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# Application of Global Navigation Satellite System (GNSS) Based Mobile Tracking to Improve the geo-traceability of the Mango Supply Chain: A Case Study

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## ABSTRACT

***Purpose:*** *Location tracing of agricultural supply chains is vital to ensure food safety. The mango supply chain in Sri Lanka involves many intermediaries and lacks traceability. GNSS-based mobile tracking is a potential technique to assure the quality of fresh produce through improved geo-traceability. Therefore, this study aimed to identify the feasibility of mobile tracking to enhance the geo-traceability of the 'Karthakolomban' mango.*

***Research Method:*** *Supply chains were chosen based on mango collectors in the Kurunegala District. Movements of mango were traced by real-time tracking of supply chain actors using the software developed to obtain the GPS location of mobile phones. Feasibility for mobile tracking was assessed using, location data, origin, route, speed, unnecessary delays and movements.*

***Findings:*** *Omaragolla mango supply chain was highly dynamic, where most of the actors, routes and origins varied without pre-planning. Only 67% of considered supply chains were successfully tracked. The rest was unsuccessful due to a lack of technical know-how of supply chain actors and signal failures. Unnecessary movements yielding 13% of additional distance and cost were observed in 25% of the supply chains. Mobile tracking enabled the identification of movements of mango, which can be used for pre-planning, monitoring of the routes of actors and ultimately ensuring geo-traceability.*

***Research Limitations:*** *Even though geo-traceability improves the traceability of the fruit supply chain, there are other methods to ensure traceability. Therefore, should be tested separately as well as coupled with the current approach.*

***Originality/value:*** *The findings of the case study can be guided to implement mobile tacking for any fixed fruits and vegetables supply chain to improve the geo-traceability aiming at the food safety of the country.*

**Keywords:** *Food safety, Real-time tracking, Supply chain actors, Traceability, Omaragolla*

## INTRODUCTION

The global concern for food safety and quality has increased during past decades due to the abundance of food scandals (Zhang *et al*., 2020). Therefore, a growing demand is created for efficient traceability systems (Aung and Chang, 2014) that ensure the confidence of consumers to purchase food commodities. Food traceability is defined as "the ability to guarantee that products moving along the food supply chain are both traced and tracked" (Bosona and Gebresenbet, 2013). ISO 8402 defines traceability as the

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"ability to trace the history, application or location of an entity, utilizing recorded identification throughout a complete or partial supply chain". Food traceability is advantageous for managerial decision making and it enhances the coordination between buyer and supplier (Rábade and Alfaro, 2006).

Tracing of exact location and tracking the true history of a product throughout the entire supply chain is an important requirement of a good traceability system (He *et al*., 2009). With technological advancement, the Geographical Information System (GIS) has become a powerful tool that supports logistic planning through its capability to manage geographical data (Caputo *et al*., 2003) where the concept of geo-traceability has evolved. Here, the Global Navigation Satellite System (GNSS) is used for real-time tracking of the transportation system, thereby tracking the outdoor location of products through the supply chain (Ahmed *et al.,* 2020; Gnimpieba *et al.,* 2015). According to Kandel *et al.* (2011), continuous tracking of the supply chain supports last-mile route planning, minimizing delays, and increasing security through improved transparency.

When considering the fruit and vegetable supply chain in Sri Lanka, most of the fruits and vegetables available in the market consist of quality defects, thus leaving the majority of customers to have less access to good quality fruits and vegetables. Mango is one of the major fruits in the country that has a higher demand in the local market as well as the export market. Furthermore, Karthakolomban is the most common and highly demanded mango variety in the country. However, one of the major restrictions that demote the mango industry is the poor quality of fresh mango which increases the postharvest loss and other market issues (Vidanapathirana *et al*., 2018; Herath *et al*., 2021). Some of the quality defects are bound to the point of origin whereas some occur between the place of origin and the market. Hence it is important to uniquely identify the reasons behind those blemishes and implement solutions.

