

Considerations in the Design of an Efficient Network to Transport Perishable Crops

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Abstract

Perishable crops are agricultural products that have a limited shelf life and are susceptible to rotting if no preventative measures are taken. Prior to reaching the consumer, the perishable items must travel substantial distances. It is difficult for any supply chain to transfer such things efficiently while maintaining their quality. In a world where everyone is fighting against global hunger, it is essential to limit these losses. This paper's major objective is to collect and present speculations regarding the optimization of Bangladesh's transportation network for perishable crops. The investigation was conducted with two key components in mind. The first component is Logistical Refinement, which addresses crop flow path and utilization of aggregation points. X-Means Clustering is utilized to determine the optimal number and position of aggregation locations in one of the major divisions of Bangladesh. Process Manipulation portion can be taken as a suggestion to improve the efficiency of transportation as it includes vehicle modification proposals and also packaging methods. Finally, an improved model was suggested for perishable crops that encompasses all available modes of transportation in Bangladesh so that it may be used to ship items attaining requisite criteria and thus improve the overall transportation network for perishable crops.

Keywords

Perishable Crops, Energy Efficiency, Aggregation Points, X-means Clustering and Multi-modal Transportation.

1. Introduction

The predicted annual loss of fruits and vegetables in Bangladesh is between 23.4% and 43.5% (Noman 2021). Approximately 3,392 Cr taka are lost annually due to post-harvest decay of fruits and vegetables (Dinajpurbd 2013). According to the Nairobi-based United Nations Environment Programme's Food Waste Index Report 2021, a typical Bangladeshi wastes 65 kilograms of food at home each year (UNEP). The research which was released on March 4 to help global efforts to halve food waste by 2030 under the Sustainable Development Goals, estimates Bangladesh's annual food waste to be around 1,06,18,233 tons (The Daily Star 2021).

Losses will be considerably greater if all available fruits and vegetables are included. Inadequate system management, such as improper aggregation, distribution, forecasting, bullwhipping, storing, and transportation, plays a significant part in the waste of perishable crops. Bangladesh lacks an understanding of post-harvest processing, transportation, storage, and packaging procedures. According to Bangladesh Agricultural Research Institute, thousands of tons of fruits and vegetables are wasted annually. Almost all perishable crops are susceptible to deterioration due to inadequate transportation and storage. Not enough cold storage facilities exist for the majority of perishable crops. The country has 414 private cold storage, with potatoes accounting for 95% of their entire capacity. The remaining 5%, according to the Bangladesh Cold Storage Association, is used to keep fruits and seafood (The Business Standard 2022). If there is a robust transportation network, food loss will be minimal and hunger will not be an issue. Therefore, loss prevention strategies must be strengthened from the outset.

A transportation network characterized by significant information sharing and vertical and horizontal coordination will suffice. Bangladesh requires a well-defined multimodal transportation network to efficiently maintain the cold

chain and distribute perishable products to clients. According to LGED officials, the government focused on the creation of such centers only after the listing in the 1980s. Aside from market infrastructure, emphasis was placed at the time on the development of various types of highways to connect growth centers, which enabled the sale of rural agricultural goods and, as a result, enhanced farmers' interest in agricultural output (The Business Standard, 2022). Since various philosophies and ideologies govern the selection and effectiveness of a transportation network developing such an efficient transportation network can surely enhance the social, environmental, and economic stability of an ecosystem and promote the use of less fuel. These factors contribute to a lower carbon footprint, financial savings, and food loss reduction.

The structure of the study focuses on the theoretical functions of a transportation network in Bangladesh, with a particular emphasis on the expected areas of development concern. Initially, the logistics circle is illustrated so that the flow of perishables may be comprehended with ease. The requirement of aggregation sites to concentrate the entire process is highlighted, with aggregation points serving as the network's central hub. The optimal number and locations of aggregation points were then determined using the X-means clustering method. Process modification highlights the need to select the most viable mode and criteria of transportation. Moreover, several performance-enhancing approaches were also discussed.

