Network Optimization for Supply Chain Management in Construction Industry

A DISSERTATION

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By

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CANDIDATE'S DECLARATION

I, Ashutosh Tejankar, Scholar No.16554014 hereby declare that the thesis titled "Network optimization for supply chain management in construction industry", submitted by me in partial fulfillment for the award of Masters in Infrastructure Systems, at Indian Institute of Technology Roorkee, India, is a record of bonafide work carried out by me. The matter/result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.

Ashutosh Tejankar

Date:
Place: Roorkee

CERTIFICATE

This is to certify that the declaration of Ashutosh Tejankar (16554014) is true to the best of my knowledge and that the student has worked under my guidance for one semester in preparing this thesis.

RECOMMENDED

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Dr. Rajat Agrawal

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ABSTRACT

Construction industry being comprised of diverse activities and an open environment work, it is difficult to track all the activities. Due to various uncertainly in activities, demand and flow of information and materials, concept of supply chain is at very preliminary stage introduced to the construction industry. Akintolaet et al. (2000) define supply chain management in construction as "the process of strategic management of information flow, activities, tasks and processes, involving various networks of organizations and linkages (upstream and downstream) involved in the delivery of quality construction products and services through the firms, and to the customer, in an efficient manner". Variable cost contributes large enough share in the total construction project and also affects the profit margins of the construction company. It is also found that the share of carbon emission from the logistics involved in construction project is more than that from the actual site work. In this project we have being tried to develop the optimization model for the variable logistics cost and the carbon emission from the overall logistics that is involved in the construction company. The model is further demonstrated with the help of real problem case studies. Inputs from the managers of construction firms are considered and suggestions and recommendations are given after studying the present practices in the supply chain management in the construction industry. Proper planning of logistics strategies also speeds up the construction work and thus reduces the project overrun cost by reducing the transportation and variable costs. The computational analysis is performed using linear programming and excel solver and the results have shown the significant reduction in cost of transportation and emission from the transportation.

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Chapter 1: Introduction

1.1. General

Supply Chain Management (SCM) is a concept that has flourished in manufacturing, originating from Just-in-time, production and logistics. In 1982, renowned consultant Keith Oliver, of strategy consulting firm 'Booz Allen Hamilton' coined the term 'Supply Chain Management'. SCM exists in both service and manufacturing organizations, although the complexity of the chain may vary greatly from industry to industry and firm to firm. The literature study shows that Infrastructure construction supply chain in India is poorly managed. It is found that non value adding activities include waste of time and materials are caused by island of information with in-effective communication between supply chain participants. It is evident that the well planned operational SCM in Infrastructure construction enables the cost reduction up to 20% of the total project cost by reducing the wastage and unnecessary transportation of materials, fuel expenses, equipment cost, indirect cost which forms the major cause for the project cost over runs. It is also observed that the big players of the construction industry are also unable to employ full-fledged integrated SCM in their organizations due to the absence of the real time information from the project stakeholders .

The peculiarity of the infrastructure construction projects is that it is in open environment activity and every project has different sets of constraints and limitations. Therefore, implementation of supply chain is little more difficult task as compared to the manufacturing industry. This Report will highlight the role of SCM in infrastructure construction projects with the help of cases from related fields and its practicability in implementation for better performance and successful execution of such projects .

In the lack of construction firms' initiative for higher productivity and better quality, construction industry has seen commoditization; where contracts are awarded on the basis of minimum bid. This in turn has reduced the profit margins and industry players have been averse of making investments for productivity enhancement. Current firm-specific cost reduction doesn't confer any sustainable advantage in the global market. With the increasing global competition, Indian firms need to involve all the stakeholders of the construction supply chain who influence the productivity of the project. This is possible only through greater coordination among various players. Firms need to follow a supply chain approach to achieve global standards. Rising revenues of construction industry and strong future prospects would encourage construction firms to make investments to achieve higher productivity. The issue of delays, cost over-runs and quality non-conformance is closely related to the Supply Chain Management (SCM) and it is believe that applying SCM principles, Use of Information Technology (IT) and supply chain integration also optimizing the transport network for the flow of goods and materials can bring significant increase in the productivity and cost saving in construction projects .

Transportation plays a significant role in the supply chain because products produced in the particular location are not consumed or sold completely in the same area. In the development of industry transport plays a crucial role by linking the sources of raw materials, the manufacturing or processing centers and the markets or the consumption points. Transportation can be through various modes viz. road, rail, water, pipeline and air some of which may find themselves in direct competition with or perhaps complementary to the other thus often creating problems of sustainability and thus there should be change of modes depending upon on the requirement and required responsiveness.

1.2. Construction Industry in India

The construction industry of India is an important indicator of the development as it creates investment opportunities across various related sectors. The industry is fragmented, with a handful of major companies involved in the construction activities across all segments; medium-sized companies specializing in niche activities; and small and medium contractors who work on the subcontractor basis and carry out the work in the field. In 2011, there were slightly over 500 construction equipment manufacturing companies in all of India. The sector is labor intensive and, including indirect jobs, provides employment to more than 35 million people .

Construction industry is the second largest economic activity in India. Indian Construction Industry can be divided into three market segments: Infrastructure, Industrial and Real Estate. Infrastructure constitutes of roads, ports, airports, irrigation, railway, and power projects etc. In the Indian context, it is estimated that 1% growth in infrastructure yields a cascading effect of 2.5% growth of GDP. There is a massive investment flow into the infrastructural development in

India and other Asian countries. Looking at the ubiquitous construction activity in the country and strong future prospects, it is important to devise the strategies to enhance the productivity in construction activity which seems to lag far behind in comparison to other manufacturing and service industries. Construction industry also contributes to the manufacturing industry through the manufacturing of construction equipments, cement, etc.

