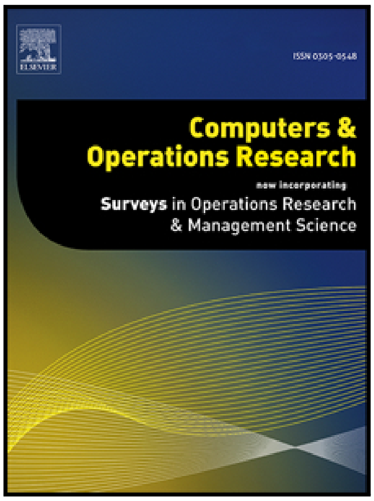
Accepted Manuscript



Heuristic Modeling for Sustainable Procurement and Logistics in a Supply Chain Using Big Data

Harpreet Kaur , Surya Prakash Singh

PII: S0305-0548(17)30120-X
DOI: 10.1016/j.cor.2017.05.008
Reference: CAOR 4245

To appear in: *Computers and Operations Research*

Received date: 28 November 2016
Revised date: 2 May 2017
Accepted date: 8 May 2017

Please cite this article as: Harpreet Kaur , Surya Prakash Singh , Heuristic Modeling for Sustainable Procurement and Logistics in a Supply Chain Using Big Data, *Computers and Operations Research* (2017), doi: 10.1016/j.cor.2017.05.008

Heuristic Modeling for Sustainable Procurement and Logistics in a Supply Chain Using Big Data

1) Harpreet Kaur

Department of Management Studies, Indian Institute of Technology Delhi, New Delhi, India

E-Mail: harpreetk.iitd@gmail.com<mailto:harpreetk.iitd@gmail.com>

2) Surya Prakash Singh*

Department of Management Studies, Indian Institute of Technology Delhi, New Delhi, India

E-Mail. surya.singh@gmail.com<mailto:surya.singh@gmail.com>

*Corresponding Author

Complete Address:

Surya Prakash Singh, Department of Management Studies, Vishwakarma Bhawan, Indian Institute of Technology Delhi, New Delhi-110016

Phone: +91-11-2659-6302 (O)

Mobile: +91-9582175850 (M)

Abstract:

Drastic climate change has enforced business organizations to manage their carbon emissions. Procurement and transportation is one of the supply chain business operations where carbon emissions are huge. This paper proposes an environmentally sustainable procurement and logistics model for a supply chain. The proposed models are of MINLP (Mixed Integer Non Linear Program) and MILP (Mixed Integer Linear Program) form requiring a variety of the real time parameters from buyer and supplier side such as costs, capacities, lead-times and emissions. Based on real time data, the models provide an optimal sustainable procurement and transportation decision. It is also shown that large sized problems possessing essential 3V's of big data, i.e., volume, variety and velocity consume non-polynomial time and cannot be solved optimally. Therefore, a heuristic (H-1) is also proposed to solve the large sized problems involving big data. T-test significance is also conducted between optimal and heuristic solutions obtained using 42 randomly generated data instances possessing essential characteristics of big data. Encouraging results in terms of solution quality and computational time are obtained.

Keywords: Sustainable procurement; Big data; Sustainable transportation; MINLP (Mixed Integer Non Linear Program); MILP (Mixed Integer Linear Program); Heuristic

1. INTRODUCTION

The global concern over environmental threats caused by various business operations has led researchers and practitioners to explore variety of approaches to reduce overall carbon footprint of a firm. Therefore, the business organizations have started reframing their strategic and operational policies to improve the environmental performance of the products or/and overall manufacturing processes starting from procurement of products till the delivery of finished goods. Hence, a complete integration and successful coordination among all the members of supply chain including raw material suppliers, manufacturers, distributors, and users is required [1]. Low carbon approach has been becoming the trend of the world economy. Carbon emission regulatory policies such as carbon cap, carbon tax, carbon offset, carbon cap and trade are being increasingly applied to various business organizations all over the globe. The globalization of business activities have led to increased demand of products and services worldwide. Therefore, the production, transportation, storage and consumption of increasing demand of products and services have further added to environmental problems.

In this information age, lot of data generates at both supplier and buyer side. However, most of the supply chain decisions still do not incorporates the big data characteristics into the decision making models. Therefore, it is important to jointly consider big data in supply chain modeling. Data available at supplier and buyer's side are mostly voluminous and also possesses variety and velocity characteristics of big data. In view of this, for effective and efficient decision making these available data should be utilized considering big data while modeling. Hence, supply chain modeling using big data provides a competitive edge to the business organization and makes the supply chain resilient and sustainable [2,3]. As much the big data is essential for decision making in highly volatile and competitive markets, it is equally challenging to store and analyse big data. This is the major reason that despite the huge scope of big data, there are very few attempts made so far to develop models using big data in supply chain modelling [4,5].

This paper proposes a joint sustainable procurement and logistics model for a carbon sensitive supply chain. The model considers the emissions caused during ordering, holding and logistics. The proposed model tends to obtain optimal decision by simultaneously minimizing procurement cost and carbon emissions cost. The proposed model is of MINLP type. MINLP is further linearized to MILP using Axioms. The model is solved using exact approach for big data possessing 3V's, i.e., volume, variety and velocity. It is observed that model takes non-polynomial time to solve in presence of big data. Therefore, a heuristic (H-1) is proposed to solve the model having big data. The optimal and heuristic solutions are also compared. T-test has been also conducted for statistical significance between heuristic and optimal solutions.

The structure of the paper is organized as follows. Detailed literature review is presented in section 2. The joint sustainable procurement and logistics model is proposed in section 3. The solution methodology using big data is provided in section 4. The numerical illustrations are analyzed in section 5. The conclusions and future scope of work are summarized in Section 6.

2. LITERATURE REVIEW

The section provides detailed exhaustive review on the recent development on sustainable procurement and its logistics in supply chain. The past review is sub-divided into two sections where the first section focus on the modeling of sustainable procurement and logistics where as the later section present the big data application in modeling of sustainable procurement and logistics. Lastly, a section is provided to link big data with sustainable procurement and logistics in supply chain.

2.1 Review on sustainable procurement and logistics models.

Low carbon or environmentally sustainable procurement is considered as the first essentially important step towards greening the business operations in supply chain. In this direction, Geffen and Rothenberg [6] were the first to examine the importance of strategic involvement between the operations of manufacturers and suppliers to achieve targeted environmental performance. The carbon emissions generated by suppliers must be considered as an important criterion for supplier selection. In this view, the past work includes identification and selection of suppliers based on sustainability criteria such as the carriers used, type of fuel used, fuel efficiency, distance from the firm, packaging material used [7-12]. The papers include qualitative assessment of suppliers based on sustainability criteria.

In mathematical modeling of procurement problems, there are mainly two ways to incorporate carbon emission constraints viz. carbon cap-and-trade and carbon tax. Past work reported by Venkat [13], Tao *et al.* [14], Helmrich *et al.* [15], Bhattini *et al.* [16], Benjaafar *et al.* [17], Abdallah *et al.* [18], Jaber *et al.* [19], Yugang *et al*. [20], Sarkis and Dhavale [21] presented lot sizing models to determine the order size in procurement models by integrating carbon emissions. Similarly, the work by Lee [22], Saadany *et al.* [23], Bouchery *et al.* [24], and Zeng *et al.* [25] proposed integrated lot sizing and supplier selection models by considering carbon emissions constraint. The discussed models do not include carrier selection aspect, although the carriers are considered to be a major contributor of carbon emissions in procurement process. Transportation of items from supplier to buyer produces considerable amount of carbon emissions which should not be ignored while modeling procurement problem. It has been established that freight transport typically accounts for 80-90% of transportation-related carbon emissions [26]. In this direction, Sheu *et al.* [27], Choelette and Venkat [28] and

Ubeda *et al.* [29] proposed models to optimize cost and carbon emissions in transportation activities, however, these models are not integrated with lot sizing and supplier selection. Integration of carrier selection with the supplier selection and lot sizing is very crucial to completely plan a sustainable procurement. From the past review it can be seen that the Liao and Ritscher [30], Songhori *et al.* [31], Palak *et al.* [32], and Kaur and Singh [33, 34] have proposed models for joint procurement problem. However, the sustainability aspect is not considered in joint procurement modeling. The various sources of carbon emissions such as ordering, holding, mode of transport, distance travelled, ordering policy, choice of fuel used etc. must be considered to model sustainable joint procurement problem. Figure 1 shows an increasing trend of research on sustainability in procurement problem since year 2000. The figure is generated using Google scholar for keyword "*sustainability+procurement*" for the article title.

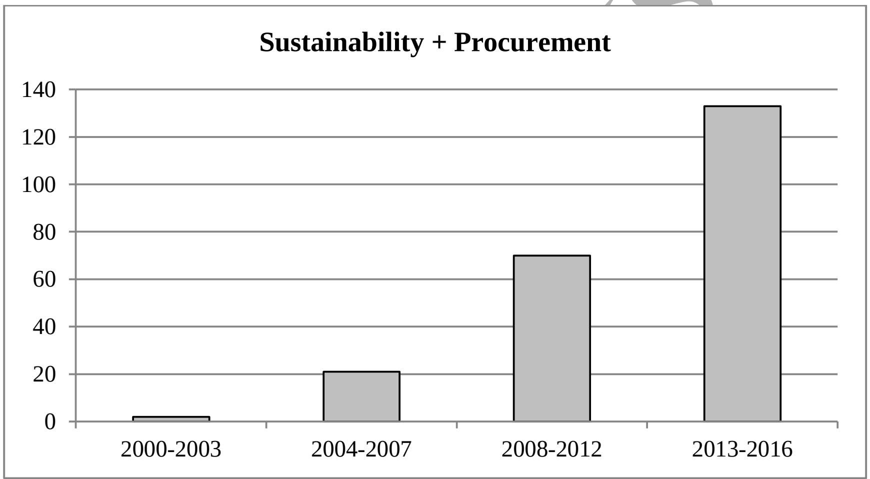


Figure 1: Past work on addressing sustainability in procurement problem

2.2 Review on supply chain models considering big data.

Today's era is referred as 'big data revolution' owing to the amount of information important for supply chain operations extracted from big data. In earlier days, data recording being manual consume huge time and energy. However, due to digitization in the form of ERP implementation in the industries, huge data is being generated and can be utilized effectively and efficiently. An effective use of big data can generate different benefits across different sectors [35, 36]. It is believed that the total global data volume doubles in eighteen months. Now, it can be said that there is more data being generated in industries than it is being handled. Due to massive digitization globally through ERP among all businesses including manufacturing industries huge data is generated and readily available for analysis. This has drawn attention of researchers and practitioners to incorporate the insights drawn through such data that is being generated on real time.

Big data has been found many applications in optimizing operations in supply chain, primarily in procurement, inventory management, logistics and distribution planning. In this direction, Stefanou [37] explored the advantages of integrating the supplier and buyer information using ERP systems for overall supply chain management. On similar lines, Tarn *et al*. [38] also emphasized on integration of ERP systems to incorporate big data in supply chain decisions. Perea-lopez *et al*., [39] proposed a dynamic distribution model considering big data and results are also compared. Gunasekaran and Nagi [40] suggested the implementation of big data using IT in supply chain practices to improve production flexibility and to gain an edge over competitors. Bose *et al.* [41] studied the efficient inventory control in supply chain using big data integration in ERP systems. O'Leary [42] advocated that the big data has capability to provide real time information to facilitate effective risk mitigation for better supply chain coordination. Pereira [43] explored the application of big data for risk mitigation in supply chain. Ilic *et al*., [44] further discussed the benefits of using big data to control the movement of goods in a supply chain. They found that the use of big data can improve the supply chain coordination among all supply chain partner, thus, to regulate supply chain velocity to follow market trend. Timely movement of goods is preferred in supply chain and it has been always seen as one of the most challenging task. Procurement is one of such operation in supply chain where delivery time is seen vital issue. Keeping this objective, recently Geerts and O'Leary [45] proposed the application of internet of things (IOT) in procurement and logistics to have a better control on movement of goods in a supply chain. This approach offers real time information on past locations and handling details of things, which further reduces the supply chain risks and enhances responsiveness. At the same time, Kwon et al. [46] presented a research model to explore the firm's competence to adopt big data analytics practices for overall business performance. Very recently, Tan *et al*., [47] proposed an analytic technique to handle, manage, and analyze the big data to deduce useful information to understand the market including suppliers and buyers. Ng *et al*. [48] also proposed a model for producer's choice for two different strategies by incorporating IoT. In the year 2016, Tayal and Singh [4] proposed a big data framework for stochastic dynamic facility layout problem (SDFLP). On similar lines, Lamba and Singh [5] also proposed conceptual frameworks for different supply chain operations such as procurement, joint procurement, and facility layout. The brief summary reviewed literature of well cited and referred papers is also tabulated in Table 1.

