Modelling and optimisation of Indian traditional agriculture supply chain to reduce post-harvest loss and CO_2 emission

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Abstract

Purpose – The purpose of this paper is to reduce the post-harvest loss occurring through respiration and CO_2 emission produce by the selected produces, during logistics. This paper proposes a supply chain (SC) structure for the Indian traditional agriculture SC planning model to reduce post-harvest loss and mixed closed transportation to reduce CO_2 emission.

Design/methodology/approach – The Indian agriculture SC structure is modeled and solved by genetic algorithm using a MATLAB Optimization toolbox. The respiration rate is measured by a static method. These values are applied in an SC planning model and the post-harvest loss and its corresponding CO_2 emission are estimated.

Findings – This paper proposes a supply structure for the Indian traditional agriculture SC to reduce the post-harvest loss; the experiments measured the respiration rate to estimate the CO_2 emission. The mixed closed transportation method is found to be suitable for short-purpose domestic transportation.

Research limitations/implications – The optimized supply structure leads to unemployment through eliminating the intermediaries. Therefore, further research encourages the conversion of intermediaries into hub instead of eliminating them.

Practical implications – This paper includes implications for the development of Indian traditional agriculture SC by an optimized supply structure and novel transportation method for the selected agriculture produces based on compatibility.

Originality/value – This paper identified that the agriculture produces respiration can also emit the CO_2. The closed transportation method can reduce the CO_2 emission of produces respiration than traditional open transportation.

Keywords Transportation, Carbon dioxide emission, Post-harvest losses, Respiration, Supply chain planning

Paper type Research paper

Nomenclature

Sets

n	Produces
f	Farmers
g	Agents
a	Auctioneers
l	Whole sellers
r	Retail store
e	Customer

D	Demand or production
Q	Supply quantity
T	Transport quantity
W	Loss quantity
PQ	Supply percentage
PW	Loss percentage
C	Carbon dioxide emission

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Decision variables

D_n	Demand or production of *n* produces
$\mathrm{PQ}_{\mathrm{nfg}}$	Supply percentage of produce *n* from farmer to agent
$\mathrm{PQ}_{\mathrm{nfa}}$	Supply percentage of produce *n* from farmer to auctioneer
$\mathrm{PQ}_{\mathrm{nfl}}$	Supply percentage of produce *n* from farmer to whole seller
$\mathrm{PQ}_{\mathrm{nfr}}$	Supply percentage of produce *n* from farmer to retail store
$\mathrm{PQ}_{\mathrm{nfe}}$	Supply percentage of produce *n* from farmer to customer
$\mathrm{PQ}_{\mathrm{nga}}$	Supply percentage of produce *n* from agent to auctioneer
$\mathrm{PQ}_{\mathrm{ngl}}$	Supply percentage of produce *n* from agent to whole seller
$\mathrm{PQ}_{\mathrm{ngr}}$	Supply percentage of produce *n* from agent to retail store
$\mathrm{PQ}_{\mathrm{nge}}$	Supply percentage of produce *n* from agent to customer
$\mathrm{PQ}_{\mathrm{nal}}$	Supply percentage of produce *n* from auctioneer to whole seller
$\mathrm{PQ}_{\mathrm{nar}}$	Supply percentage of produce *n* from auctioneer to retail store
$\mathrm{PQ}_{\mathrm{nae}}$	Supply percentage of produce *n* from auctioneer to customer
$\mathrm{PQ}_{\mathrm{nlr}}$	Supply percentage of produce *n* from whole seller to retail store
$\mathrm{PQ}_{\mathrm{nle}}$	Supply percentage of produce *n* from whole seller to customer
$\mathrm{PQ}_{\mathrm{nre}}$	Supply percentage of produce *n* from retail to customer
$\mathrm{PW}_{\mathrm{nf}}$	Loss percentage of produce *n* at famer
$\mathrm{PW}_{\mathrm{ng}}$	Loss percentage of produce *n* at agent
$\mathrm{PW}_{\mathrm{na}}$	Loss percentage of produce *n* at auctioneer
$\mathrm{PW}_{\mathrm{nl}}$	Loss percentage of produce *n* at whole seller
$\mathrm{PW}_{\mathrm{nr}}$	Loss percentage of produce *n* at retail store
$\mathrm{PW}_{\mathrm{nfg}}$	Loss percentage of produce *n* during transport from farmer to agent
$\mathrm{PW}_{\mathrm{nfa}}$	Loss percentage of produce *n* during transport from farmer to auctioneer
$\mathrm{PW}_{\mathrm{nfl}}$	Loss percentage of produce *n* during transport from farmer to whole seller
$\mathrm{PW}_{\mathrm{nfr}}$	Loss percentage of produce *n* during transport from farmer to retail store
$\mathrm{PW}_{\mathrm{nfe}}$	Loss percentage of produce *n* during transport from farmer to customer
$\mathrm{PW}_{\mathrm{nga}}$	Loss percentage of produce *n* during transport from agent to auctioneer
$\mathrm{PW}_{\mathrm{ngl}}$	Loss percentage of produce *n* during transport from agent to whole seller
$\mathrm{PW}_{\mathrm{ngr}}$	Loss percentage of produce *n* during transport from agent to retail store
$\mathrm{PW}_{\mathrm{nge}}$	Loss percentage of produce *n* during transport from agent to customer
$\mathrm{PW}_{\mathrm{nal}}$	Loss percentage of produce *n* during transport from auctioneer to whole seller
$\mathrm{PW}_{\mathrm{nar}}$	Loss percentage of produce *n* during transport from auctioneer to retail store
$\mathrm{PW}_{\mathrm{nae}}$	Loss percentage of produce *n* during transport from auctioneer to customer
$\mathrm{PW}_{\mathrm{nlr}}$	Loss percentage of produce *n* during transport from whole seller to retail store
$\mathrm{PW}_{\mathrm{nle}}$	Loss percentage of produce *n* during transport from whole seller to customer
C_n	Carbon dioxide emission rate of produce *n*

Other parameters

Q_{nf}	Capacity of farmer
Q_{ng}	Capacity of agent
Q_{na}	Capacity of auctioneer
Q_{nl}	Capacity of whole seller
Q_{nr}	Capacity of retail
Q_{nfg}	Supply quantity of produce *n* from farmer to agent
Q_{nfa}	Supply quantity of produce *n* from farmer to auctioneer
Q_{nfl}	Supply quantity of produce *n* from farmer to whole seller
Q_{nf}	Supply quantity of produce *n* from farmer to retail store
Q_{nfe}	Supply quantity of produce *n* from farmer to customer
Q_{nga}	Supply quantity of produce *n* from agent to auctioneer
Q_{ngl}	Supply quantity of produce *n* from agent to whole seller
Q_{ngr}	Supply quantity of produce *n* from agent to retail store

Q_{nge}	Supply quantity of produce *n* from agent to customer
Q_{nal}	Supply quantity of produce *n* from auctioneer to whole seller
Q_{nar}	Supply quantity of produce *n* from auctioneer to retail store
Q_{nae}	Supply quantity of produce *n* from auctioneer to customer
Q_{nlr}	Supply quantity of produce *n* from whole seller to retail store
Q_{nle}	Supply quantity of produce *n* from whole seller to customer
Q_{nre}	Supply quantity of produce *n* from retail to customer
Q_{ne}	Customer

Transport quantity of produce n

T_{nfg}	Transport quantity of produce *n* from farmer to agent
T_{nfa}	Transport quantity of produce *n* from farmer to auctioneer
T_{nfl}	Transport quantity of produce *n* from farmer to whole seller
T_{nfr}	Transport quantity of produce *n* from farmer to retail store
T_{nfe}	Transport quantity of produce *n* from farmer to customer
T_{nga}	Transport quantity of produce *n* from agent to auctioneer
T_{ngl}	Transport quantity of produce *n* from agent to whole seller
T_{ngr}	Transport quantity of produce *n* from agent to retail store
T_{nge}	Transport quantity of produce *n* from agent to customer
T_{nal}	Transport quantity of produce *n* from auctioneer to whole seller
T_{nar}	Transport quantity of produce *n* from auctioneer to retail store
T_{nae}	Transport quantity of produce *n* from auctioneer to customer
T_{nlr}	Transport quantity of produce *n* from whole seller to retail store
T_{nle}	Transport quantity of produce *n* from whole seller to customer

Wastage quantity of produce n

W_{nf}	Loss quantity of produce *n* at famer
W_{ng}	Loss quantity of produce *n* at agent
W_{na}	Loss quantity of produce *n* at auctioneer
W_{nl}	Loss quantity of produce *n* at whole seller
W_{nr}	Loss quantity of produce *n* at retail store
W_{nfg}	Loss of produce *n* during transport from farmer to agent
W_{nfa}	Loss of produce *n* during transport from farmer to auctioneer
W_{nfl}	Loss of produce *n* during transport from farmer to whole seller
W_{nfr}	Loss of produce *n* during transport from farmer to retail store
W_{nfe}	Loss of produce *n* during transport from farmer to customer
W_{nga}	Loss of produce *n* during transport from agent to auctioneer
W_{ngl}	Loss of produce *n* during transport from agent to whole seller
W_{ngr}	Loss of produce *n* during transport from agent to retail store
W_{nge}	Loss of produce *n* during transport from agent to customer
W_{nal}	Loss of produce *n* during transport from auctioneer to whole seller
W_{nar}	Loss of produce *n* during transport from auctioneer to retail store
W_{nae}	Loss of produce *n* during transport from auctioneer to customer
W_{nlr}	Loss of produce *n* during transport from whole seller to retail store
W_{nle}	Loss of produce *n* during transport from whole seller to customer