1.3. Supply Chain in Construction Industry

A definition of supply chain management is applicable to general industry, particularly retail and manufacturing bound to literature. A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers, and even customers themselves. Within each organization, such as a manufacturer, the supply chain includes all functions involved in receiving and filling a customer request . The objective of every supply chain should be to maximize the overall value generated. It is all about flow of goods, cash and information.

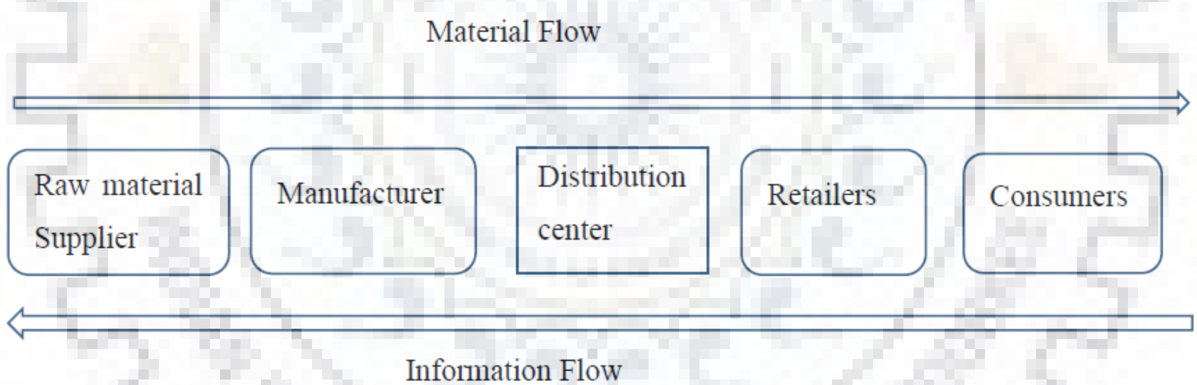


Figure 1: Supply chain flow chart

Construction supply chain involves stakeholders who are individual service providers such as subcontractors, designers, engineering consultants, transporters etc. and manufacturers of materials and equipments. On an average material cost contributes 50% to the project cost and hundreds of material and equipment suppliers take part in the supply chain. Apart from these suppliers, activities of the construction projects are subcontracted to specialty contractors such as designers, electrical, engineering, plumbing etc. Being a demand driven industry owner's involvement in the project remains crucial and continuous information flow from client is essential. Construction can be viewed as a complex of manufacturing and services. In this sense, many of the operations involved in manufacturing have similarity with construction projects in their characteristics. As an example, procuring materials and assembling them to make a product is common in both manufacturing and construction. This is the reason why Toyota, the leading Japanese auto manufacturer, has entered into housing construction and applying mass production and lean manufacturing techniques there .

Supply chain management (SCM) is a great opportunity for the construction industry primarily to reduce cost and time, and thus improve profitability. SCM principles seem to have much strength to smoothen and integrate the construction processes. The supply chains in construction could be divided into two major groups as materials chain and the construction chain, which would help to separate the procurement and management operations. However, both chains are linked through a SCM database, which is further linked with the central project database . Obstacles for supply chain management are found to be poor level of logistical competence, lack of guidance for creating strategic alliances, inability to integrate the company's internal procedures, strong project focus as well as the attitudes and traditions in the construction industry.

Some serious flaws in the current project planning practices, which ignore information and resource constraints. Also the Risk Management should be more effective, in lack of which firms cannot avoid delays and cost over-runs. Forming Integrated Supply Chains is a strategy that construction industry should follow by forming long-term relationships with suppliers; subcontractors and other supply chain players, sharing information for mutual benefits; and using IT to make it more efficient and effective .

A typical construction supply chain network has the main contractor at the centre of the hub, with links to the client, main supply agencies (i.e., sub-contractor and suppliers), and design services and any specialist management services. The above agencies all operate independently, which makes the coordination task of the contractor difficult .

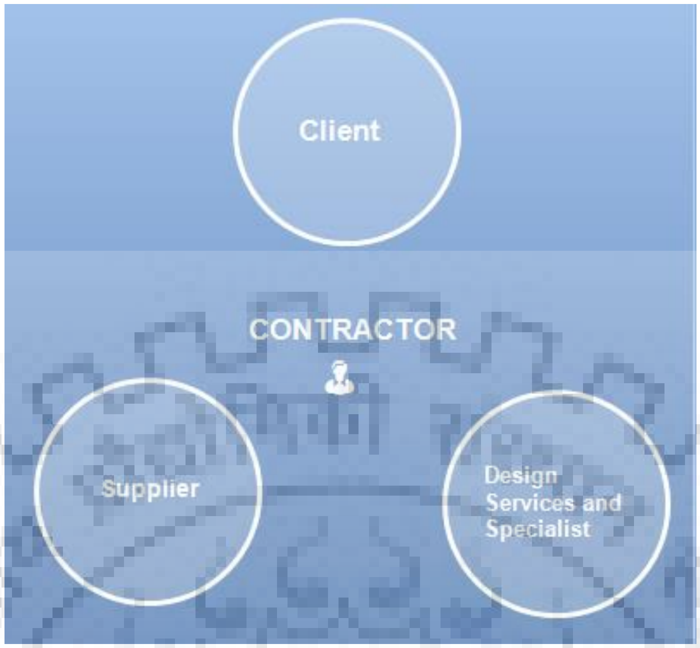


Figure 2: Elements of SCM in construction industry

The agents involved in the Indian construction industry have either no or limited knowledge about the SCM concept and its application in the construction industry .

They act as independent agencies and work in isolation. Sub-contractors and suppliers have limited collaboration with contractors, e.g., only during the project execution stage. It is observed from the study that the clients' proactive role as a leader in the supply chain is missing; this is a major barrier in the implementation of seamless SCM .