2. Literature Review

Perishable commodities unquestionably demand a well-defined transportation model. The control of labor costs, the preservation of perishable commodity value, and the use of transportation modes that offer the best trade-off between time (product quality) and cost are some of the factors that affect the profitability of perishable crops. It is possible to reduce costs by managing the trade-off between product freshness at delivery and additional labor and transportation expenses (Ahumada and Villalobos 2011). Moreover, dynamic information-based management strategies may be better than conventional labor allocation and distribution procedures. The flow of a perishable commodity depends heavily on the consumer. The extent to which clients appreciate product variation influences the economic sustainability of perishable product multimodal transport (Rossi et al. 2021). When constructing a transportation network, the transportability of cargo is a primary concern. It has been determined that the qualities of commodities have the greatest effect on their transportability. Informal representations were supplied for classified perishable cargoes, forms of carried commodities, handling methods, transport routes, types of human labor, multimodal technology, and transportation employment (Leleń and Wasiaak 2019). Cost and cargo security can be utilized to evaluate the transportation network. The technological parts of a transportation network should be created concurrently, with the interests of the cargo owner and the transportation business in mind (Muzylyov 2020). Quality transportation takes into mind customer needs. Introducing assistance technologies that facilitate cost-effective food delivery to the majority of people can boost a company's efficiency and competitiveness. There is a substantial likelihood that it will help reduce human error and reduce labor dependency (Haji et al. 2020). Costs can be reduced through the centralization of facilities. In recent times, the introduction of IoT can facilitate the exchange of information. Then there are RFID chips, which can be utilized to monitor supply, distribution, transportation, and industrial operations (Chaudhary et al. 2018). A product's perishable nature affects its replenishment cycle, order volume, product pricing, investment effort, and profit. Managers should reduce the replacement quantity per cycle and expedite the process for products that degrade quickly. To reduce the loss brought on by deterioration, an accompanying replenishment cycle should exist (Feng 2019). Similarly, the incorporation of an accepted donation policy within the product's shelf life helps reduce the costs associated with storing the goods before their expiration (Mallidis et al. 2020). This method is advised for perishable items with a low-profit margin. And forecasting future demand can contribute greatly to ordering, delivering, and storing perishable goods (Kumar et al. 2021). This technology has the potential to cut waste and total expenditures. Therefore, the market becomes advantageous for both vendors and buyers. A study examined the potential for efficiency gains, gave a brief overview of the physics of transportation, and recommended batteries supported by supercapacitors as a viable option. They have talked about cutting-edge biofuel, energy, solar, and hydrogen technologies that require fundamental changes to current vehicle technology (Hermans 2017). A framework for evaluating the effects of various short-term measures on perishable goods is presented in another study. Shifts toward different modes of transportation have been investigated using an extension of a layered modal split model. In contrast to a speed limit, a power limit and goal-based measure give certain benefits to liner shipping companies utilizing more efficient boats. For perishable cargoes, shippers can tolerate minor speed reductions without a significant mode shift (Zis and Psaraftis 2021).

During the research, articles that examined the transportation network in sections were observed. The enhancements were only attainable by keeping a limited perspective of the network. To enhance the process's efficacy, however, it is vital to analyze the big picture. Occasionally, authors gave contrasting perspectives on the subject matter. Typically, a transportation network optimized for a single variable will perform badly for others. In practice, there was no all-win theory for the transportation network. For constructing an energy-efficient transportation network, the combined strategy of process manipulation and logistical refinement remains understudied.

3. Model Background

An alliance of two significant factors plays a crucial role in designing an efficient transportation network.

1) Logistical Refinement: Logistical refinement involves modifying the micro and macro-operations of a logistics system to make the whole process more manageable and accountable. In a supply chain, logistical refinement factors facilitate the movement of products and services. To address and make any modifications, it is required to trace the flow path and identify missing components of a strategy.

a) Reimagining Transportation: The traditional perishables transportation network is focused on market activity. It gives the third party (or middleman) a lot of power over the system. However, a transportation system without the influence of middlemen can offer more accountability. By including the aggregation points, the unfair third party is eliminated. Therefore, it keeps the producers' hands on the levers of power. Figure 1 depicts many aspects of the logistics for perishable crops without the involvement of a third party.

Local transit is shown by the red crossed lines. And not much can be done to make them better because it would be difficult to implement such modifications. However, the green check highlighted lines represent mass transit, which is the primary focus of this study.