Carbon Dioxide Emission CO_2

C_{nf}	Carbon dioxide emission of produce *n* at farmer
C_{ng}	Carbon dioxide emission of produce *n* at agent
C_{na}	Carbon dioxide emission of produce *n* at auctioneer
C_{nl}	Carbon dioxide emission of produce *n* at whole seller
C_{nr}	Carbon dioxide emission of produce *n* at retail
C_{nfg}	Carbon dioxide emission of produce *n* at agent
C_{nfa}	Carbon dioxide emission of produce *n* from farmer to auctioneer
C_{nfl}	Carbon dioxide emission of produce *n* from farmer to whole seller

C_{nfr}	Carbon dioxide emission of produce *n* from farmer to retail store
C_{nfe}	Carbon dioxide emission of produce *n* from farmer to customer
C_{nga}	Carbon dioxide emission of produce *n* from agent to auctioneer
C_{ngl}	Carbon dioxide emission of produce *n* from agent to whole seller
C_{ngr}	Carbon dioxide emission of produce *n* from agent to retail store
C_{nge}	Carbon dioxide emission of produce *n* from agent to customer
C_{nal}	Carbon dioxide emission of produce *n* from auctioneer to whole seller
C_{nar}	Carbon dioxide emission of produce *n* from auctioneer to retail store
C_{nae}	Carbon dioxide emission of produce *n* from auctioneer to customer
C_{nlr}	Carbon dioxide emission of produce *n* from whole seller to retail store
C_{nle}	Carbon dioxide emission of produce *n* from whole seller to customer
C_{nre}	Carbon dioxide emission of produce *n* from retail to customer

Carbon dioxide Emission CO_2 produced by loss

CW_{nf}	Loss Carbon dioxide emission of produce *n* at farmer
CW_{ng}	Loss Carbon dioxide emission of produce *n* at agent
CW_{na}	Loss Carbon dioxide emission of produce *n* at auctioneer
CW_{nl}	Loss Carbon dioxide emission of produce *n* at whole seller
CW_{nr}	Loss Carbon dioxide emission of produce *n* at retail

CW_{nfg}	Loss Carbon dioxide emission of produce *n* at agent
CW_{nfa}	Loss Carbon dioxide emission of produce *n* from Farmer to auctioneer
CW_{nfl}	Loss Carbon dioxide emission of produce *n* from farmer to whole seller
CW_{nfr}	Loss Carbon dioxide emission of produce *n* from farmer to retail store
CW_{nfe}	Loss Carbon dioxide emission of produce *n* from farmer to customer
CW_{nga}	Loss Carbon dioxide emission of produce *n* from agent to auctioneer
CW_{ngl}	Loss Carbon dioxide emission of produce *n* from agent to whole seller
CW_{ngr}	Loss Carbon dioxide emission of produce *n* from agent to retail store
CW_{nge}	Loss Carbon dioxide emission of produce *n* from agent to customer
C_{nal}	Carbon dioxide emission of produce *n* from auctioneer to whole seller
C_{nar}	Carbon dioxide emission of produce *n* from auctioneer to retail store
C_{nae}	Carbon dioxide emission of produce *n* from auctioneer to customer
CW_{nlr}	Loss Carbon dioxide emission of produce *n* from whole seller to retail store
CW_{nle}	Loss Carbon dioxide emission of produce *n* from whole seller to customer
CW_{nre}	Loss Carbon dioxide emission of produce *n* from retail to customer

1. Introduction

As the population increases, agriculture production and supply must increase to meet the increasing demand (Alexandratos and Bruinsma, 2012). In a supply chain (SC), increasing demand can be satisfied only by efficient logistics (Lummus *et al.*, 2001). Hence, agriculture commodity has to be transported efficiently from farmers to the consuming regions, where agriculture supply chain management (ASCM) plays a prominent role (Ahumada and Villalobos, 2009; Etemadnia *et al.*, 2015). Traditionally, ASCM is viewed as a process where the agricultural produces are converted into value-added final products, and then delivered to the consumer and this process involves harvesting and consumption of the natural resources (Beamon, 1999). It is consequential to note that environmental sustainability and food security have become important issues to business practice (Kumar and Chandrakar, 2012).

The strategy of improving environmental quality reduces poverty, and brings about economic growth, with resultant improvements in health (Bhateja *et al.*, 2011; Jang and Klein, 2011). According to Syahruddin and Kalchschmidt (2011), in recent years, several measures have been made toward improving environmental hazards in ASCM in the developed countries, with the developing countries like India are yet to initiate this process. The Indian ASCM ignores some of the important issues like environmental damage, food safety, social and sustainability issues, which are driven by external factors such as customer and market demand (Syahruddin and Kalchschmidt, 2011). The environmental issues of ASCM are caused by the post-harvest losses (PHL) occurring at various levels of the SC (Hodges *et al.*, 2011).

If the PHL are reduced, then the cost of agriculture produces will reduce instantly (Murthy *et al.*, 2007). Around 30-40 percent of total produce gets wasted in India due to improper ASCM (Negi and Anand, 2015b). These PHL cannot be reduced without improving the infrastructure and awareness of the intermediaries in the ASCM on PHL (Parfitt *et al.*, 2010; Ratinger, 2013). Therefore, it is most important to plan the supply and estimate PHL quantity at every level in the agricultural SC. The supply and PHL quantity of Indian traditional ASCM can be optimized and planned by mathematical modeling (Mula *et al.*, 2010).

The mathematical model of Indian traditional ASCM is complicated, because intermediaries increased the echelon of traditional ASCM (Dalei and Dutta, 2015). Figure 1 shows the self-descriptive way of traditional ASCM that concise of many intermediaries and direct market. The purpose of this paper is to construct an optimum mathematical planning model for complex Indian traditional ASCM, and adopt a meta-heuristic genetic algorithm (GA) to solve this model. The objectives of this paper are to optimize the supply structure to reduce PHL and modify the transportation method to reduce the environmental impacts.

2. Literature review

In the recent years, there has been an increased attention in using GA to solve single- and multi-objective problems in production and operations management (Dimopoulos and Zalzala, 2000). GA is chosen as it is the most popular meta-heuristic algorithm within the context of SC planning and optimization (Fahimnia *et al.*, In press). This paper uses the GA as a meta-heuristic algorithm to optimize the supply structure of the Indian ASCM to reduce the PHL. According to Shukla and Jharkharia (2013), very little attention is given to the reduction of PHL. They listed various factors affecting ASCM as globalization, technological innovations, trade agreements, consumer awareness, environmental concerns, etc. In addition to that the PHL transpires due to many intermediaries. The PHL occur in the ASCM because they relate to wasteful behavior of intermediaries, retailers and customers (Parfitt *et al.*, 2010; Gustavsson *et al.*, 2011).

Elimination of intermediaries from the ASCM will improve its efficiency (Jansen, 1996). However, few authors (Klerkx and Leeuwis, 2008; Amrutlal, 2010) suggested to integrate the intermediaries in ASCM to optimize their supply structure. Therefore, in this research paper, intermediaries are retained for SC modeling for optimizing the SC while estimating the PHL and its CO_2 emission. Since recent years, many researchers have been focusing on environmental sustainability (Vorst *et al.*, 2010) because the agriculture sector is contributing 14 percent in total toward global CO_2 emissions (UNEP, 2012); if the agriculture sector's emission gets reduced, consequently, the overall emission will reduce (Blok *et al.*, 2001). The CO_2 emission sources in the agriculture sector are direct emission and indirect emission (Schils *et al.*, 2005).

The emission of CO_2 by the produces or land use is direct emission and the emission of CO_2 by the fuel burnt during transportation is indirect emission (Schils *et al.*, 2005). Indirect emission by the fuel burnt during transportation has attracted attention from many agriculture and automobile researchers. The less concentrated area in indirect emission

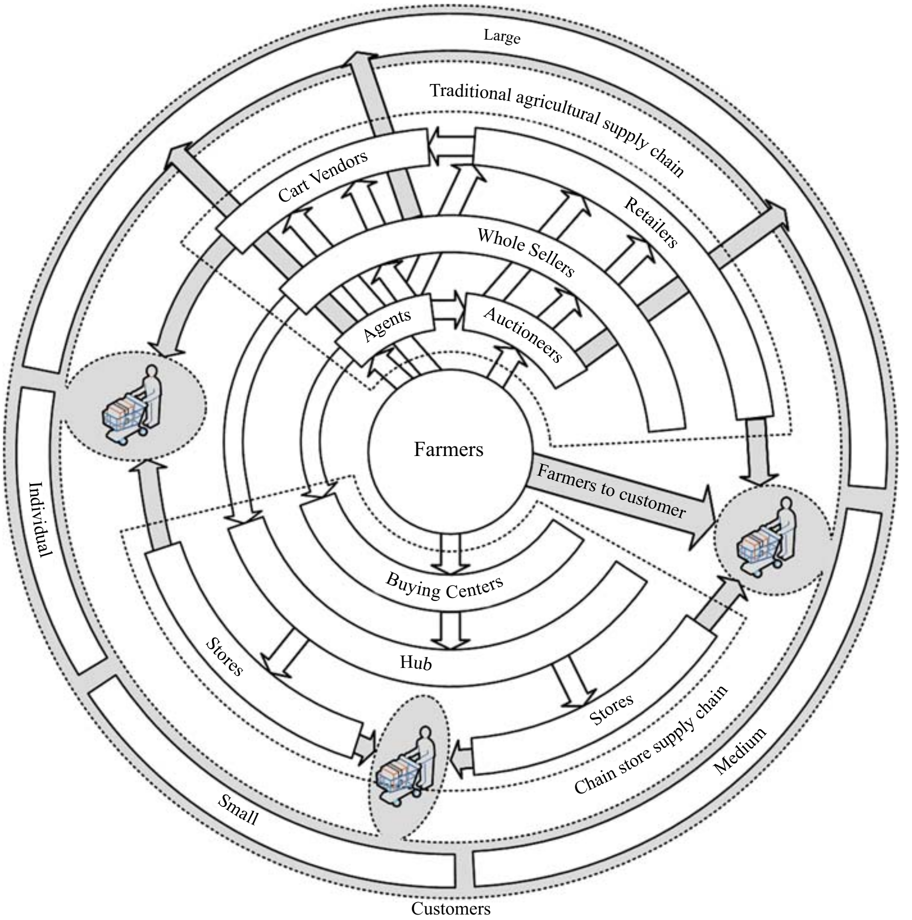

Figure 1.
Indian agriculture marketing

includes respiration releases of CO_2 after produces have been harvested (Blok *et al.*, 2001). Proper packing can maintain the quality of the produce as the CO_2 generated while packing is at an elevated level (Kader and Rolle, 2004). All agriculture produces should be properly packed before transportation.