1.4. Drivers of Supply Chain Management

Supply chain capabilities are guided by the decisions you make regarding the four major supply chain drivers. Each of these drivers can be developed and managed to emphasize responsiveness or efficiency depending on changing requirements. The four major drivers of SCM are production, facility, inventory, transportation and information. Along these drivers others drivers of supply chain management are sourcing, pricing, etc.

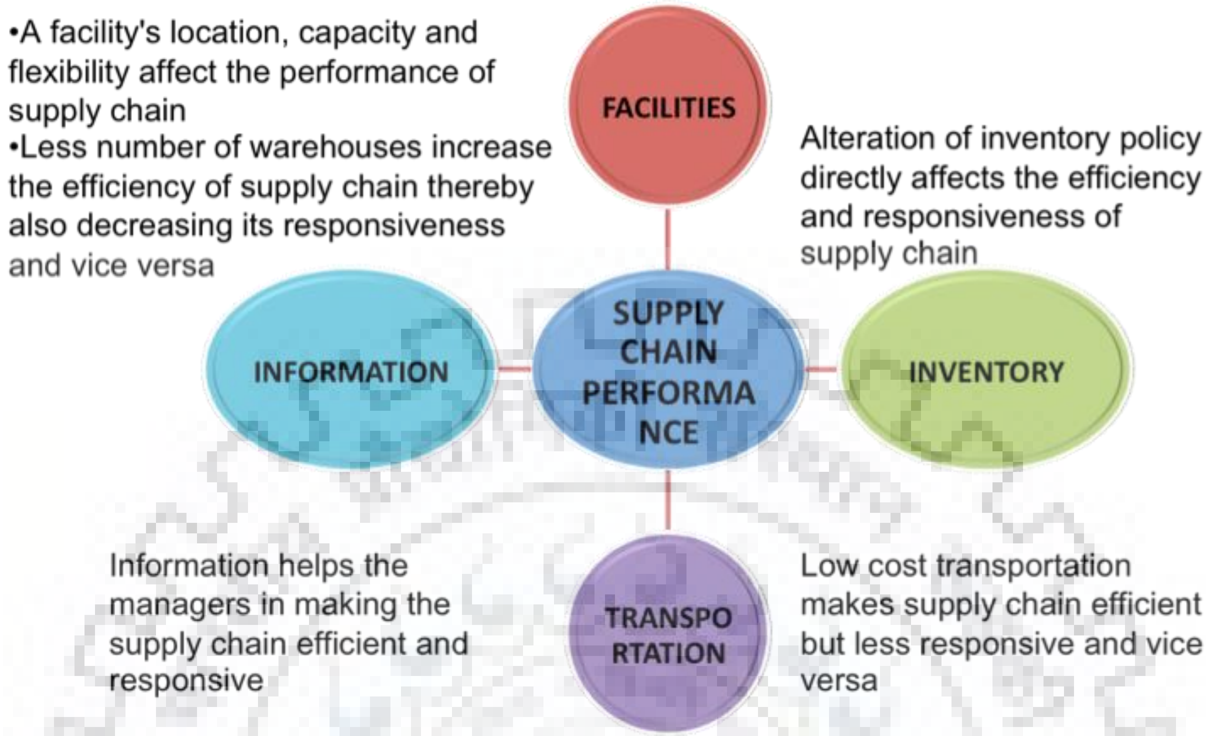


Figure 3: Drivers of supply chain management

1.5. Transportation as Driver of Supply Chain Management

Transportation is the key driver of supply chain in any industry. Transportation is moving the product or the material from one place to another. The supply chain manager is always worried about the mode of transport, location of facility, etc. Responsiveness can be achieved by the transportation mode that is fast and more flexible. Efficiency can be increased by transporting the products or materials in larger batches and doing it less often. To practice effective, cost efficient Logistics Management, an organization must lay the foundation for a responsive, economical transportation network.

The mode majorly adopted for the transportation of construction material in by road using trucks with capacity 16 to 25 tons compared to 32 tons capacity. Therefore this makes the transportation of materials more costly and thus the proper strategies are to be planned for the procurement and transporting the materials.

1.6. Supply Chain Network Design

Supply chain network design (SCND) determines the structure of a chain and affects its costs and performance. SCND deals with a variety of decisions such as determining number, size and location of facilities in a supply chain (SC) and may include tactical decisions (such as distribution, transportation and inventory management policies) as well as operational decisions (such as fulfilling customers demand).

1.7. Green Supply Chain

Green supply chain management (GrSCM) is defined as "Integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life" (Shivastava 2007). The growing importance of Green Supply Chain Management is driven mainly by the escalating deterioration of the environment, e.g. diminishing raw material resources, overflowing waste sites and increasing levels of pollution. However, it is not just about being environment friendly; it is about good business sense and higher profits . The scope of green supply chain management ranges from monitoring of the general environment management programmes to more proactive practices implemented through various Rs (Reduce, Re-use, Rework, Refurbish, Reclaim, Recycle, Remanufacture, Reverse and optimized logistics, etc.).

1.8. Need for Green Supply Chain

Anthropogenic Green house gases (GHG) are rapidly warming the earth and are causing changes in the global climate that will lead to severe environmental, economic and social impacts over the coming decade. Global GHG emissions increased around 70% between 1970 and 2004 due to the increases in population, energy demand, and human activities. As per usual scenario for motorization in India,, CO_2 emissions from road transport would increment at 7.75% every year higher than numerous other Asian nations from 203 million tons in 2005 to 905 million tons by 2025. Passenger transport shares 45% and cargo transport shares to 55% of aggregate CO_2 outflows from street transport in 2005. If it continuous, CO_2 discharges would build a few fold in between of 2008 and 2025 because of a fast development in urban populace and number of trips. This provides strong evidence for the effect of GHG on global warming as eleven of the last twelve years 1995-2006 rank among the twelve warmest years in the instrumental record of global surface temperature since 1850 (Srivastava 2007).