Furthermore, the mango supply chain in Sri Lanka is mainly based on collector groups who collect mangoes from scattered mango cultivations all around the country and distribute them to consumers in different areas through wholesalers and retailers. Also, the collection process is done without preplanning. Therefore, the collection process involves a considerable amount of traveling, which results directly in reducing the postharvest quality of fresh fruits and also adds cost to the consumer price. Thus, tracking the location information along the supply chain will help to identify the occurrence of unnecessary movements and unnecessary time delays, thereby reducing postharvest losses, improving fruit quality and reducing added costs through managing the transportation process.

GNSS-based real-time tracking is used in diverse fields of applications. Goletz and Ehebrecht (2020) used GPS loggers to track micro-informal transportation in Dar es Salaam city of Tanzania. Although their application was technically successful, they faced difficulties since operators were required to operate GPS loggers and a large sample size couldn't be achieved. Thus, the use of GPS loggers might not be a successful way of tracking the mango supply chain, where a large number of players participate. Realini *et al*., (2017) studied the precision of Nexus 9 smart devices for positioning and obtained decimetre-level accuracy and they recommend it for rapid-static surveys. Therefore, the use of smart mobile phones can be a cost-effective solution for tracking the mango supply chain. Also, limited research pieces of evidence were found to improve the geo-traceability of the fresh fruits supply chain in Sri Lanka and this research attempt would be highly important as the initial step towards fresh fruit geo-traceability in Sri Lanka.

Thus, this case study was conducted aiming to identify the feasibility of using mobile tracking as a tool to improve the geo-traceability of the fresh mango supply chain instead of using high-cost GPS loggers or vehicle tracking which are not cost-effective. In this study, we planned to identify the feasibility of optimizing the movements along the supply chain through mobile tracking, to identify constraints towards geo-traceability development, and to provide recommendations to overcome identified drawbacks for geo-traceability development of Omaragolla Karthakolomban supply chain.

## MATERIALS AND METHODS

### *Selection of Supply Chain for the Case Study*

The National Institute of Post-Harvest Management which functions under the Ministry of Agriculture had conducted a development project on the Improvement of supply and value chain management practices of Mango in Sri Lanka, during 2016-2018. Under this project, the mango collector groups scattered throughout the country were identified and developed by introducing improved postharvest technologies. *Omaragolla* mango processing zone in *Kurunegala* District was the first collector group addressed by this project. According to the field observations, the community in this mango processing zone is well-organized with their income generation, which is mainly based on island-wide mango collection, primary processing (mainly ripening, sorting, grading and packaging) and marketing. Further, according to Kularathne *et al*. (2018), the *Omaragolla* mango processing zone handles a large amount of mango which approximates to around 0.096 million mango fruits per collector per month that is supplied to the local market in Sri Lanka. The Mango Processers' Association consists of 32 members with many non-member collectors in the community. Thus, the association alone supplies more than 3.072 million mango fruits to the market in one month. Therefore, this mango processing zone was selected for the case study. From the 32 members of the collectors' association, two mango collectors were selected based on six criteria; willingness to participate, highest links with growers in the collector group (linked with more than 200 growers), highest mango handling rate in the collector group, regular collection within the season, and practicing mango collection for a long time.

The supply chain taken for the study was selected based on the two selected collectors of the *Omaragolla* mango processing zone. Growers in contact with these collectors were identified in Anuradhapura and *Kurunegala* Districts. Therefore, the growers were selected from these two districts for the study based on convenience, willingness to participate, and applicability of mobile tracking at the operative stage of the supply chain. The main wholesalers of these two collectors were in the *Colombo* district. Therefore, wholesalers were selected from *Colombo*. Retailers were thus identified by forward tracing through the supply chain, who were in the *Gampaha* district.

### *Implementation of a Mobile Tracking System*

Different types of location and route tracking technologies are available at present (mobile tracking, use of GPS loggers, vehicle tracking) (Tian, 2016; Kandel *et al*., 2011; Al Rashed *et al*., 2013). The mobile tracking method was applied for this pilot study due to its cost-effectiveness and it can be implemented by using already available smartphones with supply chain actors.