2.1 Indian agriculture SC

The Indian ASCM has become more complex and improper due to the imbalance between demand and supply (Joshi *et al.*, 2009). This complexity of ASCM and improper handling by the intermediaries plays a major role in ASCM and its PHL (Negi and Anand, 2015b). However, Indian traditional ASCM has more potential to satisfy the demand than a chain store SC; hence, it needs more research concentration (Bala, 2014). Figure 1 shows that Indian ASCM consists of two SCs: first is private retailers following the chain store SC, and second is traditional ASCM which includes many intermediaries like agents, auctioneers, wholesalers and retailers (Gigler *et al.*, 2002; Negi and Anand, 2015a, b).

The produces, which are produced by the Indian farmers, take two possible routes, namely, the agents and auctioneers, and from there, produces move to customer through whole sellers and retailers. This method is called traditional ASCM. Alternatively, depending on the quantity and cost, the produces may change the route to reach the customer directly through whole sellers and retailers in traditional ASCM (Negi and Anand, 2015a, b). The most efficient and less-practiced route is the direct market. In direct market, the produces reach the customer directly without any intermediaries like agents, auctioneers, whole sellers and retailers (Rajkumar and Jacob, 2010). The Indian farmers mostly practice traditional ASCM, which supply the agriculture products to the consumer through the intermediaries (Bahinipati, 2014).

The past research works clearly indicate the need for planning and optimizing the Indian ASCM. Since Indian agriculture transportation transports the produces through open craters (FAO, 2005; Vigneault *et al.*, 2009; Bhushan, 2013), it leads to continuous emission of CO_2 through respiration of the agricultural produces (Snowden, 2010). Therefore, this paper identifies an alternate transportation method to reduce the CO_2 emission and investigates PHL from field to plate of selected agriculture produces.

3. Adopted approach

The Indian traditional ASCM is modeled by considering all intermediaries and assumes PHL in various percentages. The percentages of PHL of different produces were estimated by many researchers such as Gangwar *et al.* (2007) and Sharma and Singh (2011). Those PHL percentages lie in between 10 and 50 percent. Therefore, the assumed percentage of losses at the first level of ASCM is 10 percent, and ends at 50 percent with an increment of 10 percent, because 10 is the lowest percentage of loss and 50 is the highest percentage of loss. In this paper, loss is nothing but non-consumed produces, which is a previous stage of degradation. According to respiration the degraded and non-consumed produces are different. Respiration was measured through the experimental setup to calculate the CO_2 emission as shown in Figure 3.

The CO_2 emitted by agricultural produces through the respiration was estimated for those PHL and also the CO_2 emissions of all undamaged supplied products were measured. The respiration of selected agriculture produces was measured in the non-degraded condition of the produce. The agricultural produces like potato and tomato were purposively selected based on their compatibility with ASCM and availability. The CO_2 evolutions of potato and tomato were measured using the respiration to estimate the respiration rate. The CO_2 evolution is applied to the overall production of respective produces to measure the overall CO_2 emission. These CO_2 evolutions were applied to the PHL quantity to measure its CO_2 emission. Therefore, this research paper formulates a mathematical model to plan the supply, estimate PHL and CO_2 emission for various optimized supplies.

3.1 Loss and emission source proposed model

Many PHL are available in this traditional ASCM like packing and transportation (Gigler *et al.*, 2002; Sharma and Singh, 2011); these PHL were intended by a mathematical model along with overall losses and loss of CO_2 emission. Figure 2 classifies Indian traditional ASCM into five different SC models and shows the PHL and CO_2 emission sources at every level. PHL are shown in Figure 2 as loss, which happens during transportation. In addition, there are two CO_2 emission sources considered in this paper which are unconsumed and fresh produces emission.

Therefore, the PHL and CO_2 emissions are high in ASCM due to the presence of multiple supply stages or the presence of intermediaries such as agents, auctioneers, whole sellers, and retailers. The produces are transported from farmer to customer through these intermediaries by open transportation in trucks (Ashby, 2008; Rajkumar and Jacob, 2010). As proper loading and unloading is not followed in the open truck transportation (Vigneault *et al.*, 2009), it leads to exploitation of farmers by the intermediaries (Ashby, 2008; Rajkumar and Jacob, 2010).

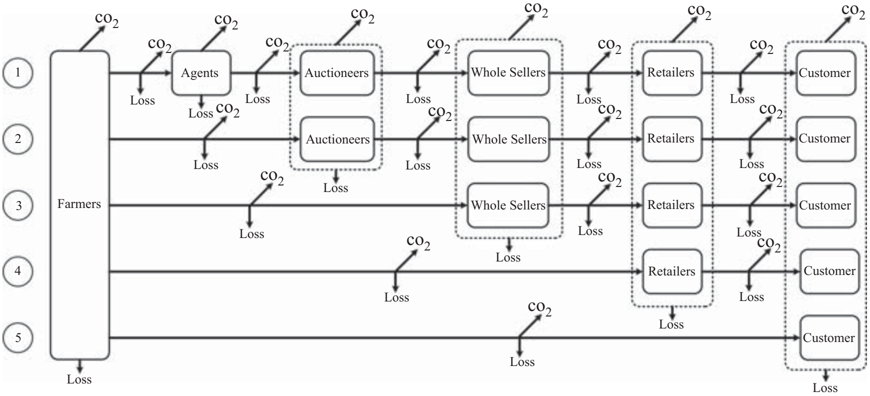

Figure 2.
Different traditional agriculture supply chain

The agricultural produces respire continuously during open truck transportation. The produces start respiration immediately after harvest until it is consumed or degraded. The static and closed method is used to measure the CO_2 emission released by produces during respiration (Yahia, 2009). Experiments were conducted individually and also mixed together to know how much CO_2 is produced. During this experiment, the produces are experimented in a closed container and respired for six hours.

3.2 Experimental setup

The agriculture produces are selected based on local production and are grouped based on their storage properties. The O_2 consumption and CO_2 evolution are measured by the static method in atmospheric temperature without any external aid. The static method can measure the respiration in a closed container (Fonseca *et al.*, 2002). The respiration of the selected agriculture produces is measured by gas sensors for the sample time of one hour and six hours. In this static method, the relative humidity of the selected produces for the reason of respiration produces water droplets after six hours; therefore, the experiments were conducted for six hours.

The sensors used in this experiment are the Vernier O_2 sensor in the range of 0-27 percent (0-270 ppt), the Vernier CO_2 sensor in the low range: 0 to 10,000 ppm and high range: 0 to 100,000 ppm, the Vernier relative humidity sensor in the range of 0 to 95 percent, and the *t*-type thermocouple in the range of 0 to 350°C. These sensors were interfaced with a computer through national instrument ELVIS II. Figure 3 shows the experimental setup. The O_2 sensor value changes with respect to the relative humidity value; therefore, the relative humidity was measured for O_2 sensor. Two produces, namely, potato and tomato were selected to measure their respiration levels as individual produces as well as mixed quantities were studied for their O_2 consumption and CO_2 evolution.

Initially, the individual agriculture produces' respiration rates were measured by the experimental setup as shown in Figure 3. In addition, two vegetables were combined and measured by this experimental setup. The agricultural produces like potato, tomato, and their combinations were experimented in the weight of 100, 200, and 300 g. Mixing of samples was based on produce selection and their compatibility. This comparative study of individual and mixed produces shows the CO_2 evolution variations along with O_2 consumption. Through this way, the CO_2 respiration rate was averaged and measured. Subsequently, those values were applied in the mathematical model to estimate the supply, transport loss quantity and CO_2 emission.

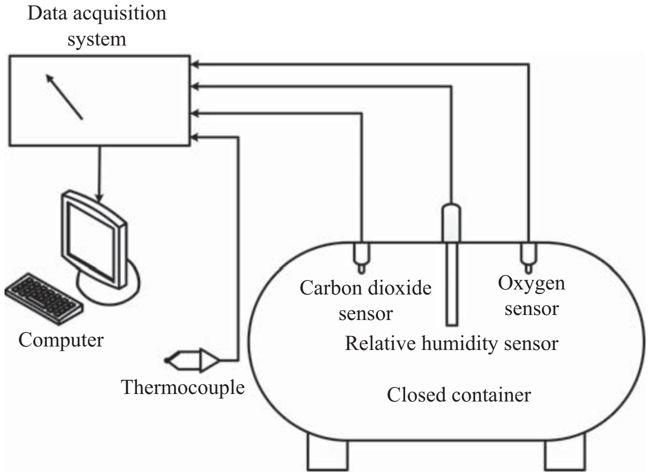

Figure 3. Experimental setup to study CO_2

3.3 Model description

An SC planning model is used here to optimize the supply between each stage and estimate the loss and CO_2 emission. This planning model considered that the demand D_n of the nth produce is equal to the farmer's production. Succeedingly, Q_n is the capacity or supply of any stage of the nth produce. Likewise, T_n, W_n, and C_n are the transport, loss quantity and CO_2 emission of the nth produce of the concerned stage, respectively. The decision variables are the percentage of supply (PQ_n) and loss (PW_n) quantities, which decide the efficiency of the whole SC in this model. The decision variables are in percentage so that they can estimate the value from the production quantity.