Table 1: Summary of reviewed literature

Authors	**Issues addressed**	**Supplier selection**	**Lot sizing**	**Logistics**	**Sustainability**	**Big data**	**Conceptual study**	**Analytical Modelling**
Brown *et al.*, 2011 and Wamba *et al.*, 2015	Sustainable Supply chain	×	×	×	✓	✓	✓	×
Fahimnia and Jabbarzadeh, 2016	Resilient sustainable Supply chain	×	×	×	✓	×	✓	×
Geffen and Rothenberg 2000	Sustainable supply chain	✓	×	×	✓	×	✓	×
Presley *et al.*, 2007; Ciliberti *et al.*, 2008; Seuring and Muller, 2008; Bai *et al.*, 2010; Kumar and Jain, 2010 ; Hsu *et al.*, 2011	Sustainable supplier selection	✓	✓	×	✓	×	×	✓
Venkat 2007, Tao *et al.*,, 2010, Helmrich *et al.*, 2012, Bhattini *et al.*, 2013, Benjaafar *et al.*, 2010, Abdallah *et al.*, 2011, Jaber *et al.*, 2012, Yugang *et al.*, 2013, Sarkis and Dhavale 2015	Sustainable lotsizing	✓	×	✓	✓	×	×	✓
Lee 2011, Saadany *et al.*, 2011, Bouchery *et al.*,2012, and Zeng *et al.*,2012	Sustainable distribution	×	✓	✓	✓	×	×	✓
McKinnon *et al.*, 2010	Sustainability in policy making	×	×	×	✓	×	✓	×
Sheu *et al.*, 2005, Choelette and Venkat 2009 and Ubeda *et al.*, 2011	Sustainability in logistics	✓	×	✓	✓	×	×	✓
Liao and Ritscher 2007, Songhori *et al.*, 2011, Palak *et al.*, 2014 and Kaur and Singh 2016a, 2016b	Sustainability in Procurement	✓	✓	✓	×	×	×	✓
Mishra *et al.*, 2013, Waller *et al.*, 2013	Role of big data in supply chain	×	×	×	×	✓	✓	×
Stefanou 1998, Tarn *et al.*, 2002 ,Gunasekaran and Nagi 2004	Big data for supplier management	✓	✓	×	×	✓	✓	×
Perea-lopez *et al.*, 2003	Big data for handling movement	×	×	✓	×	✓	×	✓
Bose *et al.*, 2008	Big data for managing inventory	✓	×	×	×	✓	×	✓
O'Leary 2008 Pereira 2009, Ilic *et al.*, 2009	Big data and ERP integration	✓	×	✓	×	✓	✓	×
Geerts and O'Leary 2014,Kwon et al., 2014 Ng *et al.*, 2015, Tan *et al.*, 2015	Logistics planning using big data	×	✓	✓	×	✓	✓	×
Tayal and Singh, 2016; Lamba and Singh, 2016	Framework for application of big data in supply chain operations	✓	✓	✓	×	✓	✓	×
Proposed Sustainable Procurement and Logistics Model	Big data in sustainable procurement and logistics decisions	✓	✓	✓	✓	✓	×	✓

2.3 Linking big data with sustainable procurement and logistics in supply chain

Based on detailed literature review carried out in the previous sections, it is realized that the big data finds huge application primarily in the procurement and logistics. Authors also found that the most of the studies carried out on big data in the context of supply chain are primarily theoretical and conceptual; however, analytical models using big data have been so far very limited. Moreover, available analytical models partially capture the big data aspects into the modeling of the sustainable procurement and logistics. Thus, authors believe that there exist huge gap in linking big data to optimize operations such as procurement and logistics in supply chain. Table 2 provides the frequency distribution of the available paper found using keywords such as "Sustainability + supply chain", "Big data + Supply chain", and "Big data + Sustainability + Supply chain" in the title of the paper using Google scholar from the year 2000.

Table 2: Frequency of published articles under title search in Google scholar

Keywords in the title	2000-2003	2004-2007	2008-2012	2013-2016	2017 onwards
Sustainability + supply chain	8	22	168	443	24
Big data + Supply chain	0	1	0	84	15
Big data + Sustainability + Supply chain	0	0	0	1	2

Table 2 shows that the work on modeling sustainable procurement and logistics using big data in supply chain is very limited. Previously developed models are limited to the single aspect of big data i.e. volume or variety. Due to increased trend in the application of big data, it has become important to develop model applying big data concept for effective and efficient decisions. Considering the gap identified above, the paper is a novel attempt to address environmentally sustainable aspect by integrating lot sizing, supplier selection and carrier selection problem in a single sustainable procurement and logistics model considering the big data approach. Big data is the proposed model considers 3V's i.e. volume, variety and velocity. Under these 3 Vs, large range of data which is not only voluminous but also dynamic (reflecting velocity aspect of 3V's) are considered. In addition, variety of products through multi-product is considered in the proposed model (reflecting variety aspect of 3 V's). The data sets utilizing

3V's concept of big data generates the possibility of variations either in demand, supplier or carrier capacities. This in turn captures fluctuations and solving the proposed model using 3 V's concept of big data makes the model capable to handle fluctuations to great extent. Therefore, by incorporating big data into supply chain modelling, the model solution is able to absorb the fluctuations. However, to manage the total carbon emissions caused during procurement, carbon cap-and-trade approach is used in the model. Various carbon emission cost incurred during ordering, transportation and holding inventories are also considered. MINLP model is proposed which is further converted to MILP using axioms. Proposed MINLP and MILP are solved for optimality using big data. In addition, these models are also solved heuristically using proposed heuristic (H-1). Following section 3 discuss the proposed models based on big data.

3. PROPOSED JOINT SUSTAINABLE PROCUREMENT AND LOGISTICS MODEL

3.1 Problem statement

The procurement and logistics problem is considered here under a carbon cap and trade scenario, where a mandatory cap over the carbon emissions of a firm is kept. However, carbon emissions saved or exceeded are traded. The problem is multi-period, multi-product, multi-supplier and multi-carrier. In addition, the emissions caused during ordering, holding items, transporting through carriers are also considered in the problem. The problem is to optimize the order allocation among set of available multi-suppliers through available multi-carrier options in a multi-period to optimize the total procurement cost including carbon emission cost. The stated problem considers dynamic lot sizing over multi-period for multi-product among multi-suppliers through multi-carriers in the presence of carbon constraint under cap-and-trade situation.

3.1.1 Linking sustainability:

To incorporate sustainability in the procurement and logistics in the supply chain, the framework is proposed and is shown in Figure 2. The procurement problem involves the process of ordering, holding and logistics. The proposed framework considers carbon emission calculation from procuring products (E_t), holding inventory (E'_t) and logistics ($F_t+F'_t$). The emissions from logistics are further considered as fixed and variable emissions ($F_t+F'_t$). Fixed emissions associated with carriers are a function of type of carrier chosen. The variable emissions associated with carrier are a function of distance travelled by the carrier (d_j), mileage (mil_m), type of fuel carrier is using (emission factor), and load carried by the carrier (X_{ijmt}). The total emissions are managed and controlled using carbon cap and trade policy, where a fixed quota (tons) is allowed for the firm. The emissions saved or exceeded can be traded in carbon market. Hence, the excess emissions are linked to the objective function of the proposed sustainable procurement and logistics model.

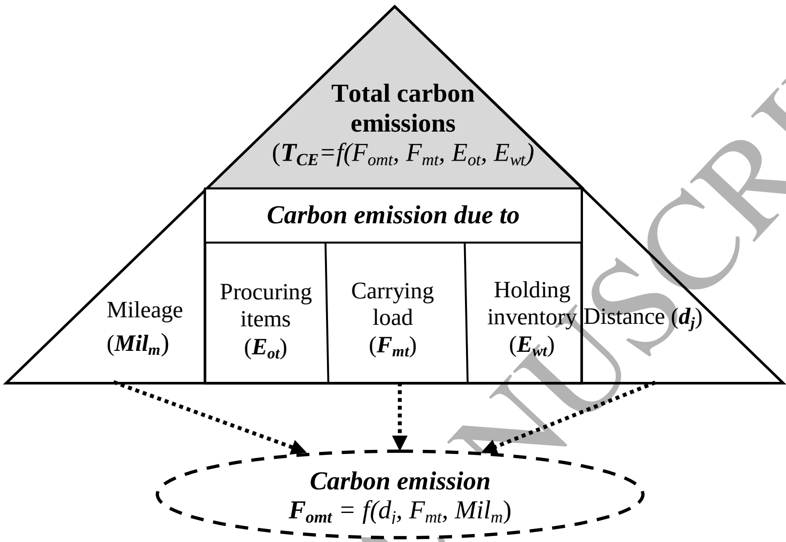


Figure 2: Building blocks for total carbon emissions calculation.

3.1.2 Linking big data:

The proposed sustainable procurement and logistics model is linked with big data using the framework proposed by Lamba and Singh [5]. The proposed framework suggest some of the ways to bring inter and intra heterogeneity by adding 3Vs (i.e. variety, volume and velocity) big data in the parameters of the proposed model. The proposed framework is provided in figure 3. Since the model involves many quantitative parameters such as costs, capacities, emissions and product demand, the 3V essential characteristics are considered for these parameters. Brief discussion on the 3Vs of the big data linked with the parameters of the proposed model is provided below.

Variety: The model considers the multi-period, multi-product, multi-supplier and multi-carrier problem, involving many parameters such as costs, capacities, emissions and demand as a function of time, product, supplier and carrier, hence bringing variety aspect in considered data.

Volume: The proposed framework suggests that considerable volume of data must be considered. Therefore, the proposed model considers the number of suppliers, number of available carriers for each suppliers, number of products and number of periods to include the volume characteristic of big data

Velocity: The parameters considered must also possess the characteristic of velocity as an essential big data characteristic. The velocity is related with the tendency of data to change on real time basis. The considered parameters such as supplier capacity, carrier capacity and demand are changing with respect to each period, product, supplier and carrier.

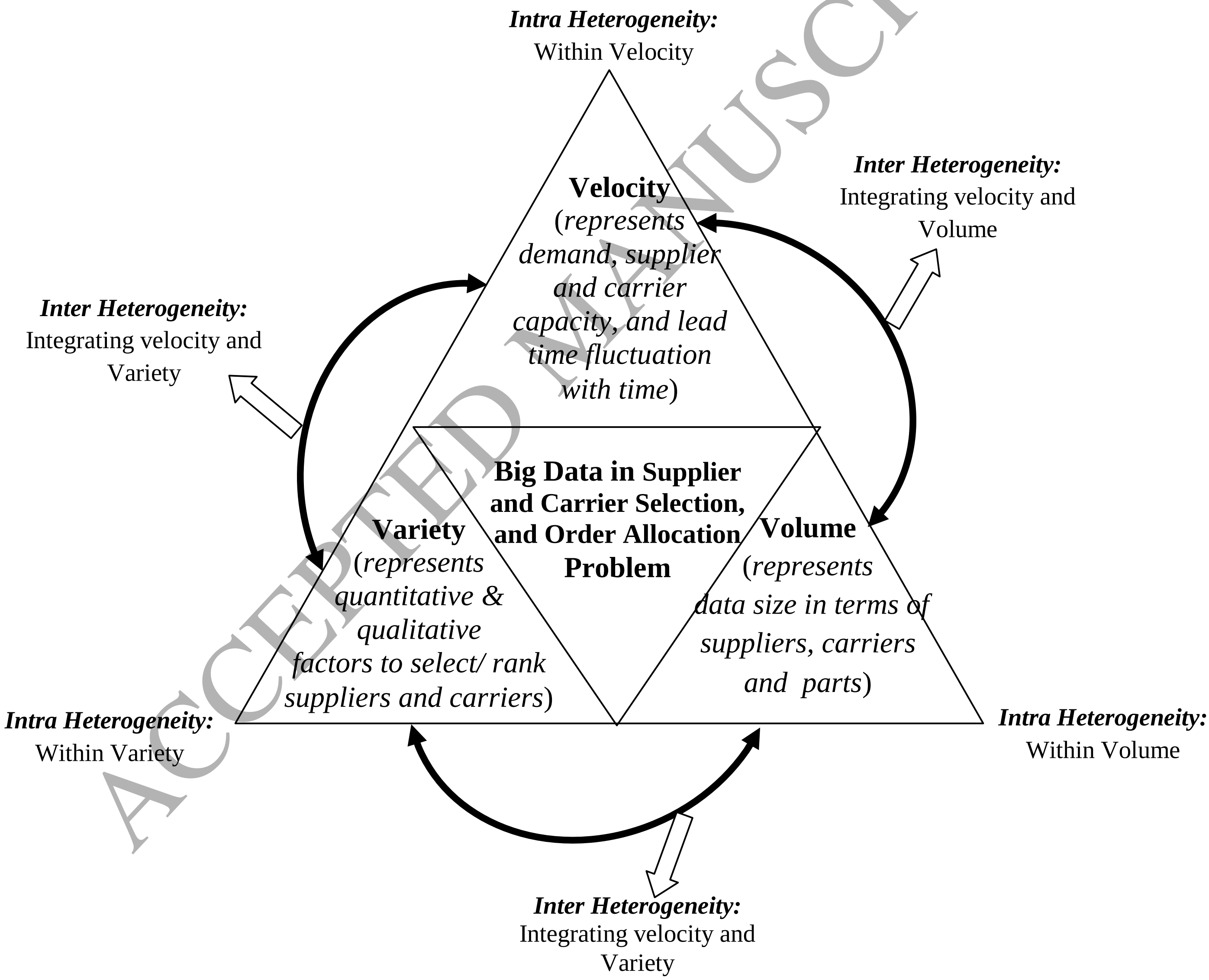


Figure 3: Framework for big data in joint procurement [5]

Therefore, using the big data framework given by Lamba and Singh [5], the essential big data characteristics i.e. 3V's are linked with the proposed sustainable procurement and logistics model.

3.2 List of assumptions

- Demands of the products are deterministic and possess essential big data characteristics in terms of volume, variety and velocity.
- To develop procurement and logistics model using big data, late deliveries and shortages are not allowed.
- Procurement and logistics model using big data captures real time demand or capacity variations for given period.
- Supplier and its carrier capacities are known and dynamic representing essential big data characteristics.
- Logistics activities are assumed to have fixed emissions for an empty carrier (no load) and variable emissions which are a function of lot-size, distance and mileage of the carrier.
- The raw material costs are linear in nature and do not include quantity discounts.

3.3 List of indices, variables and parameters

The list of indices, variables and notations used for model formulation are given below.

