

A QUANTITATIVE RISK ASSESSMENT APPROACH IN AN INTEGRATED COLD CHAIN SYSTEM ENSURING OPTIMAL SAFETY AND RELIABILITY FOR INDIAN AGRARIAN MARKET

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Abstract

India has an agrarian economy. More than 52% of its land is engaged in cultivation and with varying demography across the length and breadth of the nation, India has one of the most diverse vegetative portfolio. Each genre of produce has limits to the time-temperature abuse it can withstand beyond which deterioration starts from within which may not be apparent. We present a logistic model which ensures easy quality management of food produce emphasizing on optimization of produce quality and minimization of wastage and spoilage. The model deals with specific products and their relationship with standard tolerance levels to temperature abuse patterns along with measures to minimize them. We use the basic principles of Hazard Analysis Critical Control Points (HACCP) in sync with operational pre-requisite programs to devise a robust system helping us achieve the desired level of optimization. Based on the Hub and Spoke model for freight transfer, this model focuses on two fundamental parameters, distance between the point of cultivation to the point of sale and time taken to traverse that distance maintaining the required time-temperature combinations. The algorithm emphasizes on acquiring data that can be utilized to predict a problem and assessment of risk before it occurs. This intervention can be made to mitigate product issues resulting cost impacts using the hype cycle for food supply chain. The system is intended to monitor produce temperature history, chain of custody and helping to ensure that a food is safe and effective throughout the supply chain when reaching its intended consumer.

Keywords: Cold chain, traceability, HACCP, Critical Control Point, hype cycle

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1. INTRODUCTION

A cold chain, being a temperature-controlled supply chain network with storage and distribution being carried out in a manner that the temperature of a product is maintained in a specified range, for keeping it fresh and edible with much longer period than in normal ambient conditions. This system facilitates long- distance transport of various products as well as makes seasonal products available over the entire year. Establishing a cold supply chain in India is a long shot. The existing system is scattered and fragmented. This paper attempts to suggest bridging the gap between the existing system and the system it should be. The emerging technologies cannot be implemented unless a robust chain already exists. If technology is implemented in the current scenario, manufacturers will not only face monetary loss but the brand may also get diluted. In an agrarian structure, incorporating safety and ensuring comprehensive growth of the system, OPRP charts may be used to weigh multiple paths in between two points, to gauge not only the shortest but also the safest path. We use the Hub and Spoke model as the basis of the Cob Web structure we propose. The hub and spoke model has a central hub connected with multiple supply points, the spokes. In this paper, we propose symmetry in the

Hub and spoke model. In order to identify the drivers and challenges for the cold chain industry in India, it would be helpful to visualize what a typical cold chain network looks like. The cold chain network for fruits and vegetables is not much different from the network required for consumer perishables like milk and pharmaceuticals. In a cold chain, there are two main elements of the cold chain logistics system: (a) **Surface storage:** Storage of products in refrigerated warehouses. (b) **Refrigerated transportation:** Perishable products are transported in reefers, refrigerated vans or railway carriages.

A cold chain logistics player may be a cold storage owner or owner of a fleet of reefers, or more commonly, an integrated 3PL firm that owns the entire network from procurement to the final destination of the produce. The following are the steps of a cold chain network:

- i) The first stage is the field where the fruits and vegetables are grown and then procured by the retailer.
- ii) The produce is subsequently brought to a pre-cooling unit, located in the vicinity of the production zone. Pre-cooling operation, carried out within a short period after harvesting,

prepares the fruit or vegetable for transportation over long distances.

iii) Reefer trucks are used to transport the produce at controlled parameters from the pre-cooling unit to the cold storage. The size of these trucks generally varies from one to more than 15 tonnes.

iv) Cold storages are centrally located to cater to multiple production zones and pre-cooling units. Depending on factor time, that being how long the product needs to be stored and the direction it is heading to, the produce is stored at a controlled atmosphere. This slows down the ripening process of the produce enhancing its shelf life.

v) The produce is then taken to a processing plant, where it is processed further.