These decision variables are used to calculate the quantity supply and quantity loss at each stage. Equation (1) can estimate the loss at the farmer's end by applying the farmer's loss percentage PW_{nf}, and then the supply capacity of the farmers can be measured by Equation (2). Likewise, the supply capacity of agents, auctioneers, whole sellers and retailers can be measured by Equations (3)-(6), respectively. Equations (7) to (21) measure the supply quantities of each stage to other consequent stages. The total supply quantities were estimated by summing all the supply quantities; likewise, the total loss quantities were estimated by adding all the loss quantities. The loss quantities can be measured by Equations (36) to (53). If the loss is eliminated from the previous supply quantity, then that is nothing but the transported quantity (T_n).

Equations (22) to (35) calculate transported quantities between each stage. The transported quantities were used to measure the total quantity transported and total transportation losses. The total loss and supply quantities are shown in (54) and (55), respectively. The total CO_2 consumption of loss quantities can be measured by Equation (56). The total supply and loss quantities were large in size; therefore, those large equations were solved algebraically by the MATLAB software package. The supply quantity needs to be optimized to gain higher supply and lower losses. The supply quantity is optimized through GA. Equations (57) to (69) are constraints for the models. In that first five equations are nonlinear constraints. Second five equations are linear constraints and remaining equations are upper and lower bound.

The first five nonlinear equations are the sum of all the supply quantities, which are supplied from the farmer to other stages and should be equal to the total demand or production. In the second five equations, the quantities which are supplied from the farmer to other stages should be greater than supply quantities of each stage to other stages.

The supply quantity which is supplied by the retailer to the customer should be less than the sum of supply quantities of the farmer to the retailer and other stages to the customer. In linear equations, first is the sum of all the percentages of supply quantities supplied from the farmer to other stages which should be equal to 100; likewise, the remaining percentage of supply quantities, supplied from each stage to other stages, should be less than or equal to 100. Finally, the bound constraints should be defined for all the objectives while solving an objective using GA.

There are three bound constraints: loss, supply and CO_2 emission. These three constraints should be greater than 0; likewise, the loss should be less than demand, the supply should be less than or equal to demand, and CO_2 emission should be less than the overall emission. Based on the above constraints, the supply structure of Indian TASCM is optimized. These optimized supply structures are shown in Table I. The loss, supply and CO_2 emission quantities are estimated by Equations (54)-(56), respectively, based on the optimized supply structure:

$$W_{\mathrm{nf}} = D_n \times \mathrm{PW}_{\mathrm{nf}} \tag{1}$$

$$Q_{\mathrm{nf}} = D_n - W_{\mathrm{nf}} \tag{2}$$

$$Q_{\mathrm{ng}} = T_{\mathrm{nfg}} - W_{\mathrm{ng}} \tag{3}$$

$$Q_{\mathrm{na}} = \left[T_{\mathrm{nfa}} + T_{\mathrm{nga}}\right] - W_{\mathrm{na}} \tag{4}$$

$$Q_{\mathrm{nl}} = \left[T_{\mathrm{nfl}} + T_{\mathrm{ngl}} + T_{\mathrm{nal}}\right] - W_{\mathrm{nl}} \tag{5}$$

$$Q_{\mathrm{nr}} = \left[T_{\mathrm{nfr}} + T_{\mathrm{ngr}} + T_{\mathrm{nar}} + T_{\mathrm{nlr}}\right] - W_{\mathrm{nr}} \tag{6}$$

$$Q_{\mathrm{nfg}} = Q_{\mathrm{nf}} \times \mathrm{PQ}_{\mathrm{nfg}} \tag{7}$$

$$Q_{\mathrm{nfa}} = Q_{\mathrm{nf}} \times \mathrm{PQ}_{\mathrm{nfa}} \tag{8}$$

Table I.
Supply structures

		Supply structures	
	Type-1 in %	Type-2 in %	Type-3 in %
PQ_{nfg}	20	20	0
PQ_{nfa}	20	20	0
PQ_{nfl}	20	20	0
PQ_{nfr}	20	20	0
PQ_{nfe}	20	20	100
PQ_{nga}	25	0	0
PQ_{ngl}	25	0	0
PQ_{ngr}	25	0	0
PQ_{nge}	25	100	0
PQ_{nal}	30	0	0
PQ_{nar}	30	0	0
PQ_{nae}	40	100	0
PQ_{nlr}	50	0	0
PQ_{nle}	50	0	0
PQ_{nre}	100	100	0

$$Q_{\mathrm{nfl}} = Q_{\mathrm{nf}} \times \mathrm{PQ}_{\mathrm{nfl}} \tag{9}$$

$$Q_{\mathrm{nfr}} = Q_{\mathrm{nf}} \times \mathrm{PQ}_{\mathrm{nfr}} \tag{10}$$

$$Q_{\mathrm{nfe}} = Q_{\mathrm{nf}} \times \mathrm{PQ}_{\mathrm{nfe}} \tag{11}$$

$$Q_{\mathrm{nga}} = Q_{\mathrm{ng}} \times \mathrm{PQ}_{\mathrm{nga}} \tag{12}$$

$$Q_{\mathrm{ngl}} = Q_{\mathrm{ng}} \times \mathrm{PQ}_{\mathrm{ngl}} \tag{13}$$

$$Q_{\mathrm{ngr}} = Q_{\mathrm{ng}} \times \mathrm{PQ}_{\mathrm{ngr}} \tag{14}$$

$$Q_{\mathrm{nge}} = Q_{\mathrm{ng}} \times \mathrm{PQ}_{\mathrm{nge}} \tag{15}$$

$$Q_{\mathrm{nal}} = Q_{\mathrm{na}} \times \mathrm{PQ}_{\mathrm{nal}} \tag{16}$$

$$Q_{\mathrm{nar}} = Q_{\mathrm{na}} \times \mathrm{PQ}_{\mathrm{nar}} \tag{17}$$

$$Q_{\mathrm{nae}} = Q_{\mathrm{na}} \times \mathrm{PQ}_{\mathrm{nae}} \tag{18}$$

$$Q_{\mathrm{nlr}} = Q_{\mathrm{nl}} \times \mathrm{PQ}_{\mathrm{nlr}} \tag{19}$$

$$Q_{\mathrm{nle}} = Q_{\mathrm{nl}} \times \mathrm{PQ}_{\mathrm{nle}} \tag{20}$$

$$Q_{\mathrm{nre}} = Q_{\mathrm{nr}} \times \mathrm{PQ}_{\mathrm{nre}} \tag{21}$$

$$T_{\mathrm{nfg}} = Q_{\mathrm{nfg}} - W_{\mathrm{nfg}} \tag{22}$$

$$T_{\mathrm{nfa}} = Q_{\mathrm{nfa}} - W_{\mathrm{nfa}} \tag{23}$$

$$T_{\mathrm{nfl}} = Q_{\mathrm{nfl}} - W_{\mathrm{nfl}} \tag{24}$$

$$T_{\mathrm{nfr}} = Q_{\mathrm{nfr}} - W_{\mathrm{nfr}} \tag{25}$$

$$T_{\mathrm{nfe}} = Q_{\mathrm{nfe}} - W_{\mathrm{nfe}} \tag{26}$$

$$T_{\mathrm{nga}} = Q_{\mathrm{nga}} - W_{\mathrm{nga}} \tag{27}$$

$$T_{\mathrm{ngl}} = Q_{\mathrm{ngl}} - W_{\mathrm{ngl}} \tag{28}$$

$$T_{\mathrm{ngr}} = Q_{\mathrm{ngr}} - W_{\mathrm{ngr}} \tag{29}$$

$$T_{\mathrm{nge}} = Q_{\mathrm{nge}} - W_{\mathrm{nge}} \tag{30}$$

$$T_{\mathrm{nal}} = Q_{\mathrm{nal}} - W_{\mathrm{nal}} \tag{31}$$

$$T_{\mathrm{nar}} = Q_{\mathrm{nar}} - W_{\mathrm{nar}} \tag{32}$$

$$T_{\mathrm{nae}} = Q_{\mathrm{nae}} - W_{\mathrm{nae}} \tag{33}$$

$$T_{\mathrm{nlr}} = Q_{\mathrm{nlr}} - W_{\mathrm{nlr}} \tag{34}$$

$$T_{\mathrm{nle}} = Q_{\mathrm{nle}} - W_{\mathrm{nle}} \tag{35}$$

$$W_{\mathrm{ng}} = T_{\mathrm{nfg}} \times \mathrm{PW}_{\mathrm{ng}} \tag{36}$$

$$W_{\mathrm{na}} = \left[T_{\mathrm{nfa}} + T_{\mathrm{nga}}\right] \times \mathrm{PW}_{\mathrm{na}} \tag{37}$$

$$W_{\mathrm{nl}} = \left[T_{\mathrm{nfl}} + T_{\mathrm{ngl}} + T_{\mathrm{nal}}\right] \times \mathrm{PW}_{\mathrm{nl}} \tag{38}$$

$$W_{\mathrm{nr}} = \left[T_{\mathrm{nfr}} + T_{\mathrm{ngr}} + T_{\mathrm{nar}} + T_{\mathrm{nlr}}\right] \times \mathrm{PW}_{\mathrm{nr}} \tag{39}$$

$$W_{\mathrm{nfg}} = Q_{\mathrm{nfg}} \times \mathrm{PW}_{\mathrm{nfg}} \tag{40}$$

$$W_{\mathrm{nfa}} = Q_{\mathrm{nfa}} \times \mathrm{PW}_{\mathrm{nfa}} \tag{41}$$

$$W_{\mathrm{nfl}} = Q_{\mathrm{nfl}} \times \mathrm{PW}_{\mathrm{nfl}} \tag{42}$$

$$W_{\mathrm{nfr}} = Q_{\mathrm{nfr}} \times \mathrm{PW}_{\mathrm{nfr}} \tag{43}$$

$$W_{\mathrm{nfe}} = Q_{\mathrm{nfe}} \times \mathrm{PW}_{\mathrm{nfe}} \tag{44}$$

$$W_{\mathrm{nga}} = Q_{\mathrm{nga}} \times \mathrm{PW}_{\mathrm{nga}} \tag{45}$$

$$W_{\mathrm{ngl}} = Q_{\mathrm{ngl}} \times \mathrm{PW}_{\mathrm{ngl}} \tag{46}$$

$$W_{\mathrm{ngr}} = Q_{\mathrm{ngr}} \times \mathrm{PW}_{\mathrm{ngr}} \tag{47}$$

$$W_{\mathrm{nge}} = Q_{\mathrm{nge}} \times \mathrm{PW}_{\mathrm{nge}} \tag{48}$$

$$W_{\mathrm{nal}} = Q_{\mathrm{nal}} \times \mathrm{PW}_{\mathrm{nal}} \tag{49}$$

$$W_{\mathrm{nar}} = Q_{\mathrm{nar}} \times \mathrm{PW}_{\mathrm{nar}} \tag{50}$$

$$W_{\mathrm{nae}} = Q_{\mathrm{nae}} \times \mathrm{PW}_{\mathrm{nae}} \tag{51}$$

$$W_{\mathrm{nlr}} = Q_{\mathrm{nlr}} \times \mathrm{PW}_{\mathrm{nlr}} \tag{52}$$

$$W_{\mathrm{nle}} = Q_{\mathrm{nle}} \times \mathrm{PW}_{\mathrm{nle}} \tag{53}$$