Mobile tracking software was developed that is capable of tracking the GPS location of the mobile phone through a consultant thereby capable of tracking the movement of the supply chain actor. The developed app comprised a mobile application and a web application. The web application allows the system administrator to view the traveling paths, distances, locations, and time that was spent in each location. The mobile application collects location information of the registered mobile devices. Thus, this application was installed on the players' smartphones, and players were asked to enable the location service of the phone and the data connection during the operation of the supply chain. Collected location information is passed from the mobile application to the web application. Actors of the selected supply chain were trained to achieve accurate functioning of the mobile app. Mobile tracking was implemented in the mango harvesting season from May to July.

The physical movement of the mango was tracked by following the path of the supply chain actor through mobile tracking. The tracking was done at three (03) stages of the supply chain; i.e. Grower to the collector through the collector, collector to wholesaler through the transport service provider, and whole seller to retailer through the retailer. Location tracking data was verified by random tracking through phone calls.

Mobile tracking software resulted in point data that contained location and time information only. Therefore, tracking information was processed with Microsoft Excel and ArcGIS 10.0 software. Origin of the product, route followed, speed of movements, unnecessary time delays, and unnecessary movements were derived for further analysis. Point data were converted to line data attributed to the location and time. Speed calculation was performed in Microsoft Excel since it was not a straightforward procedure in ArcGIS. Later these speed data were exported to ArcGIS. Mapping was done to visualize the findings.

Feasibility and drawbacks of mobile tracking were identified in improving the geo-traceability of the selected '*Omaragolla Karthakolomban* Mango Supply Chain' through personal communication. Thereafter, suggestions were provided to improve the functionality of the mobile tracking to improve the geo-traceability of fresh produce.

## RESULTS AND DISCUSSIONS

### *Characterization of Selected Omaragolla Mango Supply Chain*

The selected "*Omaragolla Karthakolomban* Supply Chain" (Figure 01) provided fresh mango for the local market. The study revealed unique functions played by different actors. Selected collectors collected mangoes from different areas of the country in both 'mango seasons', the first season during May-July, and the second, during November-February. Mainly, mini trucks (with 1000 kg payload capacity) were used for the transportation of mangoes from the field to collecting centers. Mango harvesting was conducted depending on the availability of mango. On average, mango collection was done in 20 days per month within the season. The average distance travelled per day was around 100 km and it ranged from 20 km to 200 km per day. This traveling added around 15,000.00 LKR to the value chain per month as fuel cost. In addition to this, the transport cost was further increased when hired vehicles and hired laborers were used.

When considering Karthakolomban growers in the selected districts, they were predominantly scattered home garden-level growers and a few numbers of orchard-level growers. Growers who participated in the study got involved in crop management practices but not in harvesting operations. The collector was responsible for harvesting, transportation of mangoes to the collecting center, primary processing of mangoes, and distribution of mangoes to the wholesale market concerning the selected supply chain. This characteristic can be used positively for future reformations of the supply chain to fix the best path to different farms by considering the distance and convenience. Hired laborers were used by the collectors for the above-mentioned operations. Own vehicles or hired vehicles were used by the collector to transport mangoes from the field to the collectors' pack house in the *Omaragolla* area.

After completing pack house operations, mangoes were transported to the wholesale market (Manning market in Pettah, Colombo) through a transport service provider on a hired basis. The wholesaler was a commission-based broker that participated in the mango supply chain, from whom the roadside retailers acquire mangoes for their retail outlets. The supermarket chain in the country was also linked to the chain where mangoes were directly transported by collectors to supermarket collecting centers, though that amount is proportionally minute.

***Application of Mobile Tracking for Omaragolla Supply Chain and the Feasibility to Improve the Geo-traceability***

Two types of travels could be identified in the selected chains: movements of mango and movements of supply chain actors (Fig. 01). Fig. 02 visualizes the supply chain in a spatial context and depicts the movement of each supply chain actor along the supply chain.