This would force a change in the way companies manage their supply chains, they would have to find new and innovative means of optimizing the supply chain to reduce carbon emissions, across all its stages and implement green procurement to minimize its carbon footprint. On July 1st 2010, India introduced a nationwide carbon tax of 50 rupees per ton of coal both produced and imported into India now it is 400 rupees per ton. This is also a step toward reduction in emission from manufacturing, handling, storing and transporting goods.

1.9. Logistics and Variable Cost in Supply Chain of Construction Project

Logistics is often defined as managing the supply chains, the latter being a network of organizations linked by material and information flows bounded with a product (project) life cycle (from the procurement of raw materials through processing and handling the products and the final product, distribution and sales to the end-user and finally, to waste utilization). All the processes and relations concerning the above flows form a logistic system. The variable cost in supply chain and overall logistics include transportation cost, loading and unloading cost, storage cost and losses. Contractors are usually only single links of logistic chains that provide a project with products, services, information and finance.

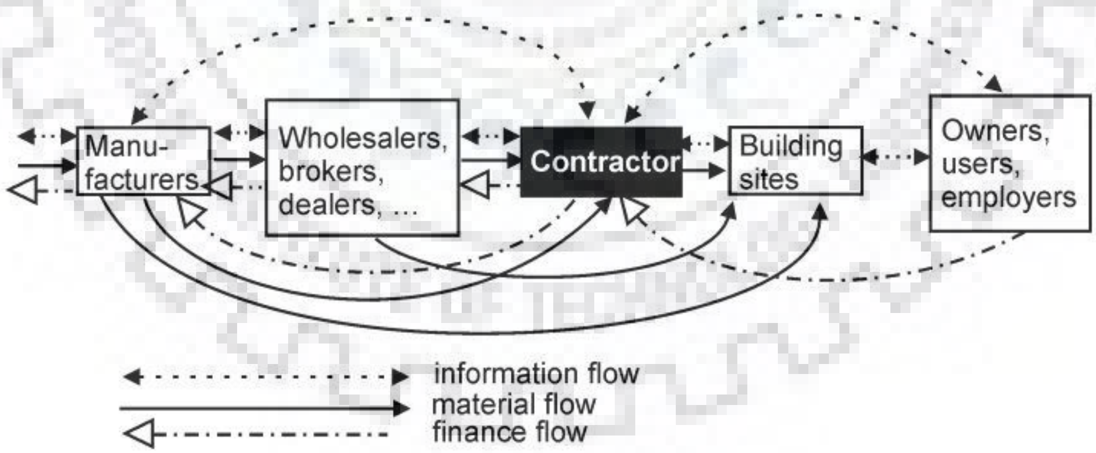


Figure 4: SCM flow chart in construction industry

Construction logistics may be considered in a number of aspects as:

- The building site as a production system and a member of many logistic chains, where complex processes are executed within time, space and budget constraints –whole project logistics.
- Supply chains delivering products from external sources to the building site (supply logistics).
- Co-ordination of material flows on the building site (on-site logistics).

The variable cost mentioned above can be dependent on various factors as

- Inventory costs are related to the number and location of stock facilities and the safety stock kept.
- Transport costs depend primarily on the mode of transport, vehicle size, shipment size and the distance between locations.
- Handling costs are related to the number of times a product is lifted in the supply chain. Major subcategory of handling costs is the costs of warehouses.