Objective 1 – total loss:

$$\begin{aligned}\min f(W) = {} & \sum_n\sum_f W_{\mathrm{nf}} + \sum_n\sum_g W_{\mathrm{ng}} + \sum_n\sum_a W_{\mathrm{na}} + \sum_n\sum_l W_{\mathrm{nl}} + \sum_n\sum_r W_{\mathrm{nr}} \\ & + \sum_n\sum_f\sum_g W_{\mathrm{nfg}} + \sum_n\sum_f\sum_a W_{\mathrm{nfa}} + \sum_n\sum_f\sum_l W_{\mathrm{nfl}} \\ & + \sum_n\sum_f\sum_r W_{\mathrm{nfr}} + \sum_n\sum_f\sum_e W_{\mathrm{nfe}} + \sum_n\sum_g\sum_a W_{\mathrm{nga}} \\ & + \sum_n\sum_g\sum_l W_{\mathrm{ngl}} + \sum_n\sum_g\sum_r W_{\mathrm{ngr}} + \sum_n\sum_g\sum_e W_{\mathrm{nge}} \\ & + \sum_n\sum_a\sum_l W_{\mathrm{nal}} + \sum_n\sum_a\sum_r W_{\mathrm{nar}} + \sum_n\sum_a\sum_e W_{\mathrm{nae}} \\ & + \sum_n\sum_l\sum_r W_{\mathrm{nlr}} + \sum_n\sum_l\sum_e W_{\mathrm{nle}} + \sum_n\sum_r\sum_e W_{\mathrm{nre}}\end{aligned} \tag{54}$$

Objective 2 – total supply:

$$\begin{aligned}\max f(Q) = {} & \sum_n\sum_f Q_{\mathrm{nf}} + \sum_n\sum_g Q_{\mathrm{ng}} + \sum_n\sum_a Q_{\mathrm{na}} + \sum_n\sum_l Q_{\mathrm{nl}} + \sum_n\sum_r Q_{\mathrm{nr}} \\ & + \sum_n\sum_f\sum_g Q_{\mathrm{nfg}} + \sum_n\sum_f\sum_a Q_{\mathrm{nfa}} + \sum_n\sum_f\sum_l Q_{\mathrm{nfl}} + \sum_n\sum_f\sum_r Q_{\mathrm{nfr}} \\ & + \sum_n\sum_f\sum_e Q_{\mathrm{nfe}} + \sum_n\sum_g\sum_a Q_{\mathrm{nga}} + \sum_n\sum_g\sum_l Q_{\mathrm{ngl}} + \sum_n\sum_g\sum_r Q_{\mathrm{ngr}} \\ & + \sum_n\sum_g\sum_e Q_{\mathrm{nge}} + \sum_n\sum_a\sum_l Q_{\mathrm{nal}} + \sum_n\sum_a\sum_r Q_{\mathrm{nar}} + \sum_n\sum_a\sum_e Q_{\mathrm{nae}} \\ & + \sum_n\sum_l\sum_r Q_{\mathrm{nlr}} + \sum_n\sum_l\sum_e Q_{\mathrm{nle}} + \sum_n\sum_r\sum_e Q_{\mathrm{nre}}\end{aligned} \tag{55}$$

Objective 3 – total carbon dioxide produced by loss:

$$\begin{aligned}\min f(\mathrm{CW}) = {} & \sum_n\sum_f \mathrm{CW}_{\mathrm{nf}} + \sum_n\sum_g \mathrm{CW}_{\mathrm{ng}} + \sum_n\sum_a \mathrm{CW}_{\mathrm{na}} + \sum_n\sum_l \mathrm{CW}_{\mathrm{nl}} \\ & + \sum_n\sum_r \mathrm{CW}_{\mathrm{nr}} + \sum_n\sum_f\sum_g \mathrm{CW}_{\mathrm{nfg}} + \sum_n\sum_f\sum_a \mathrm{CW}_{\mathrm{nfa}} \\ & + \sum_n\sum_f\sum_l \mathrm{CW}_{\mathrm{nfl}} + \sum_n\sum_f\sum_r \mathrm{CW}_{\mathrm{nfr}} + \sum_n\sum_f\sum_e \mathrm{CW}_{\mathrm{nfe}} \\ & + \sum_n\sum_g\sum_a \mathrm{CW}_{\mathrm{nga}} + \sum_n\sum_g\sum_l \mathrm{CW}_{\mathrm{ngl}} + \sum_n\sum_g\sum_r \mathrm{CW}_{\mathrm{ngr}} \\ & + \sum_n\sum_g\sum_e \mathrm{CW}_{\mathrm{nge}} + \sum_n\sum_a\sum_l \mathrm{CW}_{\mathrm{nal}} + \sum_n\sum_a\sum_r \mathrm{CW}_{\mathrm{nar}}\end{aligned}$$

$$+\sum_n\sum_a\sum_e \mathrm{CW}_{\mathrm{nae}}+\sum_n\sum_l\sum_r \mathrm{CW}_{\mathrm{nlr}}+\sum_n\sum_l\sum_e \mathrm{CW}_{\mathrm{nle}}$$

$$+\sum_n\sum_r\sum_e \mathrm{CW}_{\mathrm{nre}} \tag{56}$$

Nonlinear constraints:

$$Q_{\mathrm{nfg}}+Q_{\mathrm{nfa}}+Q_{\mathrm{nfl}}+Q_{\mathrm{nfr}}+Q_{\mathrm{nfe}} = D_n \tag{57}$$

$$Q_{\mathrm{nga}}+Q_{\mathrm{ngl}}+Q_{\mathrm{ngr}}+Q_{\mathrm{nge}} \leqslant Q_{\mathrm{nfg}} \tag{58}$$

$$Q_{\mathrm{nal}}+ Q_{\mathrm{nar}}+Q_{\mathrm{nae}} \leqslant Q_{\mathrm{nfa}}+ Q_{\mathrm{nga}} \tag{59}$$

$$Q_{\mathrm{nlr}}+Q_{\mathrm{nle}} \leqslant Q_{\mathrm{nfl}}+Q_{\mathrm{ngl}}+Q_{\mathrm{nal}} \tag{60}$$

$$Q_{\mathrm{nre}} \leqslant Q_{\mathrm{nfr}}+Q_{\mathrm{nge}}+Q_{\mathrm{nae}}+Q_{\mathrm{nle}} \tag{61}$$

Linear constraints:

$$\mathrm{PQ}_{\mathrm{nfg}}+\mathrm{PQ}_{\mathrm{nfa}}+\mathrm{PQ}_{\mathrm{nfl}}+\mathrm{PQ}_{\mathrm{nfr}}+\mathrm{PQ}_{\mathrm{nfe}} = 100 \tag{62}$$

$$\mathrm{PQ}_{\mathrm{nga}}+\mathrm{PQ}_{\mathrm{ngl}}+\mathrm{PQ}_{\mathrm{ngr}}+\mathrm{PQ}_{\mathrm{nge}} \leqslant 100 \tag{63}$$

$$\mathrm{PQ}_{\mathrm{nal}}+\mathrm{PQ}_{\mathrm{nar}}+\mathrm{PQ}_{\mathrm{nae}} \leqslant 100 \tag{64}$$

$$\mathrm{PQ}_{\mathrm{nlr}}+\mathrm{PQ}_{\mathrm{nle}} \leqslant 100 \tag{65}$$

$$\mathrm{PQ}_{\mathrm{nre}} \leqslant 100 \tag{66}$$

Bound:

$$0 \leqslant W < D_n \tag{67}$$

$$0 \leqslant Q \leqslant D_n \tag{68}$$

$$0 \leqslant \mathrm{CW} < D_n \times C_n \tag{69}$$

3.4 Proposed GA

Type 3 supply structure is optimized by GA. The GA solves the mathematical model using the MATLAB R2014a optimization tool box. The traditional optimization and search algorithms are not good enough to solve large SC problems (Kannan *et al.*, 2010). So this research paper chooses the GA because this is inspired by biological evolution and works based on survival of the fittest. GA is the stochastic search algorithm that works iteratively on a population, carrying out a search directed by the fitness of each solution (Xie and Dong, 2002). This GA is more flexible with objective function and not depends on any priori hypotheses (Naso *et al.*, 2007). In this paper, the optimization toolbox is used to run the GA solver.

There are 13 decision variables in this modeling; the GA uses the binary decoding to proceed with the problem.