3.3.1 List of indices

i index for products

j index for suppliers

m index for carriers

t index for time periods

3.3.2 List of decision variables

X_{ijmt} Lot-size of product i procured from supplier j using carrier m in period t

U_{ijmt} 1 if product i is procured from supplier j using carrier m in period t ELSE 0

Y Extra or spare carbon emissions sold or bought over entire planning horizon

I_{it} Inventory for product i carried from period t to $t+1$

3.3.3 List of parameters

D_{it} Demand for product i in period t

PC_{ijt}	Cost of procuring of product *i* from supplier *j* in period *t*
TC_{jmt}	Cost of transportation from supplier *j* using carrier *m* in period *t*
OC_{it}	Cost of ordering of product *i* procured from supplier *j* in period *t*
HC_{it}	Cost of holding inventory of product *i* period *t*
SC_{ijt}	Capacity of of product *i* with supplier *j* in period *t*
Ω_{jm}	Available truck load capacity of carrier *m* with supplier *j*
V_{jmt}	Total number of carrier *m* available with supplier *j* in period *t*
α	Carbon emissions quota (in tons) for entire planning horizon
C	Carbon price per unit (ton)
F_{mt}, $F'mt$	Amount of carbon emission in executing a lot size of *X* units of product *i* procured from supplier *j* using carrier *m* in period *t*.
F_{mt}	Carbon emissions caused when carrier *m* is empty.
F_{omt}	Variable emission factor in time period *t*
E_t	Amount of carbon emissions caused during placing an order in time period *t*
$E't$	Amount of carbon emissions caused in holding a unit of product at warehouse for period *t*
UL_{it}	Upper tolerance of lead time for product *i* in time period *t*
LL_{it}	Lower tolerance of lead time for product *i* in time period *t*
l_{jmt}	Lead time of supplier *j* using carrier *m* in time period *t*
dj	Distance of supplier *j* from the buyer
mil_m	Mileage (kms/l) of carrier *m*

3.4 Proposed Formulation

The problem is formulated as Mixed Integer Non-Linear Program (MINLP). Further, it is converted to MILP (Mixed Integer Linear Program) applying axiom, which provides optimal solution in relatively less computational time. However, bigger size MILP also consumes high computational time. To solve bigger size MILP problem, heuristic (H-1) is proposed. The t-test significance is conducted on solution quality of bigger size problem between solution obtained from MILP (code terminated after 24 hours of execution) and proposed heuristic. Based on decision variables and parameters, the sustainable procurement and logistics model using big data is formulated as MINLP and is provided below.

$$Minimize\ Z = Z_1 + Z_2 + Z_3 + Z_4 + Z_5 \quad (1)$$

$$Z_1 = \sum_i \sum_j \sum_m \sum_t PC_{ijt} X_{ijmt} \quad (1a)$$

$$Z_2 = \sum_i \sum_j \sum_m \sum_t OC_{it} U_{ijmt} \quad (1b)$$

$$Z_3 = \sum_i \sum_j \sum_m \sum_t TC_{jmt} X_{ijmt} \quad (1c)$$

$$Z_4 = \sum_i \sum_t HC_{it} I_{it} \quad (1d)$$

$$Z_5 = C * Y \quad (1e)$$

$$I_{it-1} + \sum_j \sum_m X_{ijmt} = D_{it} + I_{it} \quad \forall i,t \quad (2)$$

$$X_{ijmt} \leq (\sum_t D_{it})\, U_{ijmt} \quad \forall i,j,m,t \quad (3)$$

$$\sum_m X_{ijmt} \leq SC_{ijt} \quad \forall i,j,t \quad (4)$$

$$\sum_i X_{ijmt} \leq \Omega_{jm} V_{jmt} \quad \forall j,m,t \quad (5)$$

$$\sum_i \sum_j \sum_m \sum_t (F_{mt} + \frac{d_j}{mil_m} * emission\ factor * X_{ijmt}) U_{ijmt} + \sum_i \sum_j \sum_m \sum_t E_t U_{ijmt} + \sum_i \sum_t E'_t I_{it} = \alpha + Y \quad (6)$$

$$LL_{it} \leq U_{ijmt} l_{jmt} \leq UL_{it} \quad \forall i,j,m,t \quad (7)$$

$$X_{ijmt}, I_{it} \geq 0\ and\ are\ integer \quad \forall i,j,m,t \quad (8)$$

$$U_{ijmt} \in \{0,1\} \quad \forall i,j,m,t \quad (9)$$

$$Y\ is\ unrestricted\ sign \quad (10)$$

Equation (1) is the objective function of the proposed MINLP minimizes the total procurement cost including raw material cost (1a), ordering cost (1b), transportation cost (1c), inventory holding cost (1d) and carbon buying or selling cost (1e) over entire planning horizon. Equation (2) represents the inventory balance equation, where the excess inventory carried forward from period *t-1* added to current lot-size procured and is balanced to the demand and current inventory in period *t*. Equation (3) ensures that the lot-sizes X_{ijmt} ordered in any period must not exceed the total demand of the corresponding product *i* over entire planning horizon. Equation (4) is the supplier capacity constraint restricting the lot-size procured to the available supplier capacity. Similarly, Equation (5) is the carrier capacity constraint restricting the total amount procured using a carrier $\sum_i X_{ijmt}$ to the total carrier capacity (i.e. carrier availability*individual carrier capacity) available with supplier in period *t*. Equation (6) is the carbon emission constraint, balancing the carbon emissions (fixed as well as variable) caused by fuel consumption by the carriers and electricity consumption during ordering and holding products to the carbon cap allowed and extra carbon that has to be sold or bought. Equation (7) ensures that products ordered from various suppliers are received within the desired lead time window, if the lead time of the supplier *j* using carrier *m* is greater than the upper tolerance of the firm then that supplier and carrier is not chosen. Non-negativity and integer values of products ordered (X_{ijmt}) and inventory carried forward I_{it} are ensured in equation (8). The binary decision variable U_{ijmt} in equation (9) represents whether j^{th} supplier having m^{th} carrier is selected for i^{th} product in a time period *t* or not. Equation (10) describes the unrestricted nature of carbon emission *Y*, which can be bought or sold from carbon market depending upon its shortage or excess. If *Y* is positive it means that the firm can buy *Y* units of carbon credit from carbon market, and if *Y* is negative the firm can sell the same. *Y* being zero means that the firm neither buys nor sells the carbon credit.

4. SOLUTION METHODOLOGY

In this section, the solution methodology to solve proposed sustainable procurement and logistics is proposed. The proposed model involves cost, capacity and emission parameters on the real time possessing essential big data characteristics (3V's). To incorporate big data characteristics into the joint procurement and logistics problem, Lamba and Singh [5] proposed a big data framework for procurement and logistics. However, the demonstration of the proposed framework for real applications was not provided. This section provides an extension of the theoretical framework to further link it with the modelling of the procurement and logistics using big data. The demonstration of the proposed framework is shown through forty two data sets. These data sets are again generated utilizing the 3 Vs of big data. Since the proposed model is f MINLP, therefore to solve the problem in real time, two other methods (MILP and heuristics H-1) are proposed. The model is solved using both exact and heuristic approaches. The computational experiments for forty two different randomly generated problem instances for time (T) = 2 to 52, products (P) = 3 to 30, supplier (S) = 5 to 15, carrier (M) = 3 to 10, all possessing variety, volume and velocity are carried out. MINLP is solved using exact and heuristic approaches for big data. The proposed model is solved using exact approach which is not able to provide solution in a reasonable computational time for problems possessing big data characteristics. Therefore, a solution methodology is proposed to obtain solution for sustainable procurement and logistics model for big data. The framework is shown in Figure 4. The methodology shows the input parameters for the sustainable procurement and logistics model possessing the big data characteristics (3V's). The model is solved using linearized MINLP which is also referred as MILP. Also a binary relaxation based heuristic (H-1) is proposed to solve the problem instances which are not solved using exact approaches. In the end t-test is conducted between optimal and heuristic solutions for statistical validation. T-test shows that heuristic solution is statistically significant to optimal solution. The solution methodology and solution to computational experiments using both exact and heuristic approaches are discussed as follows.

4.1 Exact approaches

4.1.1 MINLP

The MINLP model is coded and solved in LINGO 10. All executions are carried out in a machine with Windows 7 operating system, Intel core i7 processor and 8 Gb RAM. The model code is shown in Appendix A-I. Forty two computational experiments are carried out on randomly generated problem instances possessing essential big data characteristics (3V's). It is observed from the computational experiments optimal solution is obtained up to problem instances of T=3. Moreover, it is also observed that the model is not able to provide an optimal solution for problems greater than T=3 and involving big data even after running the code for more than 24 hours. However, the feasible solution is obtained in some cases. The same can be observed from Table 3. Also, for the large size problems involving big data the model is not able to provide the feasible solution even after running the model for more than 24 hours. From the table 4, the objective function and corresponding computational time is observed. *** values in the tables indicate that no solution is obtained for running the model for 24 hours, whereas *values indicate that the obtained solution is feasible and solver is interrupted after respective computational time

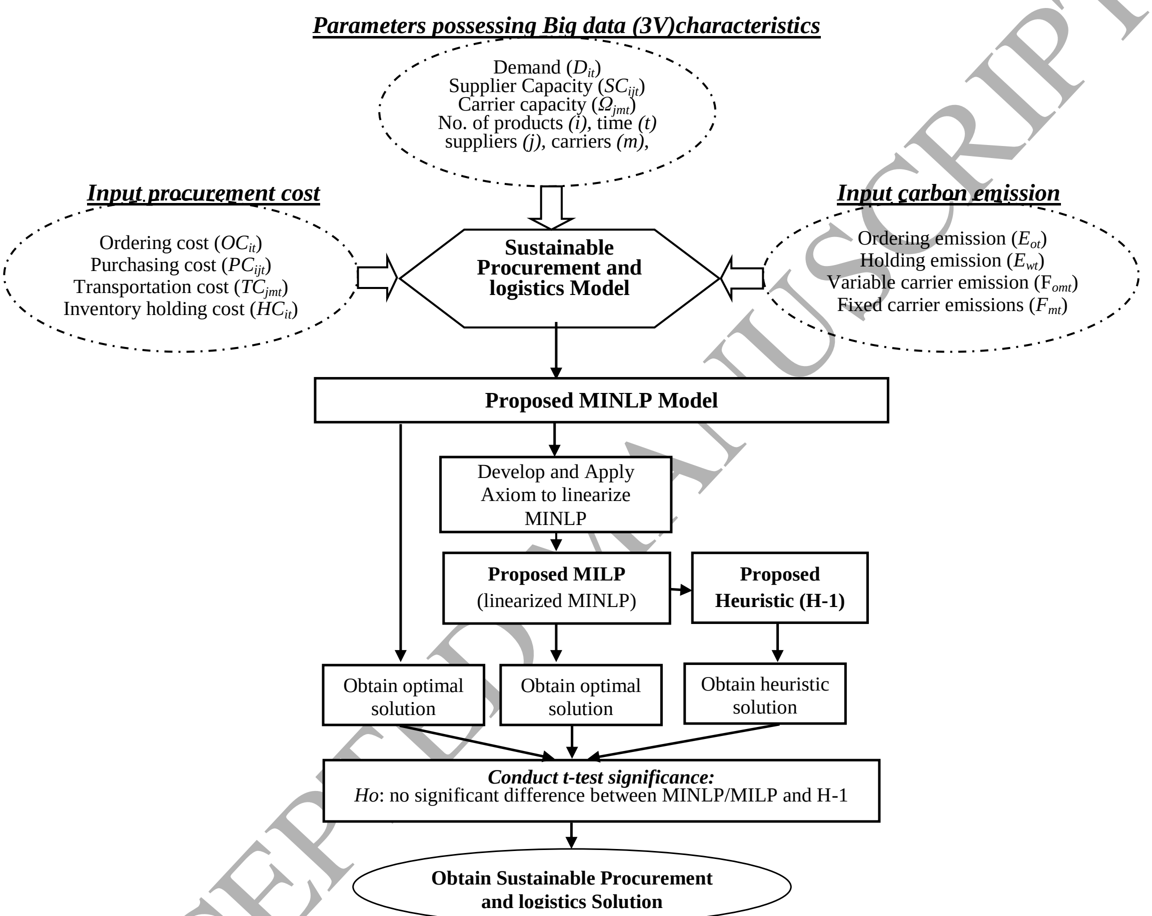


Figure 4: Solution methodology flowchart for sustainable procurement and logistics model using big data

4.1.2 Linearization of MINLP: MILP

In this section, the linear version of proposed sustainable procurement and logistics model is proposed using axioms developed. The proposed MILP provides optimal solution in computational time much lesser than MINLP. This can be also observed from Tables 3 and 4. Following axioms are derived to convert MINLP into MILP.

***Axiom 1*:** When X_{ijmt} is Integer and U_{ijmt} is Binary variable

If X_{ijmt} is positive integer then U_{ijmt} must be 1.

Similarly, if X_{ijmt} is assigned value 0 (i.e.X_{ijmt} =0) then U_{ijmt} must also get assigned 0 value (i.e. U_{ijmt} =0).

Axiom 2: When X_{ijmt} is Real and U_{ijmt} is Binary variable

If U_{ijmt} is assigned value 0 then X_{ijmt} must also get assigned 0 value (i.e.X_{ijmt} =0).

Similarly, if U_{ijmt} is assigned as 1 then X_{ijmt} must also get assigned with positive integer.

On applying Axiom 1, all multiplicative terms (X_{ijmt},U_{ijmt}) appearing in MINLP will be replaced with single term containing X_{ijmt}. Rest of the equations shown in section 3.4 will be kept same. The reformulated linearized model takes lesser computational time to get optimal solution. The same forty two problem instances (30 medium and 12 large) are solved using MILP. It is observed from computational experiments that MILP provides optimal solution in much lesser time as compared to MINLP for the medium size instances possessing big data characteristics. The same is shown in Table 3. It can be further observed that for large sized instances, MILP is also not able to provide optimal solution; however, feasible solution is obtained after running the model for around 24 hours. The same can be observed from Table 4, where feasible solution using MILP is shown for the problems where MINLP was not able to provide any solution.

From the discussion on exact approaches provided in sections 4.1.1 and 4.1.2, it can be concluded that the model is not able to provide optimal solution for large sized problems possessing big data characteristics. Therefore, a binary relaxation based heuristic is proposed to solve the model for big data.

4.2 Heuristic approach

In this section, a heuristic approach is proposed to obtain solution for sustainable procurement and logistics model for big data. As it is observed in section 4.1 that the computational time increases for both MINLP and MILP due to the increase in variables and the presence of big data. Moreover, it is also noticed that even after running for more than 24 hours, the optimal results are not obtained however; feasible solution and local optimum are achieved in some instances. Therefore, a heuristics (H-1) based on binary variable relaxation is proposed. The proposed heuristics (H-1) is tested for all instances medium and large experiments involving big data that were applied earlier for MINLP and MILP. Following are the steps for proposed heuristics (H-1).

Step 1: Relax the binary constraint from MINLP model.

The new model consists of equations (1) to equation (11), equation (13) and (14), and $U_{ijmt} \geq 0$. This is referred as relaxed MINLP

Step 2: Solve the relaxed MILNP model optimally.

Step 3: From the solution obtained by the relaxed MINLP, list all the non-zero values of Binary variable U_{ijmt}

Step 4: Set all non-zero values of U_{ijmt} as 1 and put these as constraint to the original MINLP.

Step 5: Solve the new model optimally.

