at the supply when supply increases it causes to decrease the price as per fundamentals of economics. When the price is increased it causes to reduce the demand. When demand increases, consumption is increasing and ultimately when consumption increases again supply increases.

We can see another loop that relates to intermediaries with the above-mentioned four variables. When there are a high number of intermediaries it causes high margins. As a result, price increases affect supply. When supply is increasing in order to satisfy that supply there will be a higher involvement of intermediaries in the chain. This loop is a balancing loop. The increase in the number of intermediaries leads to more PHW. It implies that when there is a high number of intermediaries, PHW grows. When the number of intermediaries increases, the number of non-value adding activities will be repeated by each intermediary. Undesirably, when PHW is increasing, the price of vegetable and fruit items tends to increase. Therefore, we can see a balancing loop here connected with the above-described variables.

We can see a loop that connects intermediaries, new economic platforms, accessibility to farms and transit time. We can see two different balancing loop behaviors in these four variables. When there is a high number of intermediaries, there will be new economic platforms. Spot markets, roadside markets, or wholesale markets are examples. Then there will be high accessibility to farmers for these intermediaries and on the flip side, farmers will have higher accessibility to these markets. Therefore, it will reduce the transit time which will ultimately reduce the number of intermediaries. The other loop is when there is a high number of intermediaries, there will be high accessibility to farms. Then it will reduce the transit time and as mentioned earlier it will reduce the number of intermediaries. In the CLD we always map the increment of a factor. Because of that when the transit time increases, several intermediaries will lean towards growing.

Considering the vehicle condition with the transit time, we observe another reinforcing loop behavior. This behavior can be observed in most of the vegetable transporting vehicles in their daily routine. If we begin with the transit time, when transit time increases, the wear and tear of the vehicle will increase. Due to wear and tear intensification, the number of repairs increases, and it causes for high depreciation of the vehicle. That will reduce the performance level of the vehicle which will ultimately increase the transit time. Therefore, transport service providers should consider more about their vehicle conditions. Ostensibly, poor vehicle conditions will cause PHW due to high transition time while transporting vegetables and fruits.

In any system, policies and regulations take a major role. In this system, the government can influence the system in a broader way. With government policies that are favorable for foreign or local investors, there will be high investments in this sector. It will lead to increased market information and public awareness. Through public awareness of the current issues and problems, public pressure for corrective measures in the value chain emerges. One example is the initiative on social media to promote the consumption of pumpkins in 2019 when there was an excess harvest. This is a reinforcing loop and that means if there is an increment in one variable there is an increase in every variable and at the end, there will be a push from the system to increase that factor more.

Continuing with the previous loop on investments, when there are high investments there will be a high number of cold storage and processing plants. Therefore, it will increase the

shelf life of the products, quantity of processed products and value-added products which has a higher market value in the export market. When the export market begins to expand, there will be new government policies to regulate and improve the current system. This loop is also behaving as a reinforcing loop and future researchers and policymakers should be more concerned about these reinforcing loop behaviors to improve the system behavior. Since the reinforcing loops are beneficial to the system, policymakers should focus more on these beneficial reinforcing loops when creating policies. If the reinforcing loops are vicious loops for the system, policymakers and actors in the system should take steps to reduce the negative effect on the system by controlling the factors inside the loop.

CONCLUSION

This study provides insights into how Sri Lanka's traditional vegetable supply chain works in different geographical locations. This study has identified certain issues in this study area of the operational level practices of DECs and provided suggestions to improve the efficiency comparing two case studies. The use of value stream mapping and system dynamics have shed deeper insights about the industry that are not visible on the surface.

Additionally, identifying the activities which are responsible for generating waste in the upstream supply chain through value stream mapping, identifying different socio-economic, ecological, and operational factors within the system which cause PHW and how they are interconnected with each other through the CLD are vital contributions of this research. Through this CLD, we can identify the root causes for the selected issue. Therefore, through favorable policy interventions actions can be taken to reduce the effect of the root causes that affect PHW.