There are different terms that are specified for the purpose of optimization. Before specifying certain values for each of these terms, all of them were tested with regard to the accuracy of the results. The selected and used MATLAB prescribed terms in the GA toolbox for optimization are shown in the flow chart. The GA starts with defining objective function and constraints as described in Section 3.3. Then double vector population and constraint-dependent creation function were applied for constraints. The initial population, scores and ranges are not required to change from default values, because the feasible solution is obtained from default values. Rank scaling is applied, because ranking automatically introduces a uniform scaling across the population and also rank fitness scaling removes the effect of the spread of the raw scores.

Stochastic uniform reproduction is applied as a selection function, and then the default elite count and crossover fraction is applied in reproduction. The constraint-dependent crossover and mutation is applied, in addition to the optimization toolbox, which applies adaptive feasible mutation, when constraints were present; likewise. if linear constraints are present, then the optimization toolbox chooses intermediate crossover function. In terms of migration, the forward direction was applied with default fraction and interval. This optimization toolbox ends when the optimized supply structure is obtained; it is described in Section 4.1 (Figure 4).

4. Results and discussions

The mathematical model is used to plan an optimized supply structure to estimate loss and CO_2 emission of Indian traditional ASCM. The previous researchers such as Gangwar *et al.* (2007) and Sharma and Singh (2011) calculated PHL for every level of ASCM, but they did

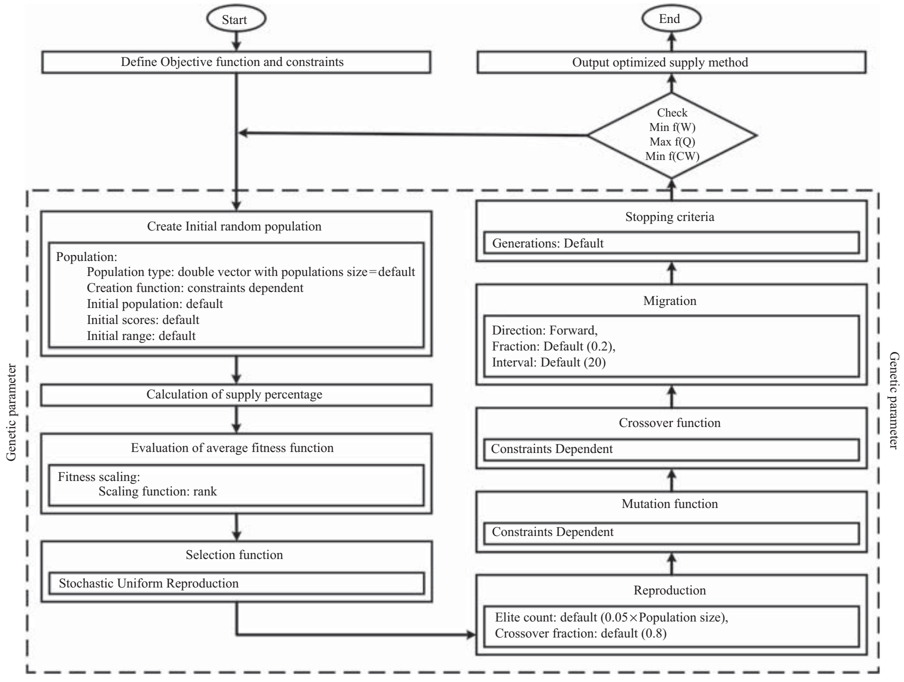

Figure 4.
Genetic algorithm flow chart

not consider the environmental impacts. Therefore, the CO_2 emissions of supply and loss were estimated through the respiration rate, which is measured for open and closed transportation of the selected produces such as potato, tomato and its combination.

4.1 *Optimization of supply*

This model is specifically used to plan the supply, estimate loss and CO_2 emission by demand or production of produces. The 13 nomenclature and 36 decision variables are described in the topic of nomenclature. The decision variables are nothing but supply quantity percentage and loss quantity percentage at each of the stages. These percentages are the input for mathematical modeling to estimate the loss and CO_2 emissions. The percentage of supply quantities of each stage like farmers to an agent is described in nomenclature and the values are shown in first column of Table I. The type 1, type 2 and type 3 columns are three different supply structures which are optimized.

The supply quantities are optimized through GA using the MATLAB R2014a optimization toolbox. Table I displays three optimized values which are called optimized supply structures. These supply structures are optimized to supply the agriculture produces to the customer through various stages. Among various supply structures, type 3 is the most optimized supply structure because this eliminates all the intermediaries. According to Neven *et al.* (2009) cooperative market is most efficient than other direct market or chain store market. Therefore, the supply structure type 1 is the most feasible option, because this method includes all the stages of ASCM. Succeeding, the supply structure type 2 supplies produces from the farmer to customer through other intermediaries directly, therefore this eliminates the supply between intermediaries.

These supply structures are applied in the mathematical model to calculate PHL and CO_2 emission. The PHL was measured by assuming loss percentage and CO_2 emissions were measured by measuring the respiration rate of produces and their group. The quantities of selected agriculture produces were identified and are shown in Table II. The agriculture produces have to be supplied to the customers to satisfy their demand without affecting the environment.

4.2 *Calculation of overall CO_2 emission*

The respiration rates of CO_2 of open and closed transportation were measured and shown in Table II. It comprises a year, production quantity of produces, as well as CO_2 emission produced by respiration of agriculture produces during open and closed transportation. Succeeding that, the respiration rate of CO_2 was applied to quantity of production to

Table II.
CO_2 respiration rate and CO_2 produced by respiration

		Production	Closed		Open		Difference
Produces	Year	In Kg	Respiration rate ml CO_2/hr.	CO_2 ml CO_2/hr.	Respiration rate ml CO_2/hr.	CO_2 ml CO_2/hr.	ml CO_2/hr.
Potato	2010-2011	42,339,000	2.33	98,527,927	6.02	592,730,222	494,202,295
	2011-2012	41,483,000		96,535,912		580,746,541	484,210,629
	2012-2013	45,344,000		105,520,922		634,799,102	529,278,180
Tomato	2010-2011	16,826,000	5.24	88,188,945	18.21	1,605,948,799	1,517,759,854
	2011-2012	18,653,000		97,764,673		1,780,325,862	1,682,561,189
	2012-2013	18,227,000		95,531,909		1,739,666,514	1,644,134,605
Potato and Tomato	2010-2011	59,165,000	4.13	244,107,434	12.21	2,981,617,987	2,737,510,553
	2011-2012	60,136,000		248,113,660		3,030,551,496	2,782,437,837
	2012-2013	63,571,000		262,286,043		3,203,658,194	2,941,372,152

estimate the overall CO_2 emission. Both potato and tomato and their combination of respiration vary in open and closed transportation. The respiration rate is highly reduced, when potato and tomato are combined together in a closed transportation.

As referred to in Table II, potato has a rate of 6.02 ml CO_2/hr, tomato and its combination have respiration rates of 18.21 ml CO_2/hr and 12.21 ml CO_2/hr, respectively, in open transportation. If the produces are transported in a closed container, then potato has a rate of 2.33 ml CO_2/hr, and tomato and its combination have respiration rates of 5.24 ml CO_2/hr and 4.13 ml CO_2/hr, respectively. The potato has the lowest respiration rate, and the transportation method of potato, tomato and their combination is shown in Table II.

However, the respiration rate changes in the closed transportation according to the headspace; if the headspace decreases, then the respiration rate also decreases. In comparison, the potato has a less respiration rate than tomato. However, both have reduced respiration in the closed transportation. Complete production of CO_2 emission is shown in Table II, which is estimated by applying the respiration rates to the overall production of agriculture production during past three years of 2014, because this work is conducted during the year of 2014. Thus, the overall CO_2 emission of Indian traditional ASCM will increase.

4.3 Calculation of loss and CO_2 emission

The CO_2 emission is not only produced by the transported agricultural produces but also emitted during PHL. Therefore, supply and loss are major sources of CO_2 emissions, which will increase the environmental impacts of Indian traditional ASCM. Table III comprises the loss of all three combinations such as potato, tomato and mixture of both, with total PHL in terms of kg for an assumed percentage of PHL for each stage, as well as supply structures and exact production of each year. If the traditional ASCM adopts type 1 supply structure, it will have 50 percent of PHL, leaving highest quantity of loss; otherwise if it adopts a most optimized supply structure type 3 with 10 percent of PHL, it will be the lowest loss. The comparison of type 1 and type 3 reveals that the total loss reduced to 15 percent in all percentage of PHL.

The PHL percentages of each stage and supply structure are interlinked with each other. The optimized supply structure reduces the loss and CO_2 emission, but the transportation method reduces CO_2 emission only. Tables IV and V comprise the CO_2 emission of loss produces during closed and open transportation, respectively. Table IV shows the significance of closed transportation by comparing CO_2 emission produced by selected produce respiration along with an assumed percentage of PHL and optimized supply structures.

Table IV clarifies that the PHL of tomato in supply structure type 3 has lowest CO_2 emission, which is 5, 10, 15, 18, and 22 percent with respect to each percentage of PHL. The supply structure type 3 of potato has CO_2 emission of 7, 14, 20 25, and 29 percent with respect to each percentage of PHL, which is slightly higher than tomato. The supply structure type 3 of mixed produces has CO_2 emission of 6, 12, 17, 22, and 25 percent with respect to each percentage of PHL. Therefore, the tomato has lowest CO_2 than both, but the potato CO_2 emission can be reduced by mixing both. The open transportation CO_2 emission is estimated and shown in Table V to compare with closed transportation.

Table V clarifies the differentiation of CO_2 emission of open transportations of selected produces compared with the PHL percentage and optimized supply structures, because this open transportation is more traditional than the existing transportation method. Table V clarifies that the CO_2 emission of open transportation is much higher. The potato has 90 percent of CO_2 emission in supply structure type 1with highest loss percentage. This table is used here to estimate the current CO_2 emission of selected produces for five different loss and three different supply structures. In Table V, it is estimated to compare the closed transportation with traditional open transportation. The difference between closed and traditional open transportation is shown in Table VI.