It is observed that the proposed heuristics solves any size of complex problem possessing essential big data characteristics. The heuristic is also applied to solve all forty two problem instances having 3V's of big data (volume, variety and velocity). The computational time is drastically saved using the proposed heuristics. Moreover, on comparing the heuristic solution with exact solution (MINLP/MILP) it is observed that the difference is minimal. The same is also reflected in the % optimality gap. The heuristic solutions and computational times are also shown in Table 2 and Table 3 for medium and large sized problem instances respectively. From Table 3 it can be seen that for large sized problems possessing big data characteristics even after running solver for around 24 hours, optimum results cannot be achieved in MINLP as well as MILP. However, proposed heuristics (H-1) provides results in few seconds with % optimality gap between 0 to 5.6 %. The similar comparison for objective function values obtained using MILP and % optimality gap for heuristic solution for medium sized instances data is shown in figure 5 and for large sized instances is shown in figure 6. It can be clearly observed that for both the cases percentage error ranges between 0 to 5.6%, which is not very high, considering the amount of time saved. The heuristic solutions are statistically compared with the global optimal solutions obtained using exact approaches. The details of t-test are provided in next section.

Table 3: Comparison between MINLP, MILP and heuristic (H-1) solutions for medium sized problems possessing big data characteristics

S.No	T	P	S	M	T*P*S*M	MINLP		MILP		Heuristics (H-1)		% optimal gap
						Objective value	CPU	Objective value	CPU	Objective value	CPU	
1	2	10	10	5	1000	91600	00:04:09	91600	0:02:00	94242.65	0:00:00	2.88
2	2	15	15	4	1800	398695.2	00:04:51	398695.2	0:01:00	400745.7	0:00:00	0.51
3	2	15	15	4	1800	755843.9	00:04:54	755843.9	0:02:00	755843.9	0:00:00	0.00
4	3	3	5	3	135	233043.2	00:02:35	233043.2	0:04:56	234963.1	0:00:00	0.82
5	3	3	5	3	135	224482.233	00:03:24	224482.233	0:10:00	227138.2	0:01:00	1.18
6	3	10	10	3	900	***	24:12:23	140143.9	02:35:24	143938.3	0:00:00	2.71
7	3	10	10	3	900	***	24:34:12	573362.5	03:54:41	574472.8	0:00:01	0.19
8	3	15	8	4	1440	230140.4*	25:43:34	227070	04:37:41	227070	0:00:00	0.00
9	3	15	8	4	1440	9240998*	24:17:24	9233702	04:10:32	9233720	0:00:00	0.00
10	3	20	15	10	9000	***	67:45:20	275430.8	1:33:00	278596.5	0:00:02	1.15
11	4	8	8	4	1024	1428539	00:22:07	1428539	2:14:11	1428539	0:00:00	0.00
12	4	8	8	4	1024	366034.7	00:35:50	366034.7	0:04:00	368628.9	0:00:00	0.71
13	5	10	10	5	2500	***	28:08:33	11868564.9	0:05:00	11869766	0:00:02	0.01
14	5	10	10	5	2500	***	27:32:45	13178019.4	0:06:00	13182939.1	0:00:02	0.04
15	5	7	8	4	1120	1539305*	24:13:20	1537561	0:05:00	1540183	0:00:02	0.17
16	5	7	8	4	1120	23086708.18*	46:40:26	23074292.6	0:04:00	23075084.2	0:00:00	0.00343
17	5	20	15	10	15000	***	22:14:41	378927.8	0:08:00	381960.1	0:00:02	0.80
18	6	10	10	5	3000	***	24:32:15	19760692.3	0:10:00	19761786.8	0:00:03	0.01
19	6	12	10	5	3600	***	26:25:49	4088326	0:07:00	4089836	0:00:01	0.04
20	6	15	10	7	6300	***	34:22:47	488618.1	0:01:00	496512.3	0:00:02	1.62
21	6	20	15	10	18000	***	45:35:12	434677	0:21:00	444805.9	0:00:03	2.33
22	7	3	5	3	315	81946.1315	24:44:14	81946.1315	0:01:00	85250.85	0:00:01	4.03
23	7	10	10	5	3500	***	24:21:23	290060.2	0:10:00	304721.5	0:00:04	5.05
24	9	10	10	5	4500	***	19:45:06	121517.312	2:14:41	125424.2	0:00:01	3.22
25	10	7	8	4	2240	4553546*	24:42:12	450043.6	0:05:00	453777.6	0:00:01	0.83
26	12	3	5	3	540	***	24:32:15	416666.4	0:04:00	419818.5	0:01:00	0.76
27	12	3	5	3	540	21974475.4	36:37:00	21974475.4	0:02:00	21974475.4	0:00:00	0.00
28	15	3	5	3	675	***	35:15:23	208657.78	2:31:21	211912.6	0:00:00	1.56
29	18	3	5	3	810	***	24:21:42	274241.3	4:43:04	277097.3	0:00:00	1.04
30	20	3	5	3	900	***	24:55:26	303474.9	3:15:17	306330.9	0:00:00	0.94

* Feasible solution obtained on interrupting solver.

*** Solver fails to provide feasible solution and execution was terminated after 24 hours.

Table 4: Comparison between MINLP, MILP and heuristic (H-1) solutions for large sized problems possessing big data characteristics

S.No	T	P	S	M	T*I*J*M	MINLP		MILP		Heuristics(H-1)		% optimal gap
						Objective value	CPU	Objective value	CPU	Objective value	CPU	
1	6	30	15	5	13500	***	43:21:24	6166955*	24:41:33	6291547	0:00:03	2.02
2	7	30	15	5	15750	***	18:24:41	18960538.27*	24:31:45	18967292	0:00:10	0.036
3	7	20	15	5	10500	***	16:52:35	501995.2*	28:02:54	510419	0:00:09	1.68
4	10	30	15	5	22500	***	24:06:33	1204046.955*	1:47:00	1208718	0:00:11	0.39
5	12	10	10	5	6000	***	15:32:45	545592.009*	24:51:10	563875	0:00:01	3.35
6	12	30	15	5	27000	***	22:12:44	2099525*	18:26:45	2106156	0:00:11	0.32
7	15	10	10	5	7500	***	22:14:25	699380.1*	12:14:39	721215	0:00:04	3.12
8	24	3	5	3	1080	361456*	22:18:36	359229*	24:55:16	362085	0:00:01	0.795
9	30	10	10	5	15000	***	26:25:49	7268852*	24:55:26	7277891	0:04:54	0.12
10	34	10	10	5	17000	***	24:32:15	11485259.65*	25:43:34	11496726	0:00:56	0.1
11	42	10	10	5	21000	***	36:37:00	10995948.13*	16:57:22	10996482	0:00:09	0.005
12	52	10	10	5	26000	***	35:15:23	13642131.32*	15:48:32	13657662	0:01:23	0.114

* Feasible solution obtained on interrupting solver.

*** Solver fails to provide feasible solution and execution was terminated after 24 hours.

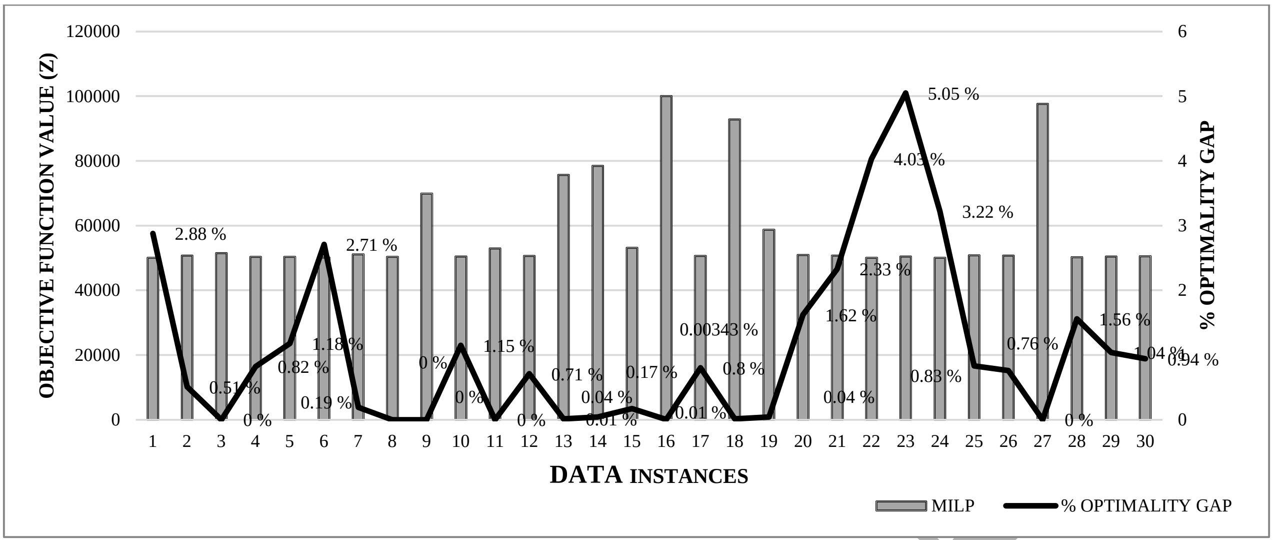


Figure 5: Distribution of optimality gap for all 30 instances for medium size problems.

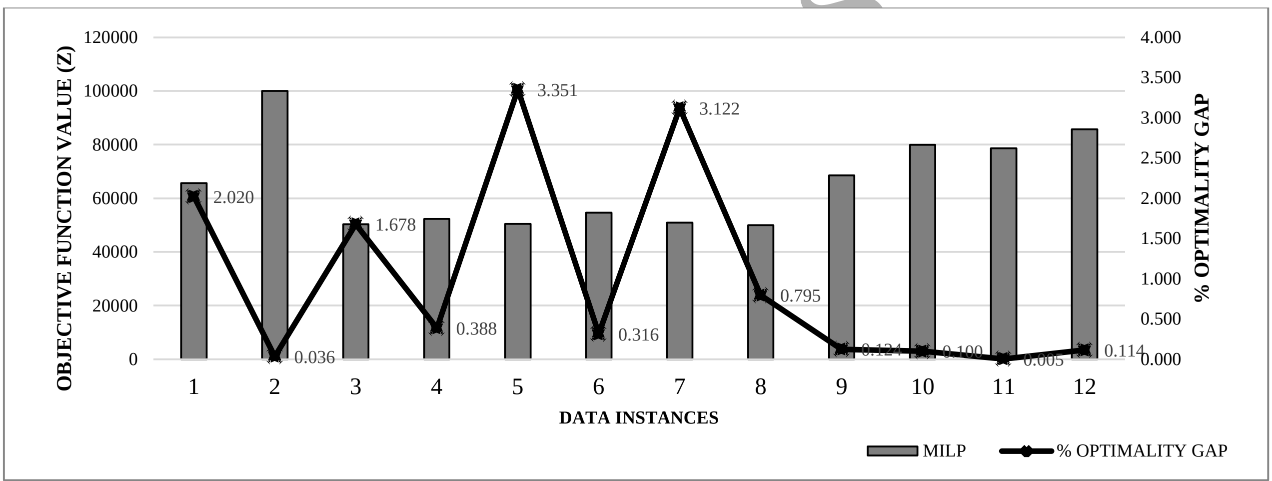


Figure 6: Distribution of optimality gap for all 12 instances for large size problems.

4.3 T-test significance

T-test is conducted in this section to statistically compare the optimal solutions obtained from MINLP/MILP and Heuristic (H-1). The null hypothesis considered for t-test states that there is no significant difference between optimal solution by MILP Model and heuristics (H-1) solution. The t-test is applied separately to medium sized and large sized problem instances possessing big data characteristics. The MILP model is solved for 30 medium sized instances optimally and for 12 large sized instances feasibly. Therefore, the t-test is conducted separately on medium sized and large sized problem instances generated using big data. Now, if the obtained t-value is less than initial t-value from the table, the two methodologies are not significantly difference. Hence, null-hypothesis is accepted, which implies that proposed heuristic can be used for problems where relaxed MINLP/MILP is unable to solve the problem in reasonable time. The table 5 shows the t-test results for both medium and large scale problems on 95% and 99% confidence intervals.

Table 5: t-test significance between objective function value of MINLP/MILP and heuristic (H-1).

	Obtained t Value	Critical t value at 95% confidence interval	Critical t value at 99% confidence interval
MILP vs H-1 (Medium size instances)	0.001789	2.145	2.756
MILP vs H-1 (Large size instances)	.0019711	2.201	3.106

5. COMPUTATIONAL EXPERIMENTS

This section illustrates the proposed solution methodology using two illustrations from the forty two computational experiments already discussed in section 4. In this section two illustrations are solved and discussed in detail. The two examples of different data sizes are discussed. The nomenclature of discussed examples follows (T-P-S-M) structure, where T, P, S, M stands for time periods, products, suppliers and carriers respectively. The illustrative examples are discussed in following subsections.

5.1 Illustration 1: 4T-8P-8S-4M Problem

The procurement and logistics problem of a manufacturing industry is considered here. The industry wants to plan the procurement and logistics decision for next four periods (4T). The industry procures eight products (8P) from eight different suppliers (8P). For the logistics, each supplier can use four different carrier types (4M), however the available capacity to the suppliers might vary. Similarly the demand and supplier capacities may vary. Similarly, the raw material costs, transportation costs, ordering and holding costs may also vary from one period to another. The industry is operating in a carbon trading market, where it is also required to manage and control emissions caused in procurement and logistics. Therefore, carbon emissions for each type of carrier used by supplier, distance travelled and mileage must be considered. Similarly, the carbon emissions for each order placed and for holding per unit of item are also accounted. All these parameters tend to vary. The real-time data fluctuations must be captured in terms of big data. The model using big data is solved using both exact and heuristic approach. The data set considered for the problem is provided in appendix B and C. The lot sizing and optimal solution from both MILP and heuristics are computed.

Table 6: MILP and Heuristic solution for 4T-8P-8S-4M problem possessing big data characteristics.