2. HUB AND SPOKE PARADIGM

The hub and spoke distribution paradigm resembles a set of connections arranged as the spokes and the wheel [1,3]. A central

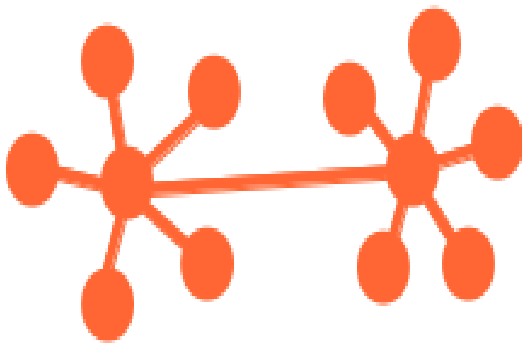


Fig 1 The interconnected hub and spoke structure

junction joins several nodes signifying efficiency in transportation. The system has several benefits as well as disadvantages but is most likely solution to build a successful cold chain system for the Indian agrarian economy. In this model, we deal with a central hub which may be a Pre-cooling center or a cold store. The individual farmers or independent growers form the other end of the spoke initially in its initial stage.

Our proposition of the CobWeb structure involves implementation of HACCP at each point in the supply chain, mapping the chain of custody with probable hazards and weighing them according to risks. Finally, we use Dijkstra's algorithm to figure out the most efficient path. To achieve safety and high efficiency of food cold chain system, it shall take into account of two aspects of restraints when allocate safety reliability: First, the safety constraint, i.e. under the condition of given initial safety reliability, Second, the cost restraint.

Table 1 HACCP chart for food supply chain

| CCP | HAZARD | LIMIT | WEIGHT |
|--------------------------|---------------------------|--------------------------------------|--------|
| Purchasing & Checking | Raw material quality | National standard | 20% |
| Loading & Handling | Increasing microbial load | Working hygiene & storage | 15% |
| Storing | Cross contamination | National storage standards | 15% |
| Transport & Distribution | Working conditions | Real time temperature control system | 10% |
| Sorting | Biochemical contamination | Expertise of professional | 10% |
| Processing | Chemical contamination | National standards | 20% |

3. COBWEB PARADIGM

In this model, we deal with a central hub which may be a Pre-cooling center or a cold store. The individual farmers or independent growers form the other end of the spoke initially in its initial stage.

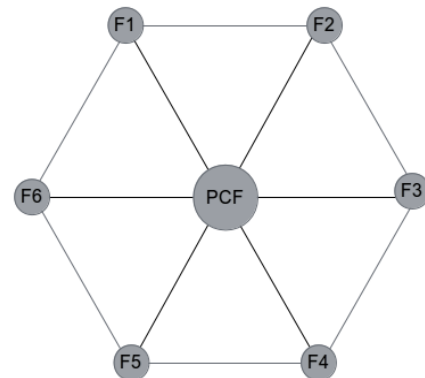


Fig 2 The pre cooling unit [PCF] connected with six unique farmers or point of production

3.1 Single Hub Assignment

Pre-Cooling Facility [PCF] acts as the hub and individual farmers [F1,F2,F3.....Fn] act as the primary producers acting at the bottom of the supply chain. For a network of n nodes, there will always be n-1 number of routes to connect all nodes to the central hub with a complexity of O(n). Assuming the need to transfer commodities between individual producers,

the bulk amount of two or more producers are transported to the central hub making the system stable, maintaining same profit level. This compares favorably to the $n(n-1)/2$ routes or complexity of $O(n^2)$ that would be required to connect each node to every other node in a point to point network.