Table III.
Total loss of each supply stage

			Production	Loss percentage										
				10%		20%		30%		40%		50%		Average
Produces	Supply	Year	In Kg	kg	%	kg	%	kg	%	kg	%	kg	%	%
								Total loss and percentage of loss						
Potato	Type-1	2010-2011	42,339,000	14,360,127	34	24,190,041	57	30,844,849	73	35,291,443	83	38,213,015	90	67
		2011-2012	41,483,000	14,069,798	34	23,700,972	57	30,221,235	73	34,577,928	83	37,440,433	90	67
		2012-2013	45,344,000	15,379,334	34	25,906,923	57	33,034,055	73	37,796,244	83	40,925,174	90	67
	Type-2	2010-2011	42,339,000	12,578,155	30	22,005,441	52	28,924,565	68	33,876,619	80	37,311,244	88	64
		2011-2012	41,483,000	12,323,853	30	21,560,540	52	28,339,775	68	33,191,710	80	36,556,894	88	64
		2012-2013	45,344,000	13,470,886	30	23,567,272	52	30,977,479	68	36,281,004	80	39,959,400	88	64
	Type-3	2010-2011	42,339,000	8,044,410	19	15,242,040	36	21,592,890	51	27,096,960	64	31,754,250	75	49
		2011-2012	41,483,000	7,881,770	19	14,933,880	36	21,156,330	51	26,549,120	64	31,112,250	75	49
		2012-2013	45,344,000	8,615,360	19	16,323,840	36	23,125,440	51	29,020,160	64	34,008,000	75	49
Tomato	Type-1	2010-2011	16,826,000	5,706,878	34	9,613,397	57	12,258,094	73	14,025,221	83	15,186,287	90	67
		2011-2012	18,653,000	6,326,542	34	10,657,239	57	13,589,102	73	15,548,106	83	16,835,243	90	67
		2012-2013	18,227,000	6,182,055	34	10,413,847	57	13,278,752	73	15,193,016	83	16,450,757	90	67
	Type-2	2010-2011	16,826,000	4,998,702	30	8,745,213	52	11,494,951	68	13,462,954	80	14,827,913	88	64
		2011-2012	18,653,000	5,541,471	30	9,694,785	52	12,743,095	68	14,924,788	80	16,437,956	88	64
		2012-2013	18,227,000	5,414,914	30	9,473,374	52	12,452,067	68	14,583,933	80	16,062,544	88	64
	Type-3	2010-2011	16,826,000	3,196,940	19	6,057,360	36	8,581,260	51	10,768,640	64	12,619,500	75	49
		2011-2012	18,653,000	3,544,070	19	6,715,080	36	9,513,030	51	11,937,920	64	13,989,750	75	49
		2012-2013	18,227,000	3,463,130	19	6,561,720	36	9,295,770	51	11,665,280	64	13,670,250	75	49
Potato and Tomato	Type-1	2010-2011	59,165,000	20,067,005	34	33,803,438	57	43,102,943	73	49,316,663	83	53,399,301	90	67
		2011-2012	60,136,000	20,396,340	34	34,358,211	57	43,810,337	73	50,126,035	83	54,275,676	90	67
		2012-2013	63,571,000	21,561,389	34	36,320,770	57	46,312,807	73	52,989,260	83	57,375,932	90	67
	Type-2	2010-2011	59,165,000	17,576,857	30	30,750,654	52	40,419,516	68	47,339,573	80	52,139,156	88	64
		2011-2012	60,136,000	17,865,323	30	31,255,325	52	41,082,871	68	48,116,497	80	52,994,850	88	64
		2012-2013	63,571,000	18,885,800	30	33,040,646	52	43,429,546	68	50,864,937	80	56,021,944	88	64
	Type-3	2010-2011	59,165,000	11,241,350	19	21,299,400	36	30,174,150	51	37,865,600	64	44,373,750	75	49
		2011-2012	60,136,000	11,425,840	19	21,648,960	36	30,669,360	51	38,487,040	64	45,102,000	75	49
		2012-2013	63,571,000	12,078,490	19	22,885,560	36	32,421,210	51	40,685,440	64	47,678,250	75	49

Table IV.
CO_2 emission during closed transportation

Produces	Supply Method	Year	Production In Kg	Respiration Rate	Respiration Closed ml CO_2/hr.	Loss percentage 10% kg	%	20% kg	%	30% kg	%	40% kg	%	50% kg	%	Average %
										CO_2 by loss ml CO_2/hr (closed)						
Potato	Type-1	2010-2011	42,339,000	2	98,649,870	33,459,097	13	56,362,795	22	71,868,499	28	82,229,061	32	89,036,325	35	26
		2011-2012	41,483,000		96,655,390	32,782,629	13	55,223,265	22	70,415,479	28	80,566,573	32	87,236,209	35	26
		2012-2013	45,344,000		105,651,520	35,833,848	13	60,363,130	22	76,969,348	28	88,065,248	32	95,355,656	35	26
	Type-2	2010-2011	42,339,000	2	98,649,870	29,307,101	11	51,272,678	20	67,394,237	26	78,932,523	31	86,935,198	34	24
		2011-2012	41,483,000		96,655,390	28,714,577	11	50,236,059	20	66,031,676	26	77,336,684	31	85,177,562	34	24
		2012-2013	45,344,000		105,651,520	31,387,165	11	54,911,744	20	72,177,526	26	84,534,739	31	93,105,402	34	24
	Type-3	2010-2011	42,339,000	2	98,649,870	18,743,475	7	35,513,953	14	50,311,434	20	63,135,917	25	73,987,403	29	19
		2011-2012	41,483,000		96,655,390	18,364,524	7	34,795,940	14	49,294,249	20	61,859,450	25	72,491,543	29	19
		2012-2013	45,344,000		105,651,520	20,073,789	7	38,034,547	14	53,882,275	20	67,616,973	25	79,238,640	29	19
Tomato	Type-1	2010-2011	16,826,000	5	88,168,240	29,904,040	10	50,374,201	16	64,232,412	21	73,492,156	24	79,576,142	26	19
		2011-2012	18,653,000		97,741,720	33,151,079	10	55,843,931	16	71,206,893	21	81,472,078	24	88,216,675	26	19
		2012-2013	18,227,000		95,509,480	32,393,970	10	54,568,559	16	69,580,659	21	79,611,406	24	86,201,969	26	19
	Type-2	2010-2011	16,826,000	5	88,168,240	26,193,197	9	45,824,914	15	60,233,544	20	70,545,878	23	77,698,262	25	18
		2011-2012	18,653,000		97,741,720	29,037,306	9	50,800,673	15	66,773,820	20	78,205,887	23	86,134,891	25	18
		2012-2013	18,227,000		95,509,480	28,374,147	9	49,640,479	15	65,248,829	20	76,419,809	23	84,167,729	25	18
	Type-3	2010-2011	16,826,000	5	88,168,240	16,751,966	5	31,740,566	10	44,965,802	15	56,427,674	18	66,126,180	22	14
		2011-2012	18,653,000		97,741,720	18,570,927	5	35,187,019	10	49,848,277	15	62,554,701	18	73,306,290	22	14
		2012-2013	18,227,000		95,509,480	18,146,801	5	34,383,413	10	48,709,835	15	61,126,067	18	71,632,110	22	14
Potato and Tomato	Type-1	2010-2011	59,165,000	4	244,351,450	82,876,732	11	139,608,198	19	178,015,156	25	203,677,819	28	220,539,115	31	23
		2011-2012	60,136,000		248,361,680	84,236,882	11	141,899,410	19	180,936,692	25	207,020,524	28	224,158,543	31	23
		2012-2013	63,571,000		262,548,230	89,048,537	11	150,004,779	19	191,271,891	25	218,845,646	28	236,962,597	31	23
	Type-2	2010-2011	59,165,000	4	244,351,450	72,592,417	10	127,000,200	18	166,932,603	23	195,512,437	27	215,334,715	30	22
		2011-2012	60,136,000		248,361,680	73,783,785	10	129,084,493	18	169,672,255	23	198,721,134	27	218,868,731	30	22
		2012-2013	63,571,000		262,548,230	77,998,353	10	136,457,867	18	179,364,024	23	210,072,190	27	231,370,628	30	22
	Type-3	2010-2011	59,165,000	4	244,351,450	46,426,776	6	87,966,522	12	124,619,240	17	156,384,928	22	183,263,588	25	16
		2011-2012	60,136,000		248,361,680	47,188,719	6	89,410,205	12	126,664,457	17	158,951,475	22	186,271,260	25	16
		2012-2013	63,571,000		262,548,230	49,884,164	6	94,517,363	12	133,899,597	17	168,030,867	22	196,911,173	25	16