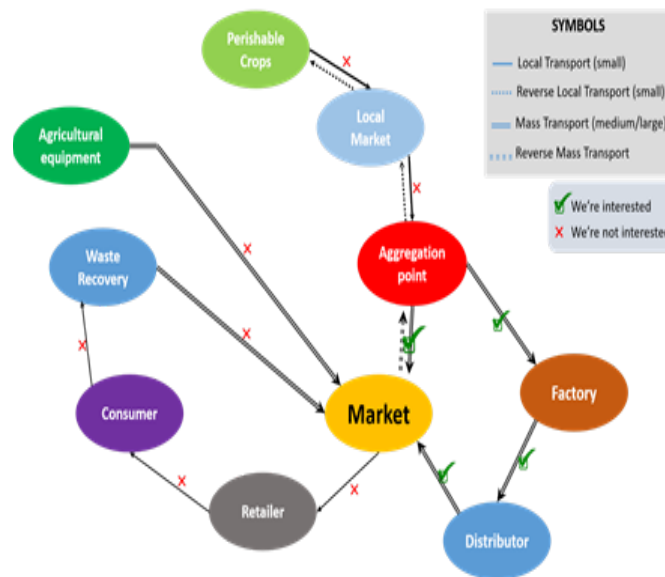


Figure 1. Logistics circle for crop transportation

b) Location of Aggregation Points: These are temporary storage facilities for perishable crops. The crops are transported to the locations of aggregation, where they are stored in freezers prior to shipment. The aggregate points may fulfill multiple functions. Adopting solar panels and advanced equipment at these aggregation sites minimizes energy waste. The selection of an aggregate point's location is not a simple procedure. A multi-objective function serves as the criterion for selection. The fundamental objective, however, is to minimize total cost. The X-means clustering approach may identify the needed number of aggregation sites and their global location for a given collection of pickup points.

For instance, the Khulna division was selected to determine the number of aggregate points. UTM coordinates of the division's Upazilas was used for this purpose (Latitude.to, 2022). These locations are visualized in Figure 2.

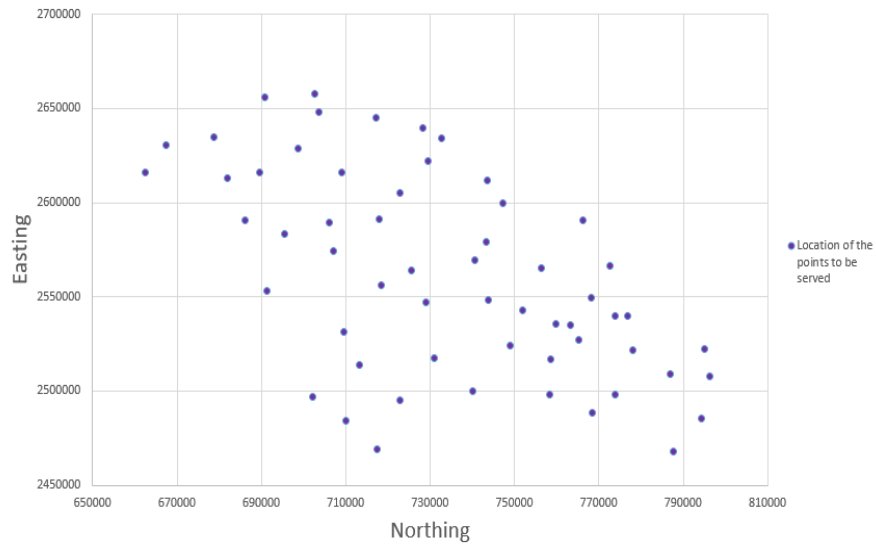


Figure 2. Cluster of UTM coordinates of upazilas of Khulna

Using the clustering method, the locations and the number of aggregation points were obtained by Squared Euclidian distance. Consequently, the dataset necessitates four aggregation points. The location data was grouped into four clusters, starting at number 0 all the way up to number 3. These groups or clusters are distinguished using separate color codes as demonstrated in Figure 3, where cross marks represent the centroid of the adjacent cluster.