Mobile tracking didn't help to track indoor processes (sorting, grading, artificial ripening, and packaging) practiced at the pack houses that take an average of 2 days of duration. Therefore, other technologies such as barcoding, QR coding, RFID, Internet of Things technology (IoT), and blockchain technology (He *et al.*, 2009; Tsang *et al.*, 2019; Tian, 2016; Hsu, *et al.*, 2008) can be combined to improve the reliability in the future. Helo and Shamsuzzoha, (2020) proposed a system that integrates the latest technologies (RFID, IoT, GPS and blockchain) for real-time tracking, authentic data sharing, and facilitating transactions in supply chains. This kind of well-developed system can provide complete traceability from start to end. However, implementing such a sophisticated traceability system is far ahead related to the Omaragolla Mango supply chain. Especially, since it is not well defined from farm to pack house. Also, the awareness of traceability among players and the presence of principle traceability requirements such as data recording, product identification, data integration, and accessibility (Islam and Cullen, 2021) were not observed among players. Therefore, traceability development of the selected chain has to be approached with a simple, cost-effective, and user-friendly approach where mobile tracking is a good initiative that can be implemented with an already available network of smart mobile phones.

When considering mango collection by selected collectors, the majority of the mangoes are collected from rural areas with poor road conditions that may cause heavy losses. However, preplanning of the collection process can be used to avoid roads with poor condition thereby minimizing the distance travelled through poor condition roads. Elik *et al.* (2019) also stated that the unavailability of appropriate transportation means, poor road condition and inefficient logistics management causes losses of perishables through the supply chain.

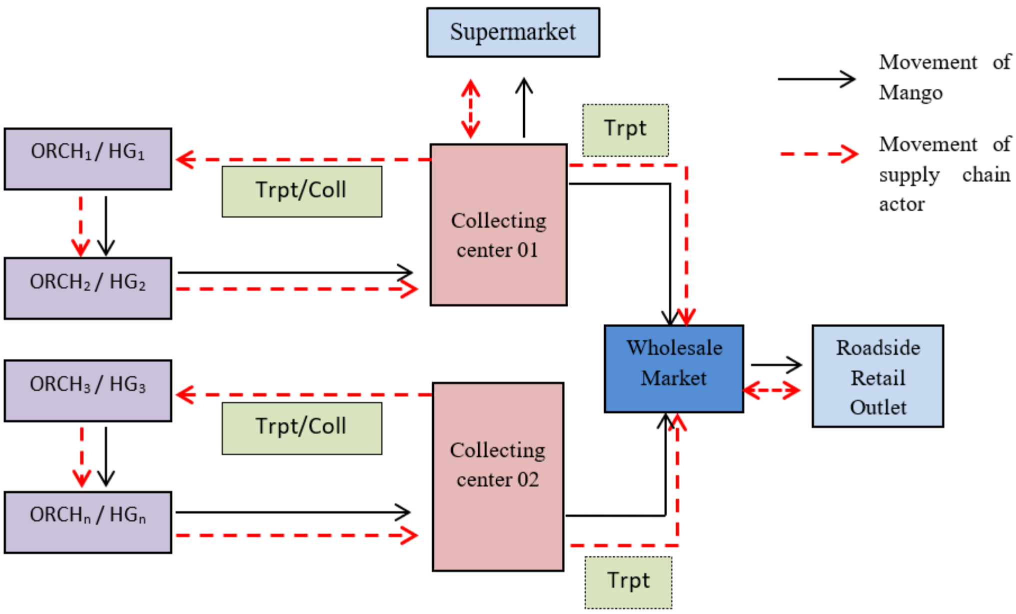


**Figure 01: Movement of mango and supply chain actors in '*Omaragolla Karthakolomban* Supply Chain' selected for the case study (ORCH = Orchard; HG = Home Garden; Trpt= Transporter; Coll= Collector)**