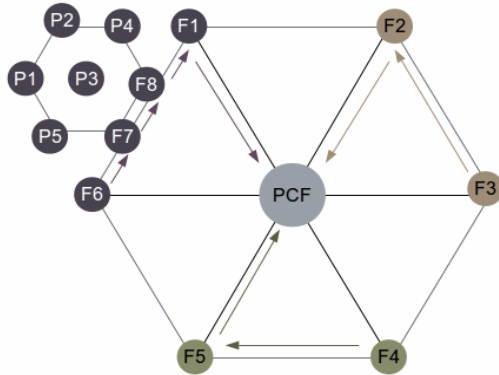


Fig 3 Increasing the number of supply points along a path

In the above figure, F6, F7 and F8 ship their individual bulk to the nearest individual producer, F1.. A reefer or a suitable carrier then ships the bulk to the pre-cooling unit. Interestingly, with increase in number of players or individual suppliers, the grid becomes more profitable. Small number of prime routes reduces the transportation cost and increases efficiency. Complicated operations like quality assurance, packaging and sorting can be done at the hub and not the farms. This will ensure uniformity of the packaged goods and ensure good returns to individual producers. The model below shows individual producers forming yet another cobweb and joining with a previous structure with a centralized pre cooling unit. A central carrier picks up bulk commodity from four individual producers and transports it to the pre-cooling facility. The individual transportation in between the producers become more efficient with increase in the number of producers. The spoke ends being simple, can be added or deleted with ease without disturbing the complexity of individual routes.

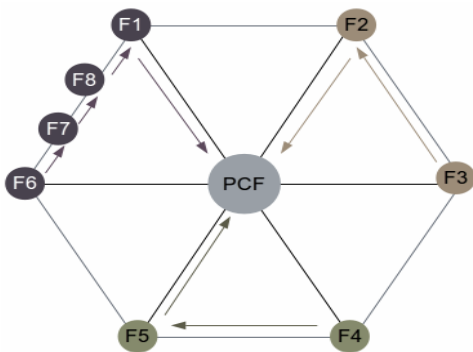


Fig 4 Successive formation of cobwebs by individual suppliers creating a mesh structure

With increase in number of spokes, they can individually form another spoke and hub model. With each increasing producer, the model becomes more efficient with individual wheels joining to form a bigger circle. Joining individual points, the least distance between the farthest individual producers can be figured out and linked to the pre-cooling unit.

3.2 Multiple Hub Assignment

The Pre-Cooling Facility [PCF] now becomes the end of the spoke and the Cold Store [CS] facility acts as the hub. The complexity and efficiency remaining the same, the cold stores can be linked and a network can be established. The model being flexible, allows n number of individual producers, n number of Pre-Cooling facilities and n number of cold store facilities.

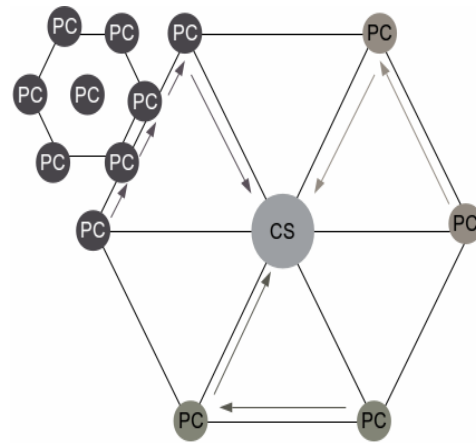


Fig 5 The pre cooling units forming spokes in the cobweb while the central cooling unit forming the hub

4. PROBABLE SHORTCOMINGS

- A centralized system makes day to day operations inflexible. Any change in a hub may result in an entirely different route which may make the operations impossible to be handled in case of unusually high demand in between spokes.
- The hub should never be starved. So the route scheduling becomes tougher. Precise traffic scheduling and timing are required to get desired results.
- The central hub acts as a limitation. Total cargo capacity of the entire network on one single hub. Any anomaly in hub can result in a shift throughout the supply chain.
- The hub is the common point of contact between any two spokes. Arriving at hub is the necessary condition before produce can be exchanged between any two spokes fulfilling any requirement. Hence minimum of two trips is required for transit of goods between any two hubs.

5. METHODOLOGY

The entire transportation chain from origin to destination has been divided into three parts:

- The collection part (Origin or supply major)
- An interior hub part (transit friend or the α factor)
- Distribution part (destination or demand major)

The simplest way to ensure a safe transit is to express factor with respect to time.

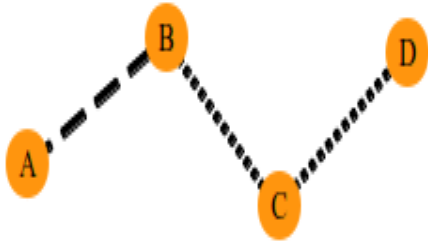


Fig 6 Transit test path

The following points when diminished will result in increased time and risk optimization.