Table V.
CO_2 emission by open transportation

				Respiration						Loss percentage						
	Supply		Production	Rate	Open	10%		20%		30%		40%		50%		Average
Produces	Method	Year	In Kg		ml CO_2/hr.	kg	%	kg	%	kg	%	kg	%	kg	%	%
										CO_2 by loss ml CO_2/hr (open)						
Potato	Type-1	2010-2011	42,339,000	6	254,880,780	86,447,967	34	145,624,045	57	185,685,993	73	212,454,485	83	230,042,349	90	67
		2011-2012	41,483,000		249,727,660	84,700,182	34	142,679,852	57	181,931,837	73	208,159,129	83	225,391,407	90	67
		2012-2013	45,344,000		272,970,880	92,583,590	34	155,959,675	57	198,865,010	73	227,533,389	83	246,369,548	90	67
	Type-2	2010-2011	42,339,000	6	254,880,780	75,720,492	30	132,472,756	52	174,125,883	68	203,937,249	80	224,613,687	88	64
		2011-2012	41,483,000		249,727,660	74,189,593	30	129,794,453	52	170,605,447	68	199,814,093	80	220,072,500	88	64
		2012-2013	45,344,000		272,970,880	81,094,735	30	141,874,977	52	186,484,424	68	218,411,644	80	240,555,588	88	64
	Type-3	2010-2011	42,339,000	6	254,880,780	48,427,348	19	91,757,081	36	129,989,198	51	163,123,699	64	191,160,585	75	49
		2011-2012	41,483,000		249,727,660	47,448,255	19	89,901,958	36	127,361,107	51	159,825,702	64	187,295,745	75	49
		2012-2013	45,344,000		272,970,880	51,864,467	19	98,269,517	36	139,215,149	51	174,701,363	64	204,728,160	75	49
Tomato	Type-1	2010-2011	16,826,000	18	306,401,460	103,922,246	34	175,059,963	57	223,219,889	73	255,399,266	83	276,542,279	90	67
		2011-2012	18,653,000		339,671,130	115,206,327	34	194,068,316	57	247,457,541	73	283,131,018	83	306,569,780	90	67
		2012-2013	18,227,000		331,913,670	112,575,228	34	189,636,155	57	241,806,069	73	276,664,830	83	299,568,294	90	67
	Type-2	2010-2011	16,826,000	18	306,401,460	91,026,359	30	159,250,320	52	209,323,060	68	245,160,387	80	270,016,287	88	64
		2011-2012	18,653,000		339,671,130	100,910,179	30	176,542,032	52	232,051,767	68	271,780,382	80	299,335,183	88	64
		2012-2013	18,227,000		331,913,670	98,605,577	30	172,510,139	52	226,752,134	68	265,573,421	80	292,498,922	88	64
	Type-3	2010-2011	16,826,000	18	306,401,460	58,216,277	19	110,304,526	36	156,264,745	51	196,096,934	64	229,801,095	75	49
		2011-2012	18,653,000		339,671,130	64,537,515	19	122,281,607	36	173,232,276	51	217,389,523	64	254,753,348	75	49
		2012-2013	18,227,000		331,913,670	63,063,597	19	119,488,921	36	169,275,972	51	212,424,749	64	248,935,253	75	49
Potato and Tomato	Type-1	2010-2011	59,165,000	12	722,404,650	245,018,134	34	412,739,976	57	526,286,937	73	602,156,457	83	652,005,470	90	67
		2011-2012	60,136,000		734,260,560	249,039,306	34	419,513,753	57	534,924,216	73	612,038,886	83	662,706,008	90	67
		2012-2013	63,571,000		776,201,910	263,264,562	34	443,476,599	57	565,479,369	73	646,998,870	83	700,560,124	90	67
	Type-2	2010-2011	59,165,000	12	722,404,650	214,613,418	30	375,465,482	52	493,522,295	68	578,016,188	80	636,619,098	88	64
		2011-2012	60,136,000		734,260,560	218,135,596	30	381,627,520	52	501,621,850	68	587,502,433	80	647,067,119	88	64
		2012-2013	63,571,000		776,201,910	230,595,616	30	403,426,286	52	530,274,754	68	621,060,882	80	684,027,933	88	64
	Type-3	2010-2011	59,165,000	12	722,404,650	137,256,884	19	260,065,674	36	368,426,372	51	462,338,976	64	541,803,488	75	49
		2011-2012	60,136,000		734,260,560	139,509,506	19	264,333,802	36	374,472,886	51	469,926,758	64	550,695,420	75	49
		2012-2013	63,571,000		776,201,910	147,478,363	19	279,432,688	36	395,862,974	51	496,769,222	64	582,151,433	75	49

Table VI. CO_2 emission difference between closed and open transportation

Produces	Supply Method	Year	Production In Kg	Loss percentage 10% kg	%	20% kg	%	30% kg	%	40% kg	%	50% kg	%	Average %
				CO_2 by loss ml CO_2/hr (difference)										
Potato	Type-1	2010-2011	42,339,000	52,988,870	21	89,261,250	35	113,817,494	45	130,225,424	51	141,006,024	55	41
		2011-2012	41,483,000	51,917,553	21	87,456,587	35	111,516,358	45	127,592,556	51	138,155,198	55	41
		2012-2013	45,344,000	56,749,742	21	95,596,545	35	121,895,662	45	139,468,141	51	151,013,892	55	41
	Type-2	2010-2011	42,339,000	46,413,391	18	81,200,078	32	106,731,646	42	125,004,726	49	137,678,489	54	39
		2011-2012	41,483,000	45,475,016	18	79,558,394	32	104,573,771	42	122,477,409	49	134,894,938	54	39
		2012-2013	45,344,000	49,707,570	18	86,963,233	32	114,306,898	42	133,876,905	49	147,450,186	54	39
	Type-3	2010-2011	42,339,000	29,683,873	12	56,243,128	22	79,677,764	31	99,987,782	39	117,173,182	46	30
		2011-2012	41,483,000	29,083,731	12	55,106,018	22	78,066,858	31	97,966,252	39	114,804,202	46	30
		2012-2013	45,344,000	31,790,678	12	60,234,970	22	85,332,874	31	107,084,390	39	125,489,520	46	30
Tomato	Type-1	2010-2011	16,826,000	74,018,206	24	124,685,762	41	158,987,477	52	181,907,110	59	196,966,137	64	48
		2011-2012	18,653,000	82,055,248	24	138,224,385	41	176,250,648	52	201,658,940	59	218,353,105	64	48
		2012-2013	18,227,000	80,181,258	24	135,067,596	41	172,225,410	52	197,053,424	59	213,366,325	64	48
	Type-2	2010-2011	16,826,000	64,833,162	21	113,425,406	37	149,089,516	49	174,614,509	57	192,318,025	63	45
		2011-2012	18,653,000	71,872,873	21	125,741,359	37	165,277,947	49	193,574,495	57	213,200,292	63	45
		2012-2013	18,227,000	70,231,430	21	122,869,660	37	161,503,305	49	189,153,612	57	208,331,193	63	45
	Type-3	2010-2011	16,826,000	41,464,311	14	78,563,960	26	111,298,943	36	139,669,260	46	163,674,915	53	35
		2011-2012	18,653,000	45,966,588	14	87,094,588	26	123,383,999	36	154,834,822	46	181,447,058	53	35
		2012-2013	18,227,000	44,916,796	14	85,105,508	26	120,566,137	36	151,298,682	46	177,303,143	53	35
Potato and Tomato	Type-1	2010-2011	59,165,000	162,141,402	22	273,131,778	38	348,271,781	48	398,478,638	55	431,466,355	60	45
		2011-2012	60,136,000	164,802,424	22	277,614,343	38	353,987,524	48	405,018,362	55	438,547,465	60	45
		2012-2013	63,571,000	174,216,025	22	293,471,820	38	374,207,478	48	428,153,224	55	463,597,527	60	45
	Type-2	2010-2011	59,165,000	142,021,001	20	248,465,282	34	326,589,692	45	382,503,751	53	421,284,383	58	42
		2011-2012	60,136,000	144,351,811	20	252,543,027	34	331,949,595	45	388,781,299	53	428,198,388	58	42
		2012-2013	63,571,000	152,597,263	20	266,968,419	34	350,910,730	45	410,988,692	53	452,657,305	58	42
	Type-3	2010-2011	59,165,000	90,830,108	13	172,099,152	24	243,807,132	34	305,954,048	42	358,539,900	50	33
		2011-2012	60,136,000	92,320,787	13	174,923,597	24	247,808,429	34	310,975,283	42	364,424,160	50	33
		2012-2013	63,571,000	97,594,199	13	184,915,325	24	261,963,377	34	328,738,355	42	385,240,260	50	33

Table VI depicts the differentiation of CO_2 emission of open and closed transportation compared with PHL percentage and optimized supply structure. The open transportation has high CO_2 emission than the closed transportation. It clearly clarifies that in supply structure type 3, the potato has lowest differentiation of 12, 22, 31, 39, and 46 percent with respect to all PHL percentage, because the potato has moderate respiration in closed transportation. By comparing Tables IV-VI, the lowest and highest CO_2 emissions of individual produces are identified. However, if the produces are mixed together, then the produces emit moderately. If tomato and potato are combined together and transported, then overall emission is reduced.

5. Conclusion

In this paper, Indian traditional ASCM was modeled as a planning model by considering intermediaries to reduce the PHL and CO_2 emission, through optimizing the supply structures and modified transportation method, respectively. This model is optimized through GA with constraints. Three alternative supply structures were considered, undergoing an optimization amongst three. One of the methods was found to have a reduced PHL. The overall losses are reduced through the optimized supply structures like type 1, type 2 and type 3. The PHLs are compared with each other to identify the optimized supply structure. The supply structure type-1 approximately replicates the existing SC, because type-1 supply structure transports produces from farmer to customer through intermediaries.

Succeeding, supply structure type-1 has average PHL of 67 percent for potato, tomato and their combination. Consequently, supply structure type-3 has lowest average PHL of 49 percent. Likewise, the supply structure type-1 and type-3 emits 67 and 49 percent of CO_2, respectively, during open transportation. Therefore, type-3 supply structure is found as well-optimized supply structure for each produce and their combinations. Even though supply structures are optimized to reduce loss, CO_2 emission is high due to open transportation. Therefore, the closed transportation is identified as alternative transportation method for potato, tomato and their combination, because the CO_2 emission is highly reduced as compared to open transportation, and in this closed transportation, tomato has lowest emission of 14 percent.

The combination of potato and tomato has CO_2 emission of 16 percent, which is higher than tomato but lower than potato. However, this mixed closed transportation reduces CO_2 emission of potato. Therefore, this research paper identified that the mixed closed transportation is the best transportation method for the short-duration domestic purpose. These supply structures and the mixed closed transportation method can only be implemented when shortest distance markets are grouped together. This grouping reduces the traveling distance and time.

6. Future work

Further this model can be extended to other produces, which is most commonly available produces to estimate the CO_2 emission and losses. Because each produces has its own respiration rate, so measuring the respiration rate of other produces to estimate the emission becomes crucial.

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