In the wholesale stage, if wholesalers can concentrate more on the quality of the product than the revenue or the profit, it will add more value to the product. With the upcoming Dambulla cold storage facility, the quality of fresh produce can be preserved. This would lead to extended life periods for the product. Therefore, it needs quality products devoid of physical damages that happen due to rough handling by value chain actors. If they can preserve the quality of the product there is a high-value market for Sri Lankan fruits and vegetables in foreign countries. Therefore, new entrepreneurs can enter new markets such as organic foods and it will create more efficiency and value to the agribusiness sector. These kinds of actions will reduce the current PHW issue in Sri Lanka.

When considering the mechanisms at TDEC, it brings more financial benefits to farmers when compared with the mechanisms at NDEC. However, due to high scalability, the NDEC process is more economical and produces less waste compared to TDEC. Despite operational issues like isolated farming areas, NDEC's current practice could not be extended elsewhere considering the heterogeneity of the market type. If NDEC can increase transparency in operations like TDEC, it will generate more value for the farming communities.

The CLD in Figure 7 provides an overall picture of how PHW links with different variables. Therefore, future researchers can gain more insights into how different activities affect PHW through this study. Additionally, people who are making policy-level decisions can get a better understanding of the systemic influences for PHW at different stages. Therefore, they can implement new policies and introduce new technology platforms to reduce actors in the vegetable supply chain by improving information sharing between both the upstream and downstream supply chain actors.

Recommendations

The reinforcing and balancing loops presented in Figure 7 can be used as a guideline to understand the ripple effects of policy decisions as well as to prioritize policy interventions. Regulation bodies and policymakers can consider value stream mapping of DECs to gain insights into the actors of the value chain and their tasks. There are best practices used in both focal DECs (Thambuththegama and Nuwara Eliya) up to some level. Respective governing

bodies can intervene and implement these best practices to other DECs in the country.

As the initial step, the respective governing bodies of agriculture and institutes should initiate awareness programs for the farmers, intermediaries, and related management officers to educate about PHW. There should also be necessary investments to develop their businesses and farms. Through that, farmers can follow Good Agricultural Practices (GAP) in their farmlands and there will be a push from the farming society to intermediaries to safely handle the harvest. As the second step, if the government can involve in creating new policies which are favorable for the industry it will attract more investments towards the industry. Ultimately it will be a reason to attract a new generation of farmers that have new business concepts to increase the quality level of the local market as well as to capture new export markets. As the third step, giving financial support through lenders to farmers and intermediaries will encourage them to use appropriate packaging materials and refrigerated vehicles and it will be a long-term investment for the industry as well as the country (Uthpala *et al,* 2021). Implementing new infrastructures like vehicles that have cold storage facilities, cold storages located at critical DECs will bring more sustainable value addition towards the industry by controlling the natural process of respiration and transpiration of vegetables along the supply chain.

Research Limitations

One of the key limitations of this study is it only focuses on the upstream of the supply chain. But there may be a considerable number of activities that cause PHW in the downstream supply chain. This needs to be further investigated. Information provided by the resource persons may be biased to some degree and finding resource persons and connecting with them to gain information is very difficult in this sector due to lack of transparency. This research undertook a very cumbersome approach to connect with leaders in the sector from many walks of life. Despite this effort, it was only feasible to connect with a few resource personnel only. It was a key limitation in this study.

Providing more robust data collection to derive data-driven outputs is imperative for the advancement of the field. Presently there is a dearth of data available at each point in the value chain to provide a deeper scientific analysis. It is recommended that future works address data gathering to solve this national-level problem. Due to the lack of data, we were unable to do a simulation to understand the problem at a more detailed level and to evaluate potential outcomes through suitable policy interventions. Future research, driven through modern approaches such as analytics, system dynamics, machine learning and artificial intelligence is encouraged.

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