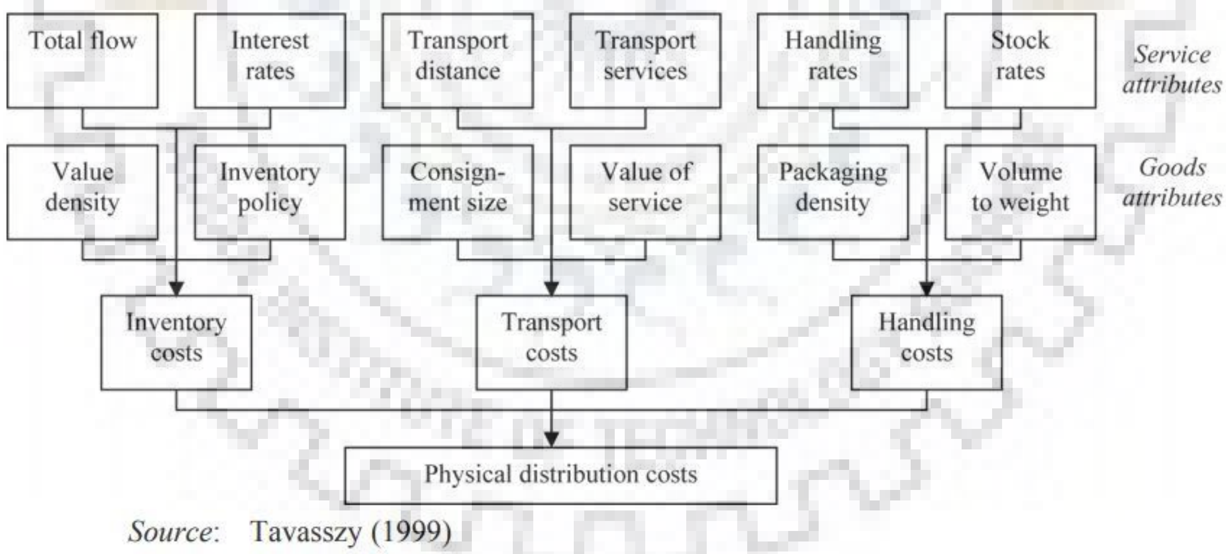


Figure 5: Physical distribution of variable costs

1.10. Logistic Network Optimization

The logistic planning in construction and project involves movement of various materials and equipment from multiple identified sources to multiple consumption points in a cost effective manner. Logistics cost has a huge share in total supply chain management of any industry or goods. Studies and literature shows that, the share of the logistics is about 25-30%. Also the improper planning of logistics and transportation strategies can lead to delay in project completion, increased emission along with project cost overrun. There are various optimization tools available, but in construction industry due to limitations of modes of transport, uncertain conditions, non recitative orders and large variation in order size, using the optimization tool becomes little difficult. It is required to set certain objective, variables and constraints to create the mathematical model which can be the optimized using the tool. The objectives, variables and constraints can be somewhat different for different projects. Accuracy and flexibility of the model is dependent on the number of variables and constants or assumptions. The actual size of company is also important. 97% of all Polish contractors employ up to 20 people and, therefore, have no logistics department in their structure therefore most of the planning fails in such case (Sobokta et.al 2005).

1.11. Material Management Techniques

There are various material management techniques available which can be used to classify the materials based o the various factors like value of the material, cot of the material, rate of consumption of the materials , etc. Some of the techniques are as follows.

1.11.1. A B C Classification

A-B-C (Always Better Control) classifies the materials or the goods based on the value of the material and the rate of consumption of the material. There are various building materials used in the construction project, therefore it is necessary to classify those materials for better control on them. According to this method of classification “Class A” materials are the most valuable materials and “Class C” material are the least valuable materials.

A- Contributes 10-20% of total inventory items with 70-80% of total value

B- Contributes 30% of total inventory items with 15-25% of total value

C- Contributes 50% of total inventory items with 5% of total value

Steps for classification of items:

1. Find out the unit cost and the usage of each material over given period
2. Multiply the unit cost by the estimated usage or demand to obtain the net value

3. List out all the items and arrange them in descending value

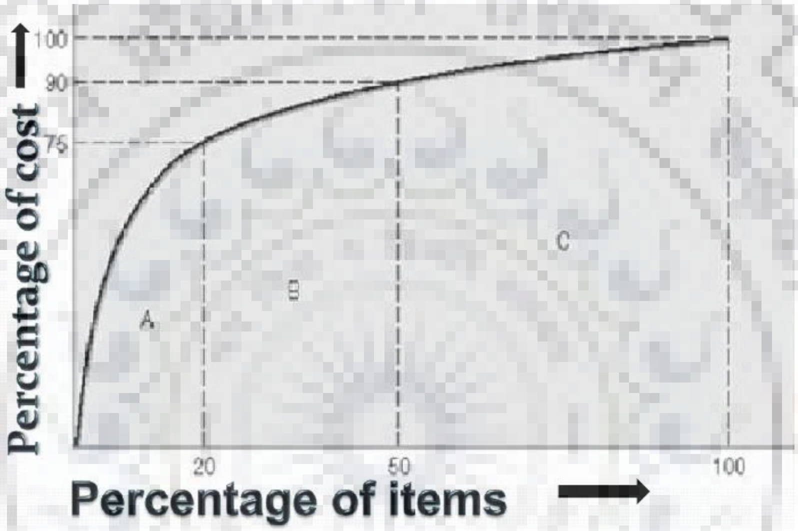
4. Accumulate value and add up number of items in descending value

5. Accumulate value and add up number of items and calculate percentage on total inventory in value and in number

6. Draw a curve, a percentage item and percentage value

7. Mark off from the curve, the rational limit of A, B, C categories

Note: A < B < C



1.11.2. F S N Classification

Supply chain management of construction projects is all about moving of materials and information between manufacturers and construction site. F-S-N analysis can be used to manage the materials based on the movement of the materials.

F – Fast moving materials

S – Slow moving materials

N – Non-moving materials

1.11.3. S D E Analysis

S-D-E (Scarce, Difficult and Easy) analysis helps in classifying the materials based on their availability. This information then used to decide the purchasing strategies

Scarce Classification comprises of items which are in short of supply, important or canalized through government agencies.

Difficult classification includes those items which are available but not easy to procure.

Easy classification covers those items which are readily available where supply exceeds demand and other which are locally available fall into this group.