- Volume / Bulk of transport (B)
- Time which it normally takes to reach the destination
- Time which it would take if α is increased or changed due the dynamism of system (X_{AD})

Thus for multiple hub assignment, minimizing the following variables gives us the optimized structure:

$$T_{AD} = T_{AB} + \alpha (T_{BC} + T_{CD}) \tag{1}$$

In a multiple hub system, taking number of reefers k departing from origin a until it leaving the next distribution site b to be a cold chain logistics unit X_{ab} , whose distribution time includes the travel time from distribution site a to b t_{ab}^c and the process time at site b (containing loading and unloading time, receiving time and meal time) t_{bk}^d :

$$t_{abk} = t_{abk}^c + t_{bk}^d$$

Fresh food requires high timeliness that have to limit its distribution with time. Here, we intend to apply time constraint, consequently the constraint $m_b \leq e_b \leq n_b$ (where m_b is the number of pre cooling units and e_b is the arrival time of vehicle at the customer b) are considered for optimization model. The food distribution routing optimization model with time and load is as follows:

$$Min Y = c \sum_{a=0}^n \sum_{b=0}^n \sum_{k=1}^m t_{abk} X_{ajk} \tag{2}$$

Where k is the number of pickup/rest points enroute to destination. Also

C = The transportation cost of reefer per unit time

t_{abk} = The travel time of the reefer in route section (V_a, V_b)

$t_{abk} = t_{bak}$

$x_{abk} = \{1 \text{ if the reefer passes through section } (V_a, V_b) \text{ else } 0\}$

$$\sum_{a=0}^n x_{abk} = 1 \quad (b=0, 1 \dots n); a \neq b \tag{3}$$

$$\sum_{a=0}^n x_{abk} = 1 \quad (k=1 \dots m); a \neq b \tag{4}$$

$$\sum_{b=1}^n x_{abk} = \sum_{b=1}^n x_{abk} \leq 1 \quad (a=0, k=0, 1 \dots m) \tag{5}$$

$$m_b \leq e_b \leq n_b \tag{6}$$

$$\sum_{k=1}^m \sum_{b=0}^n x_{abk} \leq m \quad (i=0) \tag{7}$$

Equation (3) : Multiple reefers may be used but every retail juncture will be serviced just once

Equation (4): Single reefer will serve all retail junctures

Equation (5): Displacement of every reefer is zero, they start and come back to the same spot

Equation (6): Every reefer falls within the purview of safety and timeliness

Equation (7): Number of reefers leaving V_0 cannot exceed the total number of reefers

6. TRANSIT PROTOTYPES

A range of cobweb formats can be formulated keeping in mind decisive factors as management simplicity, availability of cheap labour, demography etc. Their key characteristics, governance mechanism are explored.

6.1 Multiple Spoke Service Model

The hub has dedicated spokes servicing it. The hub's is to set the quality and performance benchmarks, mitigating risks, thus ensuring spokes comply with standards. The spokes act as supply points and inventory control largely lies within the hub.

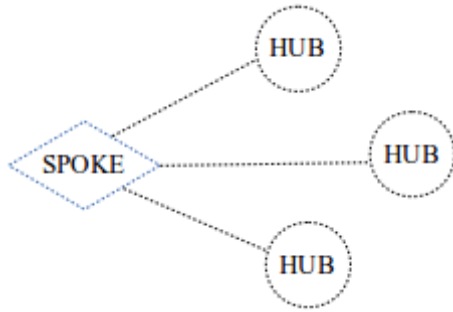


Fig 7. Multiple spoke service model

Governance Mechanism

The inventory control lies at the dedicated hub while spokes ensure regulatory compliance following regional rules in which they are located. In operations, the Hub takes decisions on supply allocation and delegates it to the spokes.

Suitable Application

This model is best suited when spokes are situated in locations having a specific value proposition which could be low-cost, cultural affinity or agricultural produce which is useful for a particular hub only and not others. This model could be applied with tier - III, IV cities acting as spokes with tier-I, II cities being the hubs.

6.2 Single Spoke Service Model

This model involves presence of a Spoke in a geographic location catering to the multiple Hubs across the nation. The Spokes would handle specific set of requests and demands in their area of specialization from the Hubs catering to their respective customer base.