		T_1	**T_2**	**T_3**	**T_4**
P_1	Demand	500	160	120	160
	lot sizing (MILP)	500	160	120	160
	Optimal solution (MILP)	$X_{(1531)}=40$; $X_{(1811)}=460$; $X_{(1742)}=160$; $X_{(1713)}=120$; $X_{(1714)}=160$			
	lot sizing (H-1)	500	160	120	160
	Heuristic solution (H-1)	$X_{(1531)}=40$;$X_{(1811)}=460$;$X_{(1742)}=160$;$X_{(1713)}=120$;$X_{(1714)}=160$			
P_2	Demand	360	350	300	350
	lot sizing (MILP)	360	350	300	350
	Optimal solution (MILP)	$X_{(2631)}=360$; $X_{(2332)}=140$; $X_{(2742)}=210$; $X_{(2523)}=300$; $X_{(2714)}=350$			
	lot sizing (H-1)	360	350	300	350
	Heuristic solution (H-1)	$X_{(2631)}=360$; $X_{(2332)}=140$; $X_{(2742)}=210$; $X_{(2523)}=90$; $X_{(2713)}=210$; $X_{(2714)}=350$			
P_3	Demand	410	420	200	420
	lot sizing (MILP)	410	420	200	420
	Optimal solution (MILP)	$X_{(3631)}=410$; $X_{(3332)}=420$; $X_{(3713)}=200$; $X_{(3714)}=420$			
	lot sizing (H-1)	410	420	200	420
	Heuristic solution (H-1)	$X_{(3631)}=410$; $X_{(3332)}=180$; $X_{(3742)}=240$; $X_{(3713)}=200$; $X_{(3714)}=420$			
P_4	Demand	280	410	365	410
	lot sizing (MILP)	280	415	360	410
	Optimal solution (MILP)	$X_{(4811)}=280$; $X_{(4332)}=200$; $X_{(4422)}=215$; $X_{(4713)}=360$; $X_{(4134)}=200$; $X_{(4714)}=210$			
	lot sizing (H-1)	280	410	365	410
	Heuristic solution (H-1)	$X_{(4811)}=280$; $X_{(4332)}=200$; $X_{(4422)}=210$; $X_{(4523)}=5$; $X_{(4713)}=360$; $X_{(4134)}=200$; $X_{(4714)}=210$			
P_5	Demand	300	200	200	120
	lot sizing (MILP)	300	200	200	120
	Optimal solution (MILP)	$X_{(5631)}=300$; $X_{(5332)}=200$; $X_{(5713)}=200$; $X_{(5714)}=120$			
	lot sizing (H-1)	300	200	200	120
	Heuristic solution (H-1)	$X_{(5631)}=300$; $X_{(5332)}=200$; $X_{(5713)}=200$; $X_{(5714)}=120$			
P_6	Demand	145	410	365	300
	lot sizing (MILP)	145	410	365	300
	Optimal solution (MILP)	$X_{(6631)}=145$; $X_{(6222)}=30$; $X_{(6332)}=380$; $X_{(6713)}=365$; $X_{(6714)}=300$			
	lot sizing (H-1)	145	410	365	300
	Heuristic solution (H-1)	$X_{(6631)}=145$; $X_{(6222)}=30$; $X_{(6332)}=380$; $X_{(6713)}=365$; $X_{(6714)}=300$			
P_7	Demand	241	200	365	300
	lot sizing (MILP)	241	200	365	300
	Optimal solution (MILP)	$X(_{7631)}=241$; $X_{(7332)=}200$; $X_{(7523)}=55$; $X_{(7713)}=310$; $X_{(7714)}=300$			
	lot sizing (H-1)	241	200	365	300
	Heuristic solution (H-1)	$X_{(7631)}=241$; $X_{(7332)}=200$; $X_{(7523)}=55$; $X_{(7713)}=310$; $X_{(7714)}=300$			
P_8	Demand	200	100	450	200
	lot sizing (MILP)	200	100	450	200
	Optimal solution (MILP)	$X_{(8631)}=200$; $X_{(8332)}=100$; $X_{(8133)}=150$; $X_{(8713)}=300$; $X_{(8714)}=200$			
	lot sizing (H-1)	200	100	450	200
	Heuristic solution (H-1)	$X_{(8631)}=200$; $X_{(8332)}=100$; $X_{(8133)}=150$; $X_{(8713)}=300$; $X_{(8714)}=200$			

The problem instance is solved as sustainable procurement and logistics model. The exact solution suggests lot for lot ordering for all the products except product P_4. However, using heuristic approach suggests lot for lot ordering policy for all the products. It can also be seen from the table 6 that heuristic solution is almost identical to optimal solution in terms of supplier and carrier selection. For instance, the demand of product P_1 for all four time periods is projected as T_1= 500, T_2= 160, T_3= 120 and T_4=160. The optimal solution using exact approach suggests the order allocation for entire planning horizon as $X_{(1531)}$=40; $X_{(1811)}$=460; $X_{(1742)}$=160; $X_{(1713)}$=120; $X_{(1714)}$=160 which exactly same heuristic solution. The same pattern observed for all the products expect for product P_4. The ordering pattern using exact approach is given as $X_{(4811)}$=280; $X_{(4332)}$=200; $X_{(4422)}$=215; $X_{(4713)}$=360; $X_{(4134)}$=200; $X_{(4714)}$=210 , whereas heuristic solution suggests the order allocation for entire planning horizon as $X_{(4811)}$=280; $X_{(4332)}$=200; $X_{(4422)}$=210; $X_{(4523)}$=5; $X_{(4713)}$=360; $X_{(4134)}$=200; $X_{(4714)}$=210. The ordering pattern is different in this case in terms of lot sizes, supplier and carrier selection. The total procurement cost using exact approach is 366034.7 whereas using heuristic approach is given as 368628.9.

There is only 0.71% difference between the total cost obtained using exact and heuristic approach. However, the heuristic solves the problem with big data characteristics in a fraction of a second. The next section shows a similar illustration for relatively larger problem instance possessing big data characteristics.

5.2 Illustration 2: 7T-10P-10S-5M Problem

The procurement and logistics problem of a manufacturing industry for planning horizon of seven time periods (7T) is considered here. The industry procures ten different products (10P) from ten suppliers (10S). The suppliers use five different carrier types (5M) for logistics activities. The procurement and logistics must also be sustainable at the same time owing to government legislations on carbon emissions. The carbon trading policy is being followed by the firm. The data available on buyer side i.e. demand, emissions quota, lead-time tolerances and on supplier side i.e. supplier capacity, carrier capacity, distances travelled, raw material and transportation costs tends to fluctuate from one period to another. It is important for a supply chain to address and absorb these fluctuations. The data is captured on real time basis and possess the essential 3V's of big data. The model integrated with big data is solved using both exact and heuristic approach. The data set considered for the problem is provided in appendix C. The results are reported and compared in Table 7.

Upon solving the problem described above as proposed sustainable procurement and logistics model using exact approach, the model suggests lot for lot ordering for products P_1, P_2, P_8 and P_{10} whereas dynamic lot sizing for P_3, P_4, P_5, P_6, P_7 and P_9. The heuristic approach however suggests lot for lot ordering for products P_1, P_2, P_3, P_4, P_5, P_6, P_8, P_9 and dynamic lot sizing for products P_7 and P_{10}. The detailed ordering plan for product P_1 for projected demand over seven periods (T_1=300, T_2=250, T_3=300, T_4=500, T_5=350, T_6=540 and T_7=200) is given as $X_{(1211)}$=300; $X_{(1312)}$=250; $X_{(1813)}$=300; $X_{(1714)}$=150; $X_{(1844)}$=350; $X_{(1725)}$=350; $X_{(1816)}$=220; $X_{(1926)}$=320; $X_{(1317)}$=200 using exact approach and is $X_{(1611)}$=200; $X_{(11021)}$=100; $X_{(1312)}$=250; $X_{(1813)}$=190; $X_{(1923)}$=110; $X_{(1714)}$=150; $X_{(1844)}$=350; $X_{(1125)}$=100; $X_{(1725)}$=250; $X_{(1116)}$=100; $X_{(1816)}$=120; $X_{(1926)}$=320; $X_{(1317)}$=200 using heuristic approach. Similarly, the detailed ordering plan for product P_2 projected demand over seven periods (T_1=200, T_2=360, T_3=200, T_4=300, T_5=450, T_6=630 and T_7=300) using exact and heuristic approach is given as $X_{(2311)}$=200; $X_{(21022)}$=360; $X_{(2513)}$=200;$X_{(2514)=}$300;$X_{(2125)=}$320;X($_{21015)}$=130; $X_{(2516)}$=300; $X_{(21016)}$=330; $X_{(21027)}$=300 and $X_{(2311)}$=200; $X_{(2312)}$=260; $X_{(2722)}$=100; $X_{(2513)}$=200; $X_{(1514)}$=300; $X_{(1125)}$=320; $X_{(11015)}$=130; $X_{(1516)}$=300; $X_{(11016)}$=330; $X_{(1317)}$=200; $X_{(1527)}$=100 respectively. Similarly, ordering plan for the rest of the products can be seen from Table 7. The ordering pattern is different in this case in terms of lot sizes, supplier and carrier selection. The total procurement cost using exact approach is 290060.2 where as using heuristic approach is given as 304721.5. There is 5.05% difference between the total cost obtained using exact and heuristic approach. However, the heuristic solves the problem with big data characteristics in a fraction of a second.

Similarly, the forty other instances are solved in similar way using both exact and heuristic approach and similarly compared. The model suggests that larger lot-size may lead to less ordering and transportation cost, however, the carbon emissions due to warehouse operations and inventory holding cost are incurred. Similarly, small and frequent lot-size lead to more carbon emissions due to transportation and increased transportation cost, but carbon emissions due to warehouse operations and inventory cost can be saved. Hence, the optimal lot-size must be ordered from suitable supplier(s) using appropriate carriers such that both the procurement cost and carbon emissions cost are minimized.

Table 7: MILP and Heuristic solution for 7T-10P-10S-5M problem possessing big data characteristics.

		T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**
P_1	Demand	300	250	300	500	350	540	200
	lot sizing (MILP)	300	250	300	500	350	540	200
	Optimal solution (MILP)	$X_{(1211)}=300$; $X_{(1312)}=250$; $X_{(1813)}=300$; $X_{(1714)}=150$; $X_{(1844)}=350$; $X_{(1725)}=350$; $X_{(1816)}=220$; $X_{(1926)}=320$; $X_{(1317)}=200$						
	lot sizing (H-1)	300	250	300	500	350	540	200
	Heuristic solution (H-1)	$X_{(1611)}=200$; $X_{(11021)}=100$; $X_{(1312)}=250$; $X_{(1813)}=190$; $X_{(1923)}=110$; $X_{(1714)}=150$; $X_{(1844)}=350$; $X_{(1125)}=100$; $X_{(1725)}=250$; $X_{(1116)}=100$; $X_{(1816)}=120$; $X_{(1926)}=320$; $X_{(1317)}=200$						
P_2	Demand	200	360	200	300	450	630	300
	lot sizing (MILP)	200	360	200	300	450	630	300
	Optimal solution (MILP)	$X_{(2311)}=200$; $X_{(21022)}=360$; $X_{(2513)}=200$;$X_{(2514)=}300$;$X_{(2125)=}320$;$X(_{21015)}=130$; $X_{(2516)}=300$; $X_{(21016)}=330$; $X_{(21027)}=300$						
	lot sizing (H-1)	200	360	200	300	450	630	300
	Heuristic solution (H-1)	$X_{(2311)}=200$;$X_{(2312)}=260$;$X_{(2722)}=100$;$X_{(2513)}=200$;$X_{(1514)}=300$; $X_{(1125)}=320$; $X_{(11015)}=130$;$X_{(1516)}=300$; $X_{(11016)}=330$; $X_{(1317)}=200$; $X_{(1527)}=100$						
P_3	Demand	120	115	100	400	500	530	450
	lot sizing (MILP)	120	115	100	430	500	500	450
	Optimal solution (MILP)	$X_{(3721)}=120$; $X_{(3312)}=115$; $X_{(3213)}=100$; $X_{(3314)}=130$; $X_{(3714)}=300$;$X_{(3125)}=500$; $X_{(3116)}=500$; $X_{(3317)}=300$; $X_{(3817)}=150$						
	lot sizing (H-1)	120	115	100	400	500	530	450
	Heuristic solution (H-1)	$X_{(3721)}=120$; $X_{(3312)}=115$; $X_{(3213)}=100$; $X_{(3314)}=100$;$X_{(3714)}=300$; $X_{(3125)}=200$; $X_{(3725)}=100$; $X_{(3815)}=200$; $X_{(3116)}=500$; $X_{(3316)}=30$; $X_{(3317)}=300$; $X_{(3817)}=150$						
P_4	Demand	250	220	250	300	600	410	350
	lot sizing (MILP)	250	220	250	300	650	410	300
	Optimal solution (MILP)	$X_{(4311)}=250$; $X_{(4212)}=220$; $X_{(4513)}=250$; $X_{(4714)}=300$; $X_{(4125)}=350$; $X_{(4725)}=300$; $X_{(4516)}=410$; $X_{(4527)=}300$						
	lot sizing (H-1)	250	220	250	300	600	410	350
	Heuristic solution (H-1)	$X_{(4311)}=250$; $X_{(4722)}=130$; $X_{(4812)}=90$; $X_{(4513)}=250$; $X_{(4514)}=170$; $X_{(4714)}=130$; $X_{(4125)}=300$; $X_{(4725)}=300$; $X_{(4516)}=410$; $X_{(4527)}=300$; $X_{(41027)}=50$						
P_5	Demand	225	320	320	200	300	350	250
	lot sizing (MILP)	225	440	200	200	350	300	250
	Optimal solution (MILP)	$X_{(5211)}=225$;$X_{(5312)}=300$; $X_{(5722)}=140$; $X_{(5923)}=200$; $X_{(5314)}=200$; $X_{(5315)}=220$; $X_{(5725)}=130$; $X_{(5926)}=300$; $X_{(5317)}=250$						
	lot sizing (H-1)	225	320	320	200	300	350	250
	Heuristic solution (H-1)	$X_{(5211)}=225$;$X_{(5312)}=300$; $X_{(5722)}=20$; $X_{(5213)}=120$; $X_{(5923)}=200$; $X_{(5314)}=70$; $X_{(5714)}=130$; $X_{(5125)}=140$; $X_{(5315)}=30$; $X_{(5725)}=130$; $X_{(5116)}=50$; $X_{(5926)}=300$; $X_{(5317)}=250$						
P_6	Demand	320	185	410	350	200	250	130
	lot sizing (MILP)	320	185	410	350	200	260	120
	Optimal solution (MILP)	$X_{(6211)=250}$; $X_{(6311)}=70$; $X_{(6722)}=185$; $X_{(6413)}=210$; $X_{(6923)}=200$; $X_{(6514)}=350$; $X_{(6125)}=200$; $X_{(6416)}=100$; $X_{(6926)}=160$;						