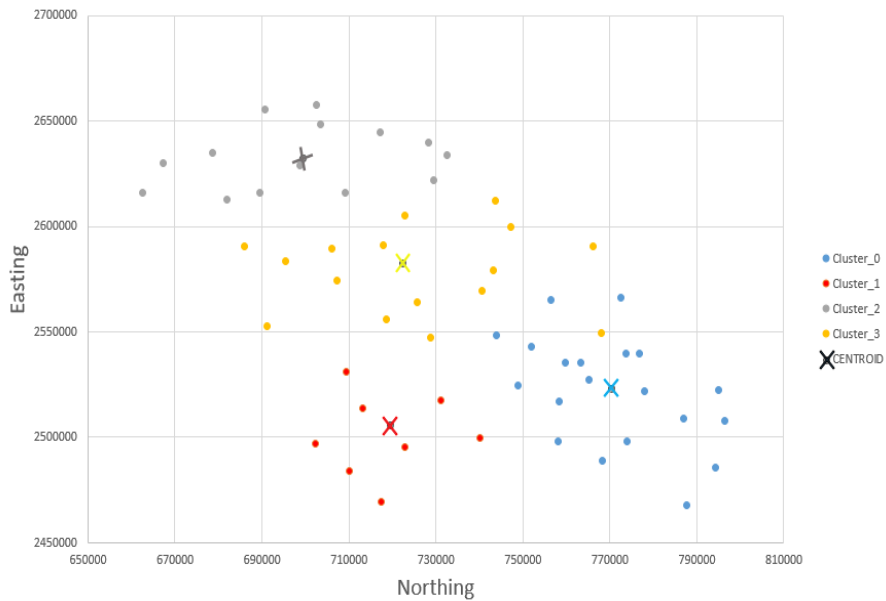


Figure 3. Centroids of the clusters

Table 1 displays the geographic locations of the created cluster centers. Similarly, the location and number of aggregation points can be determined for other divisions of Bangladesh by using X-means clustering.

Table 1. Cluster Centroids

	Northing	Easting
Centroid 0	770379.86	2523328.69
Centroid 1	719496.00	2506104.25
Centroid 2	699441.00	2632639.31
Centroid 3	722274.74	2582733.63

c) Return Voyage: A promising agricultural transport system will likely reduce the demand for refrigerated cargo. On the return journey, the vehicle will not be empty. It will convey agricultural equipment, fertilizer, and other commodities required in rural areas from the urban market.

2) Process Manipulation: Process modification refers to the changing of existing procedures and their implementation through the application of supply chain expertise, operations management, and operations research. Energy consumption is also affected by the vehicle's state of operation. Here, a few minor but essential factors were examined that can aid in improving efficiency while reducing operational expenses. These qualities are simple to uphold, and their effects can be stunning.

- **Tire Pressure:** To extend the life of tires, it is vital to maintain the correct tire pressure for a certain load.

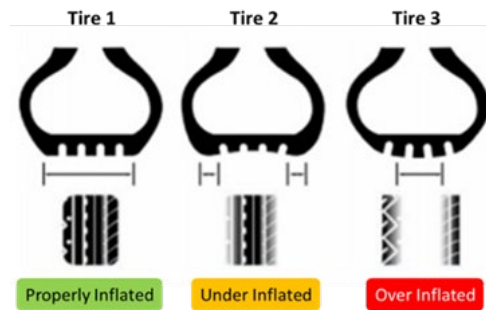


Figure 4. Level of tire flatness under pressure

In Figure 4, tire 1 is perfectly inflated, ensuring uniform friction throughout its periphery. However, tire 2 and tire 3 are under and over-inflated, respectively. So, in both cases, the friction lining is uneven, resulting in rapid wearing and imbalanced load distribution that also raises fuel consumption.

- **Constant Speed:** Continuous change in speed increases fuel consumption.
- **Quality of Fuel:** Having fewer or no impurities in the fuel improves mileage.
- **Driving Habit:** It was noticed that appropriate driving practices could save up to 15% of fuel (Government of Canada, 2021).
- **Optimal Packaging Technology (OPT):** Packaging technology has numerous advantages for farmers and customers in the agricultural sector. The technologies are being used since they aid in saving both time and money. Furthermore, this new agricultural strategy is cost-effective. One of the most crucial reasons for adopting the OPT is that it promises to enhance their income significantly. It also enables them to cultivate crops and boost productivity. Furthermore, they do not have to be concerned about crop quantity or quality. Using minimal package material with suitable chilling properties can help achieve a more extraordinary feat. The simultaneous use of rappers and optimally designed trays saves space and provides a compact arrangement for better cooling.
- **Mode of Transportation:** To deliver the goods, it is necessary to determine the optimal mode of transportation. Small, medium, and large cargo options are available if a truck is selected. Using streets as a form of mobility is not always the best alternative. There are alternative options, including waterways and railroads. Water transportation is