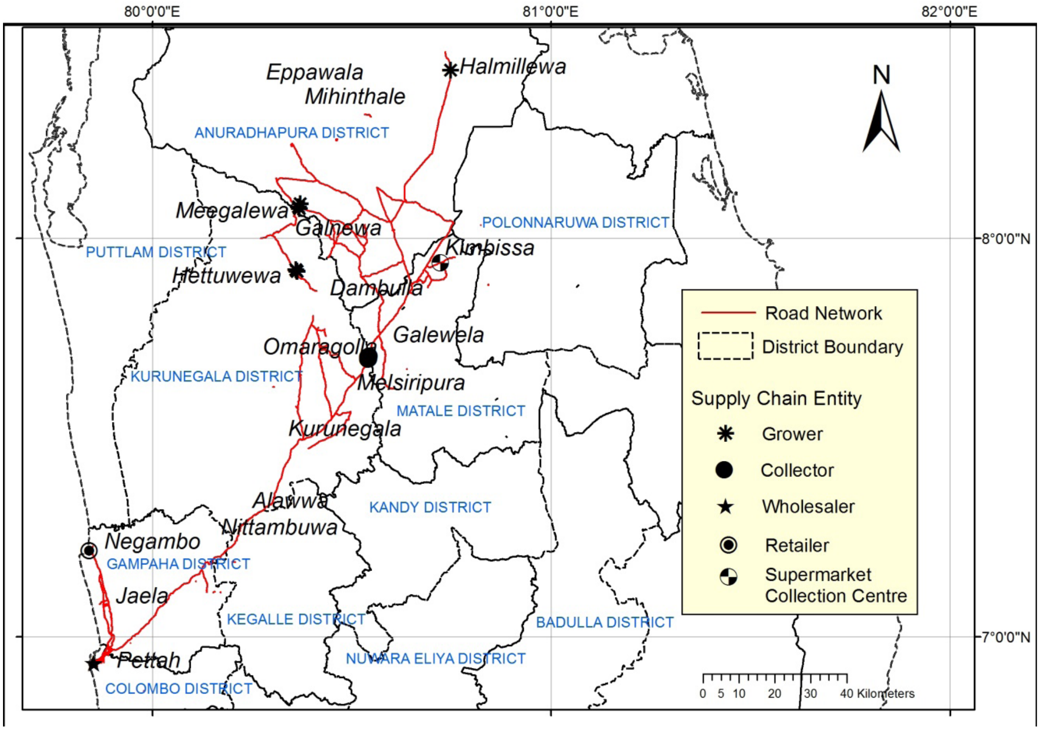


**Figure 02:** **Map of *Omaragolla Karathakolomban* supply chain with the spatial distribution of selected supply chain entities**

Both advantages and disadvantages were identified regarding the use of mobile phones for supply chain movement tracking. Mobile tracking system enabled identification of location and time aspects of the *Omaragolla* mango supply chain. Thereby it was able to derive the start of the journey, and the route followed and also to detect unnecessary movements and mango collection points and other stops within the journey, destination, and duration that the supply chain had operated (Fig. 3. and Fig. 4.). These capabilities can be positively used in improving supply chain traceability.

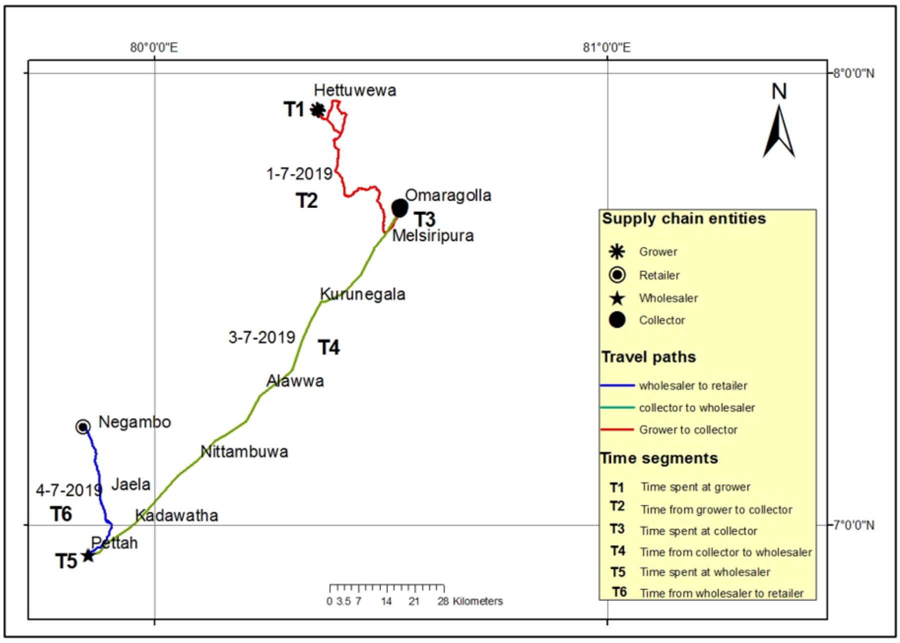


**Figure 03:** ***Omaragolla Karthakolomban* chain functioned from 01st July 2019 to 4th July 2019 based on collecting center 1**