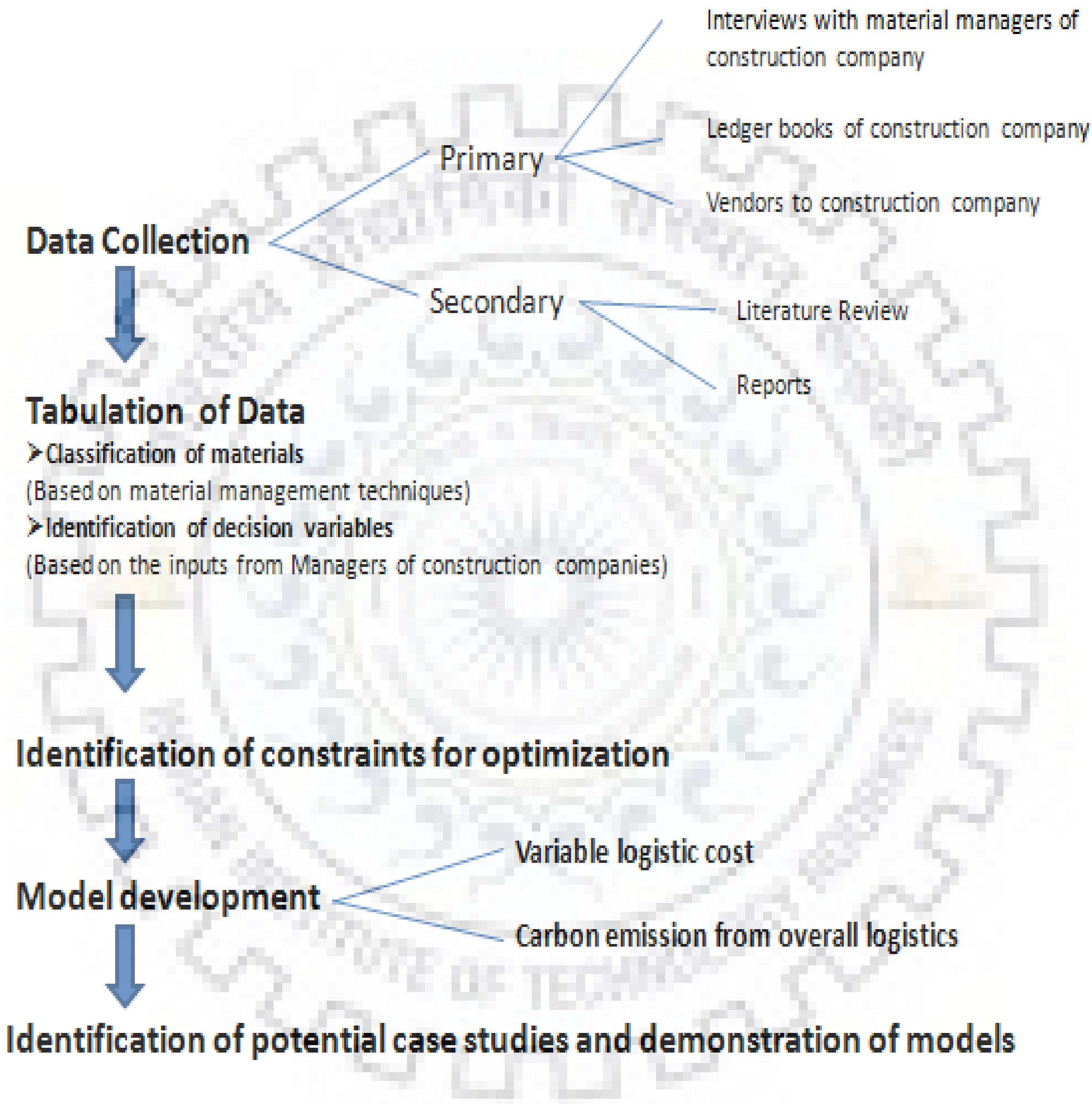
1.12. Aim

The aim of the project is to minimize the Variable logistics cost of the construction project and also reduce the carbon emission from the supply chain by optimization of the transport and overall logistic network adopted for the procurement, handling and movement of the construction material.

1.13. Objective

- To develop an optimization model for minimizing variable logistics cost in construction supply chain.
- To develop an optimization model for minimizing carbon emission from the overall logistics involved in supply chain of construction project.
- To demonstrate the optimization model by suitable case study.

1.14. Methodology



Chapter 2: Literature Review

Akintolaet .at 2000: Had conducted questionnaire survey of supply chain collaboration and management in the top UK construction industry contractors. In result along with the questionnaire survey, they followed the findings of Lathan (1994) and Egan (1997) and indicated the formation of significant numbers of partnerships, collaboration agreements between contractors, suppliers and clients. It seems that the construction supply chain management is still at very initial stage though some philosophy is evident. Contractors identified improved production planning and purchasing as key targets for the application of SCM in construction. Barriers of SCM in construction industry includes: workplace culture, lack of senior management commitment, inappropriate support structures and a lack of knowledge of SCM philosophy. To overcome these barriers innovation, training and proper implementation is necessary. In questionnaire was such designed in seven sections exploring the supply chain relationships. The contractors were asked their opinion on efficiency of tendering, value of clients and suppliers and their opinions on partnerships and also how important they find supply chain. The final section of the questionnaire looked at the success factor in supply chain collaboration and management using a five point Likert scale with '5' indicating 'high expert' or 'most important' and '1' indicating 'least extent' or 'least important'. Data analyses was carried out using the statistical package for social sciences (SPSS) and dealt with the ranking of the variables based on mean values and frequency distributions. Analysis of variance (ANOVA) was done to test the null hypothesis that mean values of the dependent variables are equal for all groups. This enabled the researchers to know whether or not the opinions of the separate contractors groups were the same on the various issues dealt with in the study . The study shows that the contractors are more oriented towards the clients rather than their suppliers in the supply chain. The study also shows that there is high correlation between the timing of publication of the Latham Report (1994) and the Egan Report (1997) with the increased number of partnership arrangements in the construction firms supply chain.

T.Subramani and S.Tamizhanban 2016: According to them SCM represents an autonomous managerial concept, although still largely dominated by logistics. By taking into account the interdependency in supply chain, all the issues are viewed and resolved. The construction industry been slower than other industries to employ the supply chain management concept and develop models that support the decision making and planning. They have demonstrated the use of mathematical tools for optimization and software like SPSS for identifying the role of supply chain in construction industry and optimization model. According to them materials like cement being the major material in the construction industry is used as the binder, used for the construction of buildings, roads, bridges etc. To produce cement variety of raw materials are used like limestone gypsum etc. Therefore the supply chain of such materials is of importance to the sustainability and execution of the project. The main target of the research was also to find out why only trucks were used as the major means of transportation in the cement industry in TamilNadu and also to use the findings of this research minimize or eliminate the likely hazards that may cause when using trucks alone as a logistics system. It was found that 73.3% of the respondents still preferred to use the road link logistic system .