		$X_{(6937)}$=120						
	lot sizing (H-1)	320	185	410	350	200	250	130
	Heuristic solution (H-1)	X_{320}=250 ;$X_{(6311)}$=70; $X_{(6722)}$=185; $X_{(6413)}$=210; $X_{(6923)}$=200; $X_{(6414)}$=190; $X_{(6514)}$=160; $X_{(6445)}$=160; $X_{(6815)}$=40; $X_{(6416)}$=90; $X_{(6926)}$=160; $X_{(6317)}$=10; $X_{(6937)}$=120						
P_7	Demand	175	120	260	360	100	200	190
	lot sizing (MILP)	175	120	260	460	0	200	190
	Optimal solution (MILP)	X($_{7311)}$=175;$X_{(7722)}$=120;$X_{(7923)}$=260;$X_{(7514)}$=310;$X_{(7714)}$=150; $X_{(7116)}$=200;$X_{(7317)}$=190						
	lot sizing (H-1)	195	100	260	460	0	200	190
	Heuristic solution (H-1)	$X_{(7311)}$=95; $X_{(7721)}$=100; $X_{(7312)}$=100; $X_{(7513)}$=210; $X_{(7923)}$=50; $X_{(7514)}$=310; $X_{(7714)}$=150; $X_{(7116)}$=200; $X_{(7317)}$=190						
P_8	Demand	220	300	320	450	470	300	390
	lot sizing (MILP)	220	300	320	450	470	300	390
	Optimal solution (MILP)	$X_{(8811)}$=220; $X_{(8812)}$=300; $X_{(81013)=}$320; $X_{(8414)=}$450; $X_{(8925)=}$470; X($_{8926)=}$300; $X_{(8527)=}$390						
	lot sizing (H-1)	220	300	320	450	470	300	390
	Heuristic solution (H-1)	$X_{(8811)}$=220; $X_{(8312)}$=200; $X_{(8812)}$=100; $X_{(8413)}$=180; $X_{(8923)}$=140; $X_{(8414)}$=450; $X_{(8125)}$=100; $X_{(8445)}$=70; $X_{(8815)}$=300; $X_{(8926)}$=300; $X_{(8317)}$=200; $X_{(8447)}$=150; $X_{(8817)}$=40						
P_9	Demand	280	200	100	500	350	200	250
	lot sizing (MILP)	280	380	0	420	350	200	250
	Optimal solution (MILP)	$X_{(9211)}$=280; $X_{(9212)}$=180;$X_{(9812)}$=200; $X_{(9414)}$=420; $X_{(9125)}$=350; $X_{(9926}$)=200;$X_{(9937}$)=250						
	lot sizing (H-1)	280	200	100	500	350	200	250
	Heuristic solution (H-1)	$X_{(9721)}$=180; $X_{(9811)}$=100;$X_{(9812)}$=200; $X_{(9923)}$=100; $X_{(9414)}$=420 ; $X_{(9514)}$=28; $X_{(9714)}$=52; $X_{(9125)}$=138; $X_{(9725)}$=52;$X_{(9815)}$=160; $X_{(9926)}$=200; $X_{(9937)}$=250						
P_{10}	Demand	315	365	250	150	340	100	360
	lot sizing (MILP)	315	365	250	150	340	100	360
	Optimal solution (MILP)	$X_{(10721)=}$315;$X_{(10312)}$=365;$X_{(10513)}$=250;$X_{(10514}$)=150;$X_{(10125)}$=340; $_{(10516}$)=100;$X_{(10527}$)=360						
	lot sizing (H-1)	315	365	250	150	440	0	360
	Heuristic solution (H-1)	$X_{(10311)}$=100; $X_{(10721)}$=215; $X_{(10312)}$=165; $X_{(10722)}$=200; $X_{(10513)}$=250; $X_{(10514)}$=150; $X_{(10125)}$=90; $X_{(10725)}$=100;$X_{(10815)}$=250; $X_{(10527)}$=360						

6. CONCLUSION AND FUTURE SCOPE OF WORK

This paper proposes a joint procurement and logistics model for a sustainable supply chain. The model is able to provide a joint decision for lot sizing, supplier and carrier selection. The model considers carbon trading policy to account and manage total emissions caused during procurement and logistics, where excess/saved emissions are directly linked to the objective function in terms of carbon cost. Hence, an effective and optimal trade-off between the economic gains of a firm and its environmental responsibilities is established by simultaneously minimizing the procurement cost and carbon emissions cost. The model is solved using parameters possessing big data characteristics (3V's). Big data captures real time changes in the parameters in terms of costs, capacities and demand fluctuations. Therefore, by incorporating big data into supply chain modelling, the model solution is able to absorb the fluctuations. However, to manage the total carbon emissions caused during procurement, carbon cap-and-trade approach is used in the model. Various carbon emission cost incurred during ordering, transportation and holding inventories are also considered. However, it is also shown in this paper that incorporation of big data into modelling increases the computational time and model is not able to solve optimally. Therefore, axioms are developed to relax the model which can effectively solve problem optimally upto 18 time periods. A heuristic (H-1) is also proposed for large sized problems using big data which provides solution very near to optimal (with upto 5% error). Large sized problems possessing big data characteristics are solved in fraction of a minute using proposed heuristics (H-1). The proposed sustainable procurement and logistics model using big data can also be attempted using different meta-heuristics, or a new heuristic approach to further improve and compare the proposed heuristic can also be proposed. The proposed model can also be extended for stochastic parameters along with big data in future. In addition, the proposed model can also be extended considering late deliveries and shortages.

Acknowledgment:

Authors thank anonymous referee for their valuable comments which has improved the quality of the manuscript.

References

[1] Fahimnia, B, Jabbarzadeh, A. Marrying supply chain sustainability and resilience: A match made in heaven. Transp Res Part E: Log & Transp Rev 2016; 91: 306-24.

[2] Brown, B, Chui, M, Manyika, J. Are you ready for the era of 'big data'. McKinsey Quarterly 2011; 4(1): 24-35.

[3] Wamba, S F, Akter, S, Edwards, A, Chopin, G, Gnanzou, D. How 'big data'can make big impact: Findings from a systematic review and a longitudinal case study. Int J Prod Eco 2015; 165: 234-46.

[4] Tayal, A, Singh, S P. Integrating Big Data analytic and hybrid firefly-chaotic simulated annealing approach for facility layout problem, Ann Oper Res 2016;pp 1–26 [online] http://link.springer.com/article/10.1007/s10479-016-2237-x.

[5] Lamba, K., Singh, S.P. Big Data analytics in supply chain management: some conceptual frameworks, Int J Auto & Log 2016; 2(4): 279-93.

[6] Geffen, C A, Rothenberg, S. Suppliers and environmental innovation: the automotive paint process. Int J Oper & Prod Manag 2000; 20(2):166-86.

[7] Presley, A, Meade, L, Sarkis, J. A strategic sustainability justification methodology for organisational decisions: a reverse logistics illustration. Int J Prod Res 2007; 45 (18–19):4595–620.

[8] Ciliberti, F, Pontrandolfo, P, Scozzi, B. Logistics social responsibility: standard adoption and practices in Italian companies. Int J Prod Eco 2008; 113;88–106.

[9] Seuring, S, Muller, M. From a literature review to a conceptual framework for sustainable supply chain management. J Clean Prod 2008;16 (15):1699–1710.

[10] Bai, C, Sarkis, J. Integrating sustainability into supplier selection with grey system and rough set methodologies, Int J Prod Eco 2010;124:252–64.

[11] Kumar, A, Jain, V. Supplier Selection: A Green Approach with Carbon Footprint Monitoring, 8th International Conference on Supply Chain Management and Information Systems (SCMIS), Hong Kong 2010;1-8.

[12] Hsu, CW, Chen, S H, Chiou, C Y. A Model for Carbon Management of Supplier Selection in Green Supply Chain Management, IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Singapore 2011; 1247 – 50.

[13] Venkat, K. Analyzing and optimizing the environmental performance of supply chains. Proceedings of the ACCEE summer study on Energy Efficiency in Industry. White Plains, New White Plains, New York, US 2007.

[14] Tao, Z, Guiffrida, A L, Troutt, M D. A green cost based economic production/order quantity model. In Proceedings of the 1st Annual Kent State International Symposium on Green Supply Chains, Canton, Ohio, US 2010.

[15] Helmrich, M R, Van den Heuvel, W, Wagelm, A P. The economic lot sizing problem with an emission constraint, 2nd International Workshop on Lot Sizing, Istanbul, Turkey 2011; pp 45-48.

[16] Battini, D, Persona, A, Sgarbossa, F. A sustainable EOQ model: theoretical formulation and applications. Research report, Department of Management and Engineering, University of Padua; 2012.

[17] Benjaafar, S, Li, Y, Daskin, M. Carbon Footprint and the Management of Supply Chains: Insights from Simple Models, IEEE Trans Auto Sci & Engg 2013;10 (1): 99-116.

[18] Abdallah, T, Diabat, A, & Simchi-Levi, D. A carbon sensitive supply chain network problem with green procurement. In Computers and Industrial Engineering (CIE), 40th International Conference on IEEE. 2010.pp. 1-6.

[19] Sarkis, J, Dhavale, D G. Supplier selection for sustainable operations: A triple-bottom-line approach using a Bayesian framework. Int J Prod Eco 2015; 166:177-91.

[20] Jaber, M Y, Glock, C H, El Saadany, A M. Supply chain coordination with emissions reduction incentives. Int J Prod Res 2013; 51(1):69-82.

[21] Yugang, Y, Zhaofu, H, Chengbin, C, Liang, L. A Dynamic Lot Sizing Model with Carbon Emission Constraint and Multi-mode Production: A General Property and a Polynomially Solvable Case, 10th IEEE International Conference on Networking, Sensing and Control (ICNSC) 2012; pp 414-417.

[22] Lee, K H. Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry, J Clean Prod 2011; 19(11):1216-23.

[23] Saadany, AMAE, Jaber, MY, Bonney, M. Environmental performance measures for supply chains. Manag Res Rev 2011;34:1202–21.

[24] Bouchery, Y, Ghaffari, A, Jemai, Z, Dallery, Y. Including sustainability criteria into inventory models. Euro J Oper Res 2012; 222: 229–40.

[25] Zeng, W, Wang, C, Zhou, H. Study on Supply Chain Operations under Carbon Emission Regulatory Policies, International Conference on Information Management, Innovation Management and Industrial Engineering 2012: pp506-509.

[26] McKinnon, A. Environmental sustainability. In. Green logistics: improving the environmental sustainability of logistics. London 2010.

[27] Sheu, J, Chou YH, Hu, CC. An integrated logistics operational model for green-supply chain management, Transp Res Part E 2005; 41:287–313.

[28] Cholette S, Venkat, K. The energy and carbon intensity of wine distribution: A study of logistical options for delivering wine to consumers, J Cleaner Prod 2009; 17:1401–13.

[29] Ubeda, S, Arcelus, FJ, Faulin, J. Green logistics at Eroski: A case study, Int J Prod Eco 2011; 131: 44–51.

[30] Liao, Z, Rittscher, J. A multi-objective supplier selection model under stochastic demand conditions. Int J Prod Eco 2007; 105(1);150-59.

[31] Songhori, M J, Tavana, M, Azadeh, A, Khakbaz, M Z. A supplier selection and order allocation model with multiple transportation alternatives, Int J Adv Manuf Tech 2011; 52: 365–76.

[32] Palak, G, Ekşioğlu, S D, Geunes, J. Analyzing the impacts of carbon regulatory mechanisms on supplier and mode selection decisions: An application to a biofuel supply chain. Int J Prod Eco 2014; 154:198-16.

[33] Kaur H, Singh S P. Modelling Flexible Procurement Problem, In Sushil, K.T. Bhal, S.P. Singh (Eds.), Managing Flexibility: People, Process, Technology and Business ; pp.147-170, Springer, New Delhi.

[34] Kaur, H, Singh, S P, Glardon, R. An Integer Linear Program for Integrated Supplier Selection: A Sustainable Flexible Framework. Glob J Flex Syst Man 2016;17(2):113-34.

[35] Mishra, S, Modi, S B, Animesh, A. The relationship between information technology capability, inventory efficiency, and shareholder wealth: A firm-level empirical analysis. J Oper Man 2013;31(6): 298-12.

[36] Waller, M A, Fawcett, S E. Data science, predictive analytics, and big data: a revolution that will transform supply chain design and management. J Bus Log 2013;34(2):77-14.

[37] Stefanou, C. Supply chain management (SCM) and organizational key factors for successful implementation of enterprise resource planning (ERP) systems. In AMCIS 1999 Proc 1999, pp. 276

[38] Tarn, J M, Yen, D C, Beaumont, M. Exploring the rationales for ERP and SCM integration. Ind Man & Data Syst 2002; 102(1): 26-34.

[39] Gunasekaran, A, Ngai, E W. Information systems in supply chain integration and management. Euro J Oper Res 2004;159(2):269-95.

[40] Bose, I, Pal, R, Ye, A. ERP and SCM systems integration: The case of a valve manufacturer in China. Info & Man 2008; 45(4): 233-41.

[41] Pereira, J V. The new supply chain's frontier: Information management. Int J Info Mngmt 2009; 29(5): 372-79.

[42] O'Leary, D E. Supporting decisions in real-time enterprises: autonomic supply chain systems. Info Syst & E-Bus Man 2008; 6(3): 239-55.

[43] Perea-Lopez, E, Ydstie, B E, Grossmann, I E. A model predictive control strategy for supply chain optimization. Comp & Chem Engg 2003; 27(8):1201-18.

[44] Ilic, A, Andersen, T, Michahelles, F . Increasing supply-chain visibility with rule-based RFID data analysis. IEEE Internet Computing 2009;13(1): 31-8.

[45] Geerts, G L, O'Leary, D. E. A supply chain of things: The EAGLET ontology for highly visible supply chains. Decis Support Syst 2014; 63, 3-22.

[46] Kwon, O Lee, N, Shin, B. Data quality management, data usage experience and acquisition intention of big data analytics. Int J Info Man 2014; 34(3); 387-94.

[47] Tan, K H, Zhan, Y, Ji, G, Ye, F, Chang, C. Harvesting big data to enhance supply chain innovation capabilities: An analytic infrastructure based on deduction graph. Int J Prod Eco 2015; 165: 223-33.

[48] Ng, I, Scharf, K, Pogrebna, G, Maull, R. Contextual variety, Internet-of-Things and the choice of tailoring over platform: Mass customisation strategy in supply chain management. Int J Prod Eco 2015; 159:76-17.