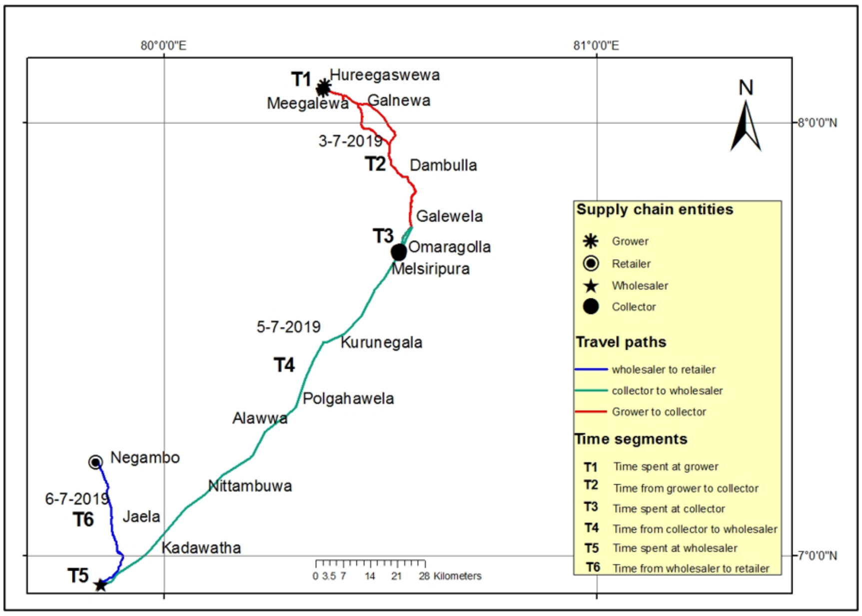


**Figure 04:** ***Omaragolla Karthakolomban*** **chain functioned from 3rd July 2019 to 6th July 2019 based on collecting center 2**

Ten complete supply chains were planned to be tracked. However, only 50% were successful due to technical constraints and mobile signal issues.

All the observed supply chains consisted of a day mango collection process. Thus it had taken 3 days on average to move mangoes from grower to retailer. However, both collectors stated that collection may take more than one day depending on the distance traveled and availability of mangos in the areas traveled. Nevertheless, unnecessary prolonging of the collection process may cause quality deterioration (Aung and Chang, 2014).

With the findings of the study, it was able to identify 6-time segments (Table 01.) that support decision-making on minimizing unnecessary time expenses. However, identification of time spent at the retailer and thereby the total time taken from farm to plate was not possible through mobile tracking alone.

### *Feasibility Analysis to Use Mobile Tracking for Omaragolla Supply Chain*

Although the introduced mobile tracking system was successful in tracking the physical movement of players, several constraints and problems were identified to improve the geo-traceability of mango fruits. These constraints and problems are discussed below.

The dynamic nature of the selected *Omaragolla Karthakolomban* supply chain was a major barrier to achieving geographical traceability via mobile tracking. Mango collection was done in an ad-hoc manner where different growers were linked to the supply chain without prior notice. Hence, it was unable to identify defined growers. This was mainly due to the unavailability of a sufficient number of contract growers and variations in the availability of mangos. Also, Possibilities were identified to overlap collection routes from different collector groups within the Maravilla mango processing zone creating inefficiencies. Therefore, an extensive database that includes information on all the growers, in real-time is required to be prepared before achieving the geo-traceability.

Apart from this, the mango collection process was done often through hired laborers where the person was changed dynamically based on labor availability. This greatly constrained the mobile tracking of the *Omaragolla Karthakolomban* chain since location tracking was based on the mobile phone of the person traveling.