Gohari Ali 2014: According to the author the success of the civil project is evaluated through parameters of quality, cost and time. The paper aims to study the role of supply chain management on construction industry. According to the findings supply chain management is crucial in different stages of construction industry including providing materials and tools as well as designing, supervising and execution stages. Due to overlap of suppliers activities and activities on site, huge construction companies spend extra time and money as the suppliers are crucial factors in the supply chain of the construction company. As the buying strategies are determined by the strategies of the company, there is no unique method to provide all the sales and related needs. This issue influences the whole process of evaluation and selecting the suppliers. Research suggest that weak design of supply chain increases the project's cost by 10%. This estimation may be even conservative. The project length may also be affected in the same way.

Sanjay Chaudhari, Amit Tindwani 2017: Study aims to assist the project manager in minimizing the material logistics cost of road project by planning the optimal movement of aggregate across three stages of supply chain: sourcing, processing and distribution. The The results obtained from the model show that planning material logistics of an entire road project using optimisation provides substantial saving in logistics costs than using common sense. Further, the magnitude of cost saving improves as the complexity of the model increases in term of enormous feasible options. Alon with other causes it is also found that lack of material planning was observed to be one of the prominent causes for time and cost overruns in road projects. Lenear programming was used to optimize the supply chain of the aggregates used for the road construction also the option of mixed integer linear programming is explaind which also helps in the location of the facilities. The total number of intermediate processing plants and its potential locations is generally the decision that the project team needs to consider. By adding the binary (0-1) variables, the model can also incorporate the optimal locations of the processing plants. The project generally consumes different types of raw materials. The proposed model can be expanded to formulate the integrated supply chain model for optimizing the movement of all the materials together from sourcing to processing plants and processing plants to consumption locations .

SyamaKrushnakumar, LinuT.Kuriakose 2014: According to them Construction industry faces a lot of inherent uncertainties and issues therefore the focus of the research was on the supplier selection. Authors discussed about the factors and methods used for the supplier selection. Supply chain management can be considered as the coordination of distributed decision making organization on material flow and information flow. According to them the criteria which have major influence on supplier selection problem are price, quality, delivery time, management, repair service, geographical location, technical capacity financial position, proper communication, customer satisfaction, reliability, long term relationship, honesty, testing certification, commitment, discounts, safety and health consideration, payment terms. Methods used for supplier selection explained are categorical method, weighted point method, analytical hierarchical process, analytical network process, technique for order preference by similarity to ideal solution (TOPSIS), Linear programming, goal programming, multi objective programming case based reasoning (CBR), artificial neural network. Also the silent features are explained for all the methods of supplier selecton.. Authors concluded that the method adopted based on the industry specific criteria are found to be successful.

Ruben Vrijhoef, LauriKoskela: Supply chain management is a concept that has flourished in manufacturing industry, originating from Just-In-Time production and logistics. Though SCM represents different managerial concept, still largely dominated by logistics. By explaining the origin and basic concept of the supply chain, the focus of the research was toward the supply chain in construction industry. Many supply chain aethods have been propose according to the literature available, e.g. quality rates, inventory, lead time and production cost, etc. According to the author, the methodology of supply chain management consists of four main elements: Supply chain assessment, Supply chain redesign, Supply chain control, Continuous supply chain improvement.

Lalit Ashok 2015: In study of the role of supply chain management in infrastructure construction projects, Author explained the objectives of construction supply chain management, components of SCM, barriers in construction SCM, etc. The application of SCM to the construction industry requires huge effort. SCM is increasingly being seen as a progression on internal programmes aimed at improving effectiveness. The focus is now not only limited to increasing internal efficiency of organizations but has been broadened to include methods of reducing waste and adding value across the entire supply chain. This article shows how simple framework can be used when evaluating changes in a supply chain. The framework is developed on the basesis of the supply chain cost model and customer service measurements, delivery precision and lead time . Basically the the article is extension of the seamless model of supply chain management in construction industry by peter et.al (2004). Supply chain management maturity model is developed which consists of five levels which are Ad-hoc i.e untertanding the SCM, Defining, Linking, Integrating, Extending. These five stages of maturity model shows the progression of activities towards effective supply chain management and process maturity. Each level mentioned contains characteristics associated with process maturity such as predictability, capability, control, effectiveness and efficiency. According to the author such integrated supply chain will significantly enhance their value and enjoy a distinct competitive advantage.

Peter E.D. Love et. Al 2004: They developer a seamless supply chain management for construction industry which presents a holistic approach to construction project SCM. Authors have proposed horizontal organization structure founded on a multi disciplinary team approach for procuring and managing the construction projects. They suggested replacing the traditional project structure to improve the communication and minimize the barriers to information flow in projects. Team members perform better when the responsibility for project development is shared. Traditional price driven selection procedures would not effective hence further as these can limit the flexibility of designers and contractors to explore innovation that result in optimal performance. Furthermore, traditional price driven selection procedures are deemed to be ineffective, when used to ensure that clients procure their buildings for the least possible cost for a less than best product . The proposed model is not much different from the some of the forms of design and construct procurement systems that are currently being used within the construction industry. The main difference is in the focus that is placed on inter organizational collaboration and cooperation.