Appendix A
(LINGO code of the proposed MINLP)

```
SETS:
TIME/1..4/;  !T;
PRODUCT/1..8/; !I;
SUPPLIER/1..8/; !J;
CARRIER/1..4/; !M;
PXSXCXT(TIME,PRODUCT,SUPPLIER,CARRIER):x,U;
PXSXT(TIME,PRODUCT,SUPPLIER):PC, SC;
PXT(TIME,PRODUCT):In,D,HC,UL, LL , OC;
SXC(SUPPLIER,CARRIER):CC, E ;
CXT(TIME,CARRIER):  Fm;
CONSTANT(TIME):W, Em, Qm;
SXCXT(TIME,SUPPLIER,CARRIER):V, G, TC;
S(SUPPLIER):B;
PXSXC(PRODUCT,SUPPLIER,CARRIER);
PXCXT(PRODUCT, CARRIER, SUPPLIER);
R(CARRIER):K;
ENDSETS

MIN = Z1+Z2+Z3+Z4+Z5;

Z1= @SUM(PXSXCXT(T,I,J,M):PC(T,I,J)*x(T,I,J,M));
Z2= @SUM(PXSXCXT(T,I,J,M):OC(T,I)*U(T,I,J,M));
Z3= @SUM(PXSXCXT(T,I,J,M):TC(T,J,M)*x(T,I,J,M));
Z4= @SUM(PXT(T,I):HC(T,I)*In(T,I));
Z5= (Yt/1000)*C;
Z1+Z2+Z3+Z4+Z5=Z;
!THE INVENTORY BALANCE CONSTRAINT;
@FOR(TIME(T)|T#EQ#0:@SUM(PRODUCT(I):In(T,I))= 0);
@FOR (TIME(T)|T#EQ#1:@FOR(PRODUCT(I):@SUM(SXC(J,M):x(T,I,J,M))-D(T,I)-
In(T,I)= 0));
@FOR(TIME(T)|T#GE#2:@FOR(PRODUCT(I):@SUM(SXC(J,M):x(T,I,J,M))-D(T,I)-
In(T,I)+In(T-1,I)=0));
!CARRIER AVAILABILITY CONSTRAINT;
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J):@FOR(CARRIER(M): x(T,I,J,M) <=
CC(J,M)*V(T,J,M)*U(T,I,J,M)))));
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @FOR(CARRIER(M):
G(T,J,M)*U(T,I,J,M)<= UL(T,I)))));
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @FOR(CARRIER(M):
G(T,J,M)*U(T,I,J,M)>= LL(T,I)))));
@SUM(PXT(T,I):Qm(T)*In(T,I))+@SUM(PXSXCXT(T,I,J,M):Em(T)*U(T,I,J,M))+
@SUM(PXSXCXT(T,I,J,M):Fm(T,M)*U(T,I,J,M))+@SUM(PXSXCXT(T,I,J,M):(B(J)*x(T,I,J
,M)* U(T,I,J,M)*2.39/K(M)))= Yt+10000;
!WAREHOUSE STORAGE CONSTRAINT;
@FOR(TIME(T): @SUM(PRODUCT (I):In(T,I)) <= W (T));

!THE SUPPLIERS CAPACITY CONSTRAINT;
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @SUM(CARRIER(M):x(T,I,J,M)) <=
SC(T,I,J))));
@FOR (PXSXCXT(T,I,J,M):@BIN(U));
@FOR (PXSXCXT:@GIN(X));
@FOR (PXT:@GIN (In));
@FREE(Yt);
Data:
```

```
!Import the Data from Excel Sheet;
PC, OC, SC, TC, CC, V, HC, D, B, K, G, UL, LL, Fm, W, Em, Qm, C =
@OLE('D:\MODEL\4T8P8S4M.XLSX', 'PC', 'OC', 'SCL', 'TC', 'CCL', 'V', 'HC',
'DL','B', 'A', 'G', 'UL', 'LL', 'Fm', 'W', 'Em', 'Qm', 'C_');
!Export LINGO results to excel sheet;
@OLE('D:\ MODEL \4T8P8S4M.XLSX',  'x', 'U', 'Y', 'Z', 'Z1_', 'Z2_', 'Z3_',
'Z4_', 'Z5_' ) = x, U, Yt, Z,  Z1, Z2, Z3, Z4, Z5;

ENDDATA
```

Appendix B
(LINGO code of the proposed MILP)

```
SETS:
TIME/1..4/;  !T;
PRODUCT/1..8/; !I;
SUPPLIER/1..8/; !J;
CARRIER/1..4/; !M;
PXSXCXT(TIME,PRODUCT,SUPPLIER,CARRIER):x,U;
PXSXT(TIME,PRODUCT,SUPPLIER):PC, SC;
PXT(TIME,PRODUCT):In,D,HC,UL, LL , OC;
SXC(SUPPLIER,CARRIER):CC, E ;
CXT(TIME,CARRIER):  Fm;
CONSTANT(TIME):W, Em, Qm;
SXCXT(TIME,SUPPLIER,CARRIER):V, G, TC;
S(SUPPLIER):B;
PXSXC(PRODUCT,SUPPLIER,CARRIER);
PXCXT(PRODUCT, CARRIER, SUPPLIER);
R(CARRIER):K;
ENDSETS

MIN = Z1+Z2+Z3+Z4+Z5;

Z1= @SUM(PXSXCXT(T,I,J,M):PC(T,I,J)*x(T,I,J,M));
Z2= @SUM(PXSXCXT(T,I,J,M):OC(T,I)*U(T,I,J,M));
Z3= @SUM(PXSXCXT(T,I,J,M):TC(T,J,M)*x(T,I,J,M));
Z4= @SUM(PXT(T,I):HC(T,I)*In(T,I));
Z5= (Yt/1000)*C;
Z1+Z2+Z3+Z4+Z5=Z;
!THE INVENTORY BALANCE CONSTRAINT;
@FOR(TIME(T)|T#EQ#0:@SUM(PRODUCT(I):In(T,I))= 0);
@FOR (TIME(T)|T#EQ#1:@FOR(PRODUCT(I):@SUM(SXC(J,M):x(T,I,J,M))-D(T,I)-
In(T,I)= 0));
@FOR(TIME(T)|T#GE#2:@FOR(PRODUCT(I):@SUM(SXC(J,M):x(T,I,J,M))-D(T,I)-
In(T,I)+In(T-1,I)=0));
!CARRIER AVAILABILITY CONSTRAINT;
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J):@FOR(CARRIER(M): x(T,I,J,M) <=
CC(J,M)*V(T,J,M)*U(T,I,J,M)))));
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @FOR(CARRIER(M):
G(T,J,M)*U(T,I,J,M)<= UL(T,I)))));
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @FOR(CARRIER(M):
G(T,J,M)*U(T,I,J,M)>= LL(T,I)))));
@SUM(PXT(T,I):Qm(T)*In(T,I))+@SUM(PXSXCXT(T,I,J,M):Em(T)*U(T,I,J,M))+
@SUM(PXSXCXT(T,I,J,M):Fm(T,M)*U(T,I,J,M))+@SUM(PXSXCXT(T,I,J,M):(B(J)*x(T,I,J
,M)*2.39/K(M)))= Yt+10000;
!WAREHOUSE STORAGE CONSTRAINT;
@FOR(TIME(T): @SUM(PRODUCT (I):In(T,I)) <= W (T));

!THE SUPPLIERS CAPACITY CONSTRAINT;
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @SUM(CARRIER(M):x(T,I,J,M)) <=
SC(T,I,J))));
@FOR (PXSXCXT(T,I,J,M):@BIN(U));
@FOR (PXSXCXT:@GIN(X));
@FOR (PXT:@GIN (In));
@FREE(Yt);
Data:
```

```
!Import the Data from Excel Sheet;
PC, OC, SC, TC, CC, V, HC, D, B, K, G, UL, LL, Fm, W, Em, Qm, C =
@OLE('D:\MODEL\4T8P8S4M.XLSX', 'PC', 'OC', 'SCL', 'TC', 'CCL', 'V', 'HC',
'DL','B', 'A', 'G', 'UL', 'LL', 'Fm', 'W', 'Em', 'Qm', 'C_');
!Export LINGO results to excel sheet;
@OLE('D:\ MODEL \4T8P8S4M.XLSX',  'x', 'U', 'Y', 'Z', 'Z1_', 'Z2_', 'Z3_',
'Z4_', 'Z5_' ) = x, U, Yt, Z,  Z1, Z2, Z3, Z4, Z5;
```

Appendix C
(LINGO code of the proposed heuristic (H-1))

```
SETS:
TIME/1..4/;  !T;
PRODUCT/1..8/; !I;
SUPPLIER/1..8/; !J;
CARRIER/1..4/; !M;
PXSXCXT(TIME,PRODUCT,SUPPLIER,CARRIER):x,U;
PXSXT(TIME,PRODUCT,SUPPLIER):PC, SC;
PXT(TIME,PRODUCT):In,D,HC,UL, LL , OC;
SXC(SUPPLIER,CARRIER):CC, E ;
CXT(TIME,CARRIER):  Fm;
CONSTANT(TIME):W, Em, Qm;
SXCXT(TIME,SUPPLIER,CARRIER):V, G, TC;
S(SUPPLIER):B;
PXSXC(PRODUCT,SUPPLIER,CARRIER);
PXCXT(PRODUCT, CARRIER, SUPPLIER);
R(CARRIER):K;
ENDSETS

MIN = Z1+Z2+Z3+Z4+Z5;

Z1= @SUM(PXSXCXT(T,I,J,M):PC(T,I,J)*x(T,I,J,M));
Z2= @SUM(PXSXCXT(T,I,J,M):OC(T,I)*U(T,I,J,M));
Z3= @SUM(PXSXCXT(T,I,J,M):TC(T,J,M)*x(T,I,J,M));
Z4= @SUM(PXT(T,I):HC(T,I)*In(T,I));
Z5= (Yt/1000)*C;
Z1+Z2+Z3+Z4+Z5=Z;
!THE INVENTORY BALANCE CONSTRAINT;
@FOR(TIME(T)|T#EQ#0:@SUM(PRODUCT(I):In(T,I))= 0);
@FOR (TIME(T)|T#EQ#1:@FOR(PRODUCT(I):@SUM(SXC(J,M):x(T,I,J,M))-D(T,I)-
In(T,I)= 0));
@FOR(TIME(T)|T#GE#2:@FOR(PRODUCT(I):@SUM(SXC(J,M):x(T,I,J,M))-D(T,I)-
In(T,I)+In(T-1,I)=0));
!CARRIER AVAILABILITY CONSTRAINT;
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J):@FOR(CARRIER(M): x(T,I,J,M) <=
CC(J,M)*V(T,J,M)*U(T,I,J,M)))));
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @FOR(CARRIER(M):
G(T,J,M)*U(T,I,J,M)<= UL(T,I)))));
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @FOR(CARRIER(M):
G(T,J,M)*U(T,I,J,M)>= LL(T,I)))));
@SUM(PXT(T,I):Qm(T)*In(T,I))+@SUM(PXSXCXT(T,I,J,M):Em(T)*U(T,I,J,M))+
@SUM(PXSXCXT(T,I,J,M):Fm(T,M)*U(T,I,J,M))+@SUM(PXSXCXT(T,I,J,M):(B(J)*x(T,I,J
,M)*2.39/K(M)))= Yt+10000;
!WAREHOUSE STORAGE CONSTRAINT;
@FOR(TIME(T): @SUM(PRODUCT (I):In(T,I)) <= W (T));

!THE SUPPLIERS CAPACITY CONSTRAINT;
@FOR(TIME(T):@FOR(PRODUCT(I):@FOR(SUPPLIER(J): @SUM(CARRIER(M):x(T,I,J,M)) <=
SC(T,I,J))));
@FOR (PXSXCXT:@GIN(X));
@FOR (PXT:@GIN (In));
@FREE(Yt);
Data:
!Import the Data from Excel Sheet;
```

```
PC, OC, SC, TC, CC, V, HC, D, B, K, G, UL, LL, Fm, W, Em, Qm, C =
@OLE('D:\MODEL\4T8P8S4M.XLSX', 'PC', 'OC', 'SCL', 'TC', 'CCL', 'V', 'HC',
'DL','B', 'A', 'G', 'UL', 'LL', 'Fm', 'W', 'Em', 'Qm', 'C_');
!Export LINGO results to excel sheet;
@OLE('D:\ MODEL \4T8P8S4M.XLSX',  'x', 'U', 'Y', 'Z', 'Z1_', 'Z2_', 'Z3_',
'Z4_', 'Z5_' ) = x, U, Yt, Z,  Z1, Z2, Z3, Z4, Z5;
```

Appendix B

Data set of 4T-8P-8S-4M instance.