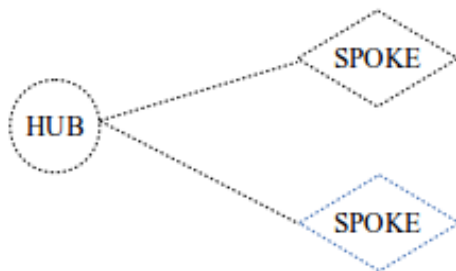


Fig 8 Single spoke service Model

Governance Mechanism

The spoke has a separate layer involved in managing the day to day operations. It has in its discretion prioritizing its work according to demands received from different hubs. This model to some extent mandates some degree of coordination between the spoke and hubs.

Suitable Application

This scenario typically observed when the spoke has the necessary resources to support one critical demand. An example of this competency could be supply of specific genres of mangoes to national hubs from Nagpur node or supply of apples from Srinagar node.

6.3 Multi Spoke Multi Hub Service Model

This model has hubs with multiple shared spokes serving them. Each hub has a network of spokes while each spoke serve multiple hubs. Spokes have internally dedicated supplies to cater to its hubs.

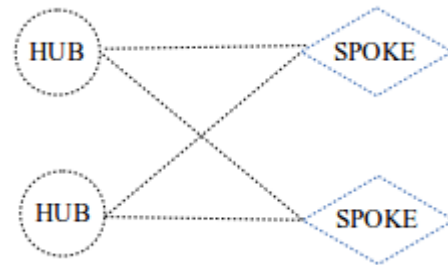


Fig 9 Multi spoke multi hub service model

Governance Mechanism

Spokes report to multiple hubs, there would be a thin managerial layer handling the overall operations of the spokes as it requires some degree of coordination and quality management is carried out at the hubs.

Suitable Scenario

A spoke is shared when it functions as a pivotal delivery/ supply point that support multiple deliveries/supplies along demand centres. This model is best suited when spokes have supplies which maybe a common requirement at more than one hub, for example, Nellore and Nagpur sharing equal mango production and supplying to rest of India.

7. DESIGNATING HUBS AND SPOKES

7.1 Weighing the Path

There may be multiple pathways in between the demand and supply. We use the operational pre requisite programs [OPRPs] to weight each individual path depending on the parameters in that path and form a weighted graph. Using modern tracking technologies, we can have controlled atmosphere reefers which have temperature probes and any deviation from the mean will trigger an alarm and the driver as well as the control centre will be informed. The severity and likelihood may be determined by the freight controller depending on the controlling factors like the time-temp combination, shelf life and the relative humidity.

| α/γ | Severity | Likelihood | Score |
|-----------------------|----------|------------|-------|
| Temp-Time combination | X | Y | XY |
| Shelf Life | A | B | AB |
| Relative Humidity | C | D | CD |

In a diverse agronomy like that of India, each different climatic conditions in different parts, fruits and vegetable production is scattered throughout the country. The demand however is more or less equal in every part of the nation. As an example, West Bengal ranks first in production of Pineapples whereas Andhra Pradesh ranks first in production of Tomatoes. The demand for tomatoes is more or less equal in every part of the nation.

7.2 Most Efficient Path

Once, the score has been settled on every path, the path can be weighted based on the scores and a weighted di graph can be obtained. Applying the Dijkstra's algorithm on the weighted di graph, we may obtain the least weight path and hence the most efficient one.

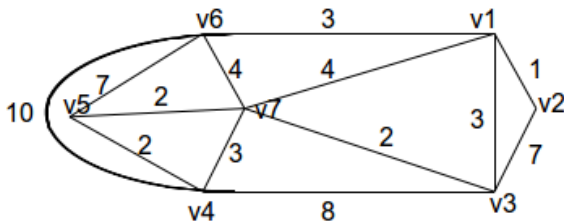


Fig 10 Weighted paths

Assuming more or less equal demand for some high demand produce, we may assign hubs and spoke designation to areas depending on productivity. The spokes need to be weighted depending on prime factors affecting the ease of transportation. The factors may include availability of reefers, the bulk amount to be transported, consumer demand or the political stability.