SudhirYadav, GargiSajitra Ray: The authors studied the SCM practices followed in flyover projects and compared them with the seamless SCM model for construction proposed by Love et.al 2004. A case study approach was followed for the research work. Structured interviews were conducted to understand the SCM practices in flyover projects in India. The developed model advocates leading roles for client and strategic needs analysis and value management study that are missing in the studied projects. All of the projects studied faced cost and time overruns. The seamless SCM model may be extended to developing countries by incorporating requirements related to the long-term relationship between project agents and, if possible, by suggesting that clients should not select agents using only the minimal cost criteria. The extended model also proposes SCM training for all project agents before the start of the project. Strategic needs analysis and value management study should be an integral part of the construction project to improve project efficiency. According to them implementing the seamless SCM model calls for the early involvement so that the smooth and continuous supply chain model and strategies can be planned. The research objective was to study and compare the current SCM practices in a flyover project in the Indian construction industry with a seamless project SCM model for construction. To identify barriers in implementing the above mentioned seamless supply chain model for flyover projects in the Indian construction industry and suggest modifications or improvements to the model. Four flayover projects were selected, they were typical in nature because all four projects were implemented by government authorities which sereved as clients under public private partnership. They found that the involvement of all agents in a construction project e.g. contractors, sub contractors, suppliers, structural consultants and third party consultant is lacking at the project design stage, which leads to several problems at the execution stage. The practice in the Indian construction industry is to involve these agents once the design is finalised. It is not possible to include all agents at the design stage because they are selected through a tendering process, with the cheapest cost as one of the criteria. It is suggested that the client can invite all qualified bidders to participate in design discussions and that later, whoever qualifies, as per the client's norm, may be given the contract.

Martha C. Cooper, Lisa M. Ellram 1993: Particular focus of the research was on the involvement and implication of supply chain management for purchasing and logistics. Aslo a framework for differentiated between traditional systems and supply chain management systems. These characteristics are then related to the process of establishing and managing a supply chain. They suggested that information systems such as electronic data interchange (EDI) can contribute to the speed of operations through redusing order cycle time on the purchasing side. Aslo information technologies such as EDI helps in managing the flow of goods on the processing, distribution and consumption side. Purchasing and logistics managers should take advantage of their unique position and knowledge to pay leadership roles in design and implementation of integrated supply chains. Logistics functions have also assisted purchasing to achieve better coordination of inbound transportation and warehousing.

Egilmez et.al 2015: They have done study on the emissions from the supply chain and discussed about the green supply chain. A two step hierarchical approach was developed by authors. First, Economic input-output based life cycle assessment is utilized to quantify the green house gas emissions associated with US residential, commercial and industrial building stock. Second, a mixed integer linear programming (MILP) based optimization framework was developed to identify the optimal GHG emissions reduction for each industry across the supply chain network of US economy. The decision making in terms of construction related expenses and energy use options have considerable impacts across the supply chains. According to them construction sector will continue to be a major contributor of increasing global CO_2 emissions. Four fifth of the total GHG emissions is associated from the logistic associated with the construction supply chain and one fifth of the total emissions is associated to the on site construction work. The result of the mathematical model indicated that ready mix concrete manufacturing was found to be as one of the major sector responsible for overall GHG emissions across the supply chain. All in, ready mix concrete manufacturing sector, electric power generation, transmission and distribution and lighting fixture manufacturing sectors generally found to be the heaviest GHG emitter industries in the supply chains.

WaliKlibi 2009: This thesis provides a methodology for Supply Chain Network (SCN) design under uncertainty. Due to random environmental factors such as demand, prices, exchange rates..., and to disruptive events such as natural disasters, strikes, the SCN designed must be robust enough to cope with these events. The design problem formulation is based on the generic distributed decision-making framework proposed by Schneeweiss. It is defined as a multistage stochastic program taking into account decisions under risk, user response anticipations and resilience strategies. Several experiments are performed in order to validate the concepts introduced in the methodology proposed. The Location Transportation Problem (LTP) is defined as a hierarchical strategic decision problem to set depots location and mission and is characterized by multiple transportation options and multi-period customer demands. First, the LTP under random demand is formulated as a two-stage stochastic program with recourse and a hierarchical heuristic solution approach is proposed to solve it.

Tarik Abdullah et.all 2010: According to them, nature facing with growing concerns over the environmental impact of human activities and increasing regulatory pressure, companies are beginning to recognize the importance of greening their supply chains by minimizing carbon emissions of their activities. An original equipment manufacturer that is concerned with minimizing the environmental impact of its activities should choose its suppliers based on the tradeoff between costs and respective emissions. In this paper, they have developed an MIP model for the carbon-sensitive supply chain that minimizes emissions throughout the supply chain by taking into consideration green procurement. A sensitivity analysis of their model and results on several small problems are included in the paper. The experimental analysis shows that companies will tend to reduce their carbon emissions significantly with the introduction of carbon price by decentralizing the supply chain and multi-sourcing to reduce the transportation and production emissions.

Samir K. Srivastava 2007 : They have presented a state-of-the-art literature review of GrSCM integrating the complete range and scope of activities in the area. There literature review highlights the ongoing integration process in green supply chain management. The primary areas of emphasis have been quality, operations strategy, supply-chain management, product and process technologies.

Chapter 3: Optimization Model

This Chapter describes the assumption, preliminary assumption, objective functions, constraints and formation of supply chain model. Along with model which illustrates the supply chain in the construction industry for selected materials, an optimization model is used to describe a problem or system. Optimization problems include two components one like objective function and second like constraints. Linear programming is used to form the mathematical equations which can be solved for the real problem.

3.1. Supply Chain Model

Among various materials some of the materials are selected after various interview surveys and data from the construction firms. Some of the materials like sand and bricks which have periodical demand and not much storage precautions required for such materials can be directly supplied to the site from the excavation site or kilns. For materials like cement and steel, procurement strategies are to be planned as the various purchases, transportation and storage options can be available. Also economical order quantity plays a role in material management for such materials. Also some of the materials are required during particular stage of construction and some materials are required throughout the construction work.

If we consider the firm that is engaged in various construction work at different locations then it is difficult in determining the capacities of its various supply chain activities at various sites i.e. procurement or purchase, storage and distribution of the materials to the various demand or consumption points. There may be more chances for the contractor of lack of coordination between different stakeholders of the project and different sites at a time.