**Table 01: Time taken to move between different stages in the supply chain.**

| Supply chain entity | GR | | Coll | | WS | | RT |
|---|---|---|---|---|---|---|---|
| Time segment | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | |
| Day of the chain | 1st | 1st | 1st to 3rd | 3rd | 3rd and 4th | 4th | |
| Time duration spent | 2 hrs and 24 min | 3 hr and 21 min | 48 hr and 38 min | 6hr | 6 hr and 35 min | 1 hr and 34 min | |

*GR – grower, Coll – collector, WS – wholesaler, RT – retailer, $T_1$ - time spent at grower from arriving at grower to departure, $T_2$ - the time from grower to collector, $T_3$- time spent at the collector, $T_4$ - time from collector to wholesaler, $T_5$ - time spent at wholesaler, $T_6$ - time from wholesaler to retailer*

Selected *Omaragolla* mango supply chain supplied fresh mango to the market where no major processing activities were involved. However, the mixing and splitting of mango lots collected from various geographical locations constrained the geographical traceability by disabling the identification of the exact origin. Olsen and Borit (2018) have emphasized the importance of having a mechanism to identify each batch, a mechanism to record transformations and identify unit attributes. Therefore, the *Omaragolla* mango supply chain should be improved by considering the above facts to attain geographical traceability in the future.

However, for the selected supply chain a very basic level product identification method was identified at the level of collector. The collector displayed his name/brand which is called '*Vilasan*'. The importance of this is that the wholesaler and the retailer can identify the collector that is responsible for the set of mangoes. However, recalling was impossible up to the grower level since many mixing and splitting operations are done at the collector level without keeping track. Hence, the use of product identification technologies is needed to improve the traceability of the *Omaragolla Karthakolomban* chain. The use of product identification technologies, that identify the product or batch with a unique code to be shared within the chain, is an essential requirement for tracing the history and tracking the physical location of products (Opara, 2003; Kelepouris *et al*., 2007). Therefore, a simple product identification technique such as simple tagging or barcoding can be used as the initial step, despite the highly complicated technologies like Radio Frequency Identification (RFID) technologies.

Geo-traceability information will not be meaningful without other conventional traceability data. Hence, record keeping is mandatory to forward the pass of information through the supply chain and to be able to trace it back. However, Record keeping of traceable information was not observed in the selected chain which was identified as a shortcoming.

Hence, the identification of traceable resource units (TRUs) (Dabbene *et al*., 2014), the use of suitable product identification technology (Khan *et al*., 2018), record keeping on transformations (Hu *et al*., 2013), and sharing of necessary information (Anica-Popa, 2012) are mandatory requirements. These requirements should be fulfilled starting from the grower and across other intermediate entities within the supply chain followed by mobile tracking of movements for geo-traceability improvement.

*Omaragolla* mango supply chain consists of a high degree of logistic uncertainty, which may adversely affect the supply chain efficiency by creating an extra cost and an extra distance to the supply chain. According to Sanchez-Rodrigues *et al* (2010), Extra distance increases fuel usage thereby increasing the cost and $CO_2$ emission whereas extra time creates inefficiencies by not fully utilizing available vehicle resources. Hence, it is mandatory for future planning of mango collection to minimize the uncertainty.

## CONCLUSION

The case study revealed that mobile tracking was technically possible as an application of geo-traceability in the selected chain. However, it was not feasible to improve the geo-traceability of the selected *Omaragolla* mango supply chain due to several reasons; unavailability of fixed chains, unavailability of fixed actors, logistic uncertainty, and mixing and splitting of mango lots collected from various geographical locations. Therefore, mobile tracking can be implemented on already available defined supply chains as an initial step. Later on, more supply chains can be included in the system. Simultaneously, an extensive database is to be developed to enclose all the information on the mango fresh fruit supply chain including locational information and other important attributes.

Meanwhile, mobile tracking has a huge feasibility to be used in fixed fruits and vegetable supply chains to improve as a cost-effective means of tracking

### *Conflict of Interest*

The authors declare that there is no conflict of interest.

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