Table-2: Dijkstra's algorithm

| V1 | V2 | V3 | V4 | V5 | V6 | V7 |
|----------|----|----------|----------|----------|----------|----------|
| ∞ | 0 | ∞ | ∞ | ∞ | ∞ | ∞ |
| 1 | 0 | 7 | ∞ | ∞ | ∞ | ∞ |
| 1 | 0 | 4 | ∞ | ∞ | 4 | 5 |
| 1 | 0 | 4 | 14 | 11 | 4 | 5 |

| | | | | | | |
|---|---|---|----|----|---|---|
| 1 | 0 | 4 | 12 | 11 | 4 | 5 |
| 1 | 0 | 4 | 8 | 7 | 4 | 5 |

8. CONCLUSIONS

Ensuring quality and safety of the produce is the most challenging and vital part in its journey from farm to fork. Implementing technology, certifications will work towards a safer food and profitable returns for the producers. Currently, India still employs crude methods of tracking and maintains manual database of goods transported. Using the Hype cycle for food technology in the current scenario, we can spot the most efficient and up to date technology that is stable and will give higher rate of returns eventually.

Establishing a cold supply chain in India is a long shot. The existing system is scattered and fragmented. This paper attempts to suggest bridging the gap between the existing system and the system it should be. The emerging technologies cannot be implemented unless a robust chain already exists. If technology is implemented in the current scenario, manufacturers will not only face monetary loss but brand may also get diluted. The technologies presently used globally cannot be replicated in the Indian scenario due to the fragmented system existing in the country.

The pre-cooling units need to be modified depending on the type of fruit and vegetable, the variety and the amount. Majority of the cold warehouses have same facilities irrespective of the commodity stored. Generally, the warehouses are of a specified Capacity irrespective of the amount of commodity stored. These factors make the storage costly. Customized supply chain needs to be implemented as majority of the farmers do not have bulk amount to be transported to the pre cooling units directly. We propose designing a community cooling unit with very low capacity (<10 tonne) setup for every 50 farmers. The units may be eco-friendly with solar panels. The farmers can stock their produce till the store reaches its capacity and then a bulk can be transported to the pre-cooling facility. The interconnected hubs [point to point] and the spokes adhering to their respective hubs if implemented throughout the nation will resemble a multiple hub and spoke model [Fig.11] with multiple spokes catering to multiple hubs. In the first phase, individual hubs need to be created aligned to the spokes such that the spokes can efficiently connected to each other and then to the hub. Different hub based on the target area, the production and yield, hubs may be created with the prime districts acting as spokes. In the second phase individual hubs will get connected using a point to point network [P2P] and thus two distinct hubs with n number of spokes each have a free flow within the grid. A nationwide distribution of hubs and spokes will resemble the Fig. 14 with nodes being primary hubs and constituents being end of spokes. Signals are placed strategically in between connections to assure quality of

transported produce. They also act as a safe point in case of breakdown at any juncture, traffic can be diverted through the signals to the next nearest hub.

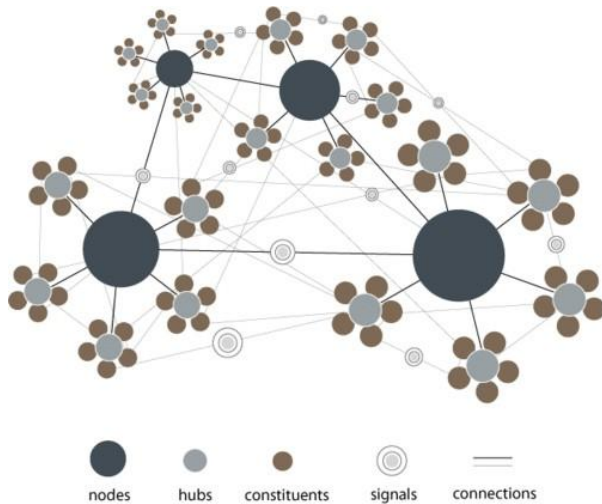


Fig 11 A cobweb model with in hubs

Implementing the hub and spoke model with quality checks at signals, will ensure a smooth flow of produce from the point of production to the consumers. Each path is weighed on the basis of the following parameters:

- Integration of resources to provide a consistent customer experience across Spokes throughout the country.
- Complex transition management processes.
- Navigating the regulatory regimes across Spoke locations tend to be complex.

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BIOGRAPHIES



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