		DEMAND	PURCHASING COST	ORDERING COST	SUPPLIER CAPACITY	TRANSPORTATION COST			
						M_1	M_2	M_3	M_4
T_1	P_1	500	8,10,10,5,4,15,3,5#	1000	300,390,410,250,490,410,210,460#	90,80,95,90,55,85,90,30#	80,65,75,100,75,40,90,90#	100,85,30,60,35,25,60,75#	45,50,65,95,45,85,60,65#
	P_2	360	15,12,4,4,14,7,15,8	1000	260,350,480,500,250,470,480,230				
	P_3	410	11,12,5,13,14,8,4,6	1000	460,320,480,490,400,410,270,300				
	P_4	280	14,13,11,11,5,14,13,	1000	320,290,200,290,400,410,440,290				
	P_5	300	3,9,12,14,11,6,5,6	1000	300,410,440,230,410,330,330,200				
	P_6	145	9,9,11,5,3,5,15,13	1000	320,370,360,420,290,380,480,450				
	P_7	241	6,8,5,4,3,7,12,14	1000	250,270,220,200,470,450,220,310				
	P_8	200	15,5,15,8,15,5,4,15	1000	390,420,290,270,430,280,270,320				
T2	P_1	160	12,6,11,13,13,8,3,10	1000	460,250,320,230,300,350,250,460	55,85,45,80,40,45,75,40,	45,35,35,40,55,50,80,85	70,40,,25,70,40,55,100,75,50,60,65,80 70,50,40,55	80,70,30,50,100,70,30,85
	P_2	350	10,8,13,3,12,4,7,6	1000	400,470,300,480,230,350,210,390				
	P_3	420	12,11,12,8,14,15,6,7	1000	270,450,460,420,240,310,240,440				
	P_4	410	9,10,4,3,11,9,14,10	1000	420,490,200,400,310,270,350,440				
	P_5	200	3,11,6,5,5,15,13,14	1000	450,250,430,260,490,440,490,420				
	P_6	410	6,5,4,9,7,5,12,13	1000	490,470,380,360,470,270,500,310				
	P_7	200	6,6,3,6,10,6,15,8	1000	320,470,490,380,400,400,400,500				
	P_8	100	8,9,5,12,10,9,3,14	1000	460,300,210,340,230,490,280,230				
T3	P_1	120	12,15,3,14,12,12,13,	1000	490,430,250,350,260,390,300,430	85,50,60,80,65,45,25,75,	70,70,45,80,35,90,85,100	40,55,100,75,55,60,65,80	60,70,45,100,80,55,35,40
	P_2	300	15,4,12,14,4,5,12,8	1000	220,460,360,490,400,470,210,210				
	P_3	200	3,14,8,9,8,10,10,11	1000	440,250,470,200,260,400,270,420				
	P_4	365	8,5,15,8,4,12,3,5	1000	380,240,460,200,290,500,360,420				
	P_5	200	13,6,6,15,11,11,14,1	1000	370,480,330,460,420,200,200,440				
	P_6	365	7,13,8,10,13,7,15,15	1000	500,430,300,420,450,260,390,260				
	P_7	365	15,11,12,13,9,10,6,1	1000	370,340,210,200,340,260,310,320				
	P_8	450	5,15,11,7,12,4,6,6	1000	260,380,410,220,400,440,300,280				
T4	P_1	160	5,12,7,7,3,10,3,4	1000	440,400,230,340,310,220,320,210	85,50,60,80,65,45,25,75	70,70,45,80,35,90,85,100	45,50,65,95,45,85,60,65	60,70,45,100,80,55,35,40
	P_2	350	13,6,11,7,13,9,4,7	1000	300,340,400,320,210,420,390,360				
	P_3	420	3,9,6,7,12,4,6,6	1000	230,300,230,330,390,330,480,320				
	P_4	410	4,10,11,8,10,5,10,11	1000	490,310,380,210,260,490,210,450				
	P_5	120	6,5,11,10,7,4,5,10	1000	420,210,350,220,400,470,290,200				
	P_6	300	1,13,3,15,6,14,12,4	1000	420,390,340,400,240,460,390,500				
	P_7	300	8,13,15,14,14,13,15,	1000	290,280,460,300,470,390,350,260				
	P_8	200	1,7,3,5,13,13,5,3	1000	490,300,250,450,420,280,490,240				
Carrier Capacity: M_1= 400, M_2= 600, M_3= 800, M_4= 1000 (same for all suppliers over entire planning horizon)									

#: {S1,S2…Sn} for purchasing cost, supplier capacity and transportation cost for each kind of carrier M

APPENDIX C

Data set of 7T-10P-10S-5M instance

		Demand	Purchasing cost	Ordering cost	Supplier capacity	Transportation cost				
						M_1	M_2	M_3	M_4	M_5
T1	P_1	300	3,4,5,3,4,3,3.5,5,4,3	400	200,300,250,150,500,200,0,300,100,200[@]	6,5,4,6,6,5.5,5.54.56.5,7	7,5.5,4.5,6.5,7,6,4,6,6,5.5	7.5,6.5,5,6,7.5,6.5,4.5,6.5,7,6	8,7,5.5,5.8,6.5,6,5,6,7.5,6.5	8,7.5,6,6.5,7.5,6.5,5.5,5.8,6.5,6
	P_2	200	10,9,8,9,10,8,9,9,8,7	300	200,300,250,150,500,200,0,300,63,200					
	P_3	120	6,7,8,7,6,5,6,7,7,6	500	350,250,400,450,50,200,390,500,400,300					
	P_4	250	15,14,13,14,15,14,13.5,13,15,13	600	450,360,200,190,420,360,250,40,0,600					
	P_5	225	10,8,9,9,8,7,8,9,10,8	300	540,200,260,540,350,480,150,310,500,300					
	P_6	320	6,5,6,7,7,6,8,7,6,5	100	100,260,300,450,740,0,0,300,500,200					
	P_7	175	15,14,13.5,13,15,13,13,14,15,14	800	450,250,170,420,350,495,52,160,300,250					
	P_8	220	3,2,4,3,3,2,4,2,2,3	900	450,300,250,650,470,120,100,250,360,500					
	P_9	280	5,5,6,6,5,7,6,5,6,7	00	650,250,300,410,260,300,540,350,300,450					
	P_{10}	315	11,12,11,12,13,12,12,13,11,11	600	500,300,450,300,500,300,200,100,0,450					
T2	P_1	250	3.5,5,3,3.5,5,4,3,5,4,3	400	100,200,100,300,450,650,500,410,110,200	6,5,4,6,6,5.5,5.5,4.5,6.5,7	7,5.5,4.5,6.5,7,6,4,6,6,5.5	7.5,6.5,567.56.54.56.576	8,7,5.5,5.8,6.5,6,5,6,7.5,6.5	8,7.56,6.5,7.5,6.5,5.5,5.8,6.5,6
	P_2	360	9,9,8,9,9,8,7,9,8,7	350	320,200,500,560,300,1200,0,200,200,330					
	P_3	115	6,7,5,6,7,7,6,7,7,6	500	500,200,300,100,200,900,100,200,850,650					
	P_4	220	13.5,13,14,13.5,13,15,13,13,15,13	600	520,300,200,210,170,450,300,320,120,200					
	P_5	320	8,9,7,8,9,10,8,9,10,8	300	140,240,250,300,400,500,130,140,500,400					
	P_6	185	8,7,6,8,7,6,5,7,6,5	100	500,200,300,250,260,650,450,300,140,750					
	P_7	120	13,14,13,13,14,15,14,14,15,14	800	200,400,450,630,150,500,740,140,300,200					
	P_8	300	4,2,2,4,2,2,3,2,2,3	900	300,100,100,200,300,150,400,450,600,900					
	P_9	200	6,5,7,6,5,6,7,5,6,7	700	500,600,200,300,150,0,450,300,140,750					
	P_{10}	365	12,13,12,12,13,11,11,13,11,11	600	650,250,300,410,260,300,540,350,300,450					
T3	P_1	300	3,4,3,4,5,3,3.5,3,4,5	450	500,300,450,300,500,300,200,100,0,450	6,5,6,5,4,6,6,5.5,5.5,4.5	7,5.5,7,5.5,4.5,6.5,7,6,4,6	7.5,6.5,7.5,6.5,5,6,7.5,6.5,4.5,6.5	8,7,8,7,5.5,5.8,6.5,6,5,6	8,7.5,8,7.5,6,6.5,7.5,6.5,5.5,5.8
	P_2	200	9,10,8,9,8,9,9,10,9,8	360	100,200,100,300,450,650,500,410,110,200,					
	P_3	100	7,6,5,7,8,7,6,6,7,8	200	320,650,250,300,410,260,300,540,350,300,					
	P_4	250	14,15,14,14,13,14,13.5,15,14,13	600	500,500,300,450,300,500,300,200,100,					
	P_5	320	9,8,7,8,9,9,8,10,8,9	300	520,100,200,100,300,450,650,500,410,110					
	P_6	410	7,7,6,5,6,7,8,6,5,6	100	140,320,200,500,560,300,1200,140,750					
	P_7	260	13,15,13,14,13.5,13,13,15,14,13.5	800	450,500,200,300,100,200,900, 100,200,					
	P_8	320	3,3,2,2,4,3,4,3,2,4	900	540,520,300,200,210,170,450,300,320, 120					
	P_9	100	6,5,7,5,6,6,6,5,5,6	700	100,140,240,250,300,400,500,130,140,500					
	P_{10}	250	12,13,12,12,11,12,12,11,12,11	600	450,500,200,300,250260,650,450,300,140					
T4	P_1	500	3,4,3,4,5,3,3.5,3,4,5	400	450,200,400,450,630,150,500,740,140,300	6.5,7,6,5,4,6,4,6,6,5.5	6,5.5,7,5.5,4.5,6.5,4.5,6.5,7,6	7,6,7.5,6.5,5,6,5,6,7.5,6.5	7.5,6.5,8,7,5.5,5.8,5.5,5.8,6.5,6	6.5,6,8,7.5,6,6.5,6,6.5,7.5,6.5
	P_2	300	9,10,8,9,8,9,9,10,9,8	300	100,300,100,100,200,300,150,400,450,600					
	P_3	400	7,6,5,7,8,7,6,6,7,8	500	320,500,600,200,300,150,0,500,300,450					
	P_4	300	14,15,14,14,13,14,13.5,15,14,13	600	500,650,50,300,410,260,300,540,350,300					
	P_5	200	9,8,7,8,9,9,8,10,8,9	300	300,300,200,210,170,450,300,320,120,200					
	P_6	350	7,7,6,5,6,7,8,6,5,6	100	140,240,250,300,400,500,130, 140,500,400					
	P_7	360	13,15,13,14,13.5,13,13,15,14,13.5	800	450,360,200,190,420,360,250,40,0,600					
	P_8	450	3,3,2,2,4,3,4,3,2,4	900	540,200,260,540,350,480,150,310,500,					

	P_9	500	6,5,7,5,6,6,6,5,5,6	00	100,260,300,450,740,0,450,300,140,750					
	P_{10}	150	12,13,12,12,11,12,12,11,12,11	600	450,250,170,420,350,495,52,160,300,250					
T5	P_1	350	3,4,3,4,5,3,3.5,3,4,5	400	450,300,250,650,470,120,100,250,360,	5.5,7,6,6,6,5.5,5.5,4.5,6.5,5	4,5.5,7,6.5,7,6,4,6,6,5.5	4.5,6,7.5,6,7.5,6.5,4.5,6.5,7,6.5	5,6.5,8,5.8,6.5,6,5,6,7.5,7	5.5,6,8,6.5,7.5,6.5,5.5,5.8,6.5,7.5
	P_2	450	9,10,8,9,8,9,9,10,9,8	350	100,200,100,300,450,650,500,410,110,					
	P_3	500	7,6,5,7,8,7,6,6,7,8	500	320,200,500,560,300,1200,0,200,200,					
	P_4	600	14,15,14,14,13,14,13.5,15,14,13	600	500,200,300,100,200,900,100,200,850,					
	P_5	300	9,8,7,8,9,9,8,10,8,9	300	520,300,200,210,170,450,300,320,120,					
	P_6	200	7,7,6,5,6,7,8,6,5,6	100	140,240,250,300,400,500,130,140,500,					
	P_7	100	13,15,13,14,13.5,13,13,15,14,13.5	800	450,360,200,190,420,360,250,40,0,600					
	P_8	470	3,3,2,2,4,3,4,3,2,4	900	540,200,260,540,350,480,150,310,500,					
	P_9	350	6,5,7,5,6,6,6,5,5,6	700	100,260,300,450,740,0,					
	P_{10}	340	12,13,12,12,11,12,12,11,12,11	600	450,250,170,420,350,495,52,160,300,250					
T6	P_1	540	3,4,3,4,5,3,3.5,3,4,5	450	450,300,250,650,470,120,100,250,360,500	4,6,6,5,4,6,6,5.5,5.5,4.5	4.5,6.5,7,5.5,4.5,6.5,7,6,4,6	5,6,7.5,6.5,5,6,7.5,6.5,4.5,6.5	5.5,5.8,8,7,5.5,5.8,6.5,6,5,6	6,6.5,8,7.5,6,6.5,7.5,6.5,5.5,5.8
	P_2	630	9,10,8,9,8,9,9,10,9,8	360	100,520,300,200,210,170,450,300,320,120					
	P_3	530	7,6,5,7,8,7,6,6,7,8	200	320,140,240,250,300,400,500,130,140,500					
	P_4	410	14,15,14,14,13,14,13.5,15,14,13	600	500,450,360,200,190,420,360,250,40,0					
	P_5	350	9,8,7,8,9,9,8,10,8,9	300	520,540,200,260,540,350,480,150,310,500					
	P_6	250	7,7,6,5,6,7,8,6,5,6	100	140,100,260,300,450,740,0,0,300,500					
	P_7	200	13,15,13,14,13.5,13,13,15,14,13.5	800	450,450,250,170,420,350,495,52,160,300					
	P_8	300	3,3,2,2,4,3,4,3,2,4	900	540,450,300,250,650,470,120,100,250,360					
	P_9	200	6,5,7,5,6,6,6,5,5,6	700	100,100,200,100,300,450,650,500,410,110					
	P_{10}	100	12,13,12,12,11,12,12,11,12,11	600	450,320,200,500,560,300,1200,450,300,140,					
T7	P_1	200	3,4,3,4,5,3,3.5,3,4,5	450	450,500,200,300,100,200,900,100,200,850	6.5,5,4,6,6,5.5,5.5,4.5,6.5,7	6,5.5,4.5,6.5,4,6,6,5.5,5.5,4.5	7,6.5,5,6,4.5,6.5,7,6,4,6	7.5,7,5.5,5.8,5,6,7.5,6.5,4.5,6.5	6.5,7.5,6,6.5,5.5,5.8,6.5,6,5,6
	P_2	300	9,10,8,9,8,9,9,10,9,8	360	450,320,200,500,560,300,1200,350,495,52					
	P_3	450	7,6,5,7,8,7,6,6,7,8	200	450,500,200,300,100,200,900,100,200,500					
	P_4	350	14,15,14,14,13,14,13.5,15,14,13	600	100,520,300,200,210,170,450,300,320,650					
	P_5	250	9,8,7,8,9,9,8,10,8,9	300	320,140,240,250,300,400,500,130,140,200					
	P_6	130	7,7,6,5,6,7,8,6,5,6	100	500,200,300,100,200,900,100,200,850,400					
	P_7	190	13,15,13,14,13.5,13,13,15,14,13.5	800	520,300,200,210,170,450,300,320,120,600					
	P_8	390	3,3,2,2,4,3,4,3,2,4	900	140,240,250,300,400,500,130,40,500,300					
	P_9	250	6,5,7,5,6,6,6,5,5,6	700	450,360,200,190,420,360,250,40,0,200					
	P_{10}	360	12,13,12,12,11,12,12,11,12,11	600	540,200,260,540,350,480,150,310,500,250					
Carrier Capacity: M_1= 400, M_2= 600, M_3= 700, M_4= 800, M_5= 1000 (same for all suppliers over entire planning horizon)										

#: {S1,S2…Sn} for purchasing cost, supplier capacity and transportation cost for each kind of carrier M