prominent in the southern area of Bangladesh, despite the absence of a rail network. Moreover, whenever practicable, additional cargo compartments can be transported on public trains. The mode of conveyance to be employed in the process will be determined based on a variety of considerations, including the amount of crops, the type of crops, the distance of the destination, the infrastructure of the districts, and the most convenient vehicle on the route, etc.

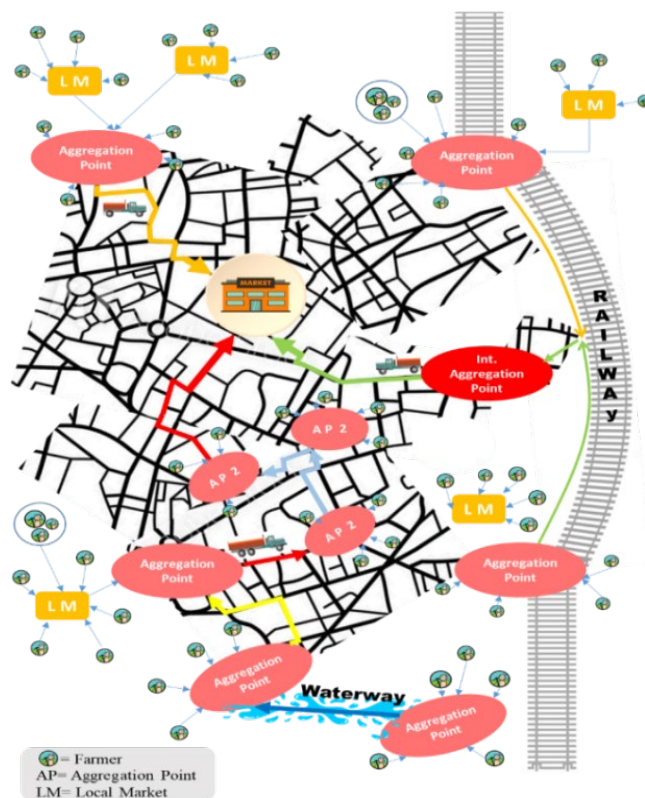


Figure 5. Illustration of an energy-efficient transportation model

The model delivers perishable crops to metropolitan markets efficiently and effectively. Figure 5 shows how these crops will go from producers to local markets. The market representative buys them and transports them to the nearest aggregation station for temporary or long-term cold storage.

4. Discussion

The study discusses all the aspects of designing an efficient transportation network for perishables. Efficiency could be achieved by the combination of various facets of logistical refinement and process manipulation. Selection and location of the appropriate number of aggregation points along the transportation route minimize the risk of rotting perishable crops. In this study, by means of X-means clustering, four aggregation points were identified for the Khulna region. Likewise, aggregation points for other regions may also be determined using the same approach. Last of all, the determination of the appropriate means of transport is also vital in achieving overall efficiency in terms of energy and cost. Besides, the extensive practice of fuel-saving habits such as maintaining correct tire pressure, constant speed, driving habits, etc. also contributes to efficiency. All of these factors combined can help achieve substantial improvement in the transportation network design.

5. Conclusion

An efficient transportation network design has various feasible outputs at its disposal. The inclusion of aggregation points allows the process to be centralized, performing multiple functions. The introduction of X-means clustering makes it easy to find out the required number of aggregation points concerning the pickup locations, which improves the quality of the transportation network. On-time maintenance and appropriate control of parameters like tire pressure, fuel quality, vehicle speed, acceleration, etc., also significantly cut fuel costs. Only the implication of

proper driving habits can save a considerable amount of fuel. In order to achieve overall efficiency, it is also crucial to select the most suitable mode of transportation. An exemplary location data of the Khulna division has been used to verify the results of clustering. An investigation has shown the centroids to be located roughly at the center with some deviations. This paper simply addresses the various components of designing an efficient network; however, the physical application of the factors is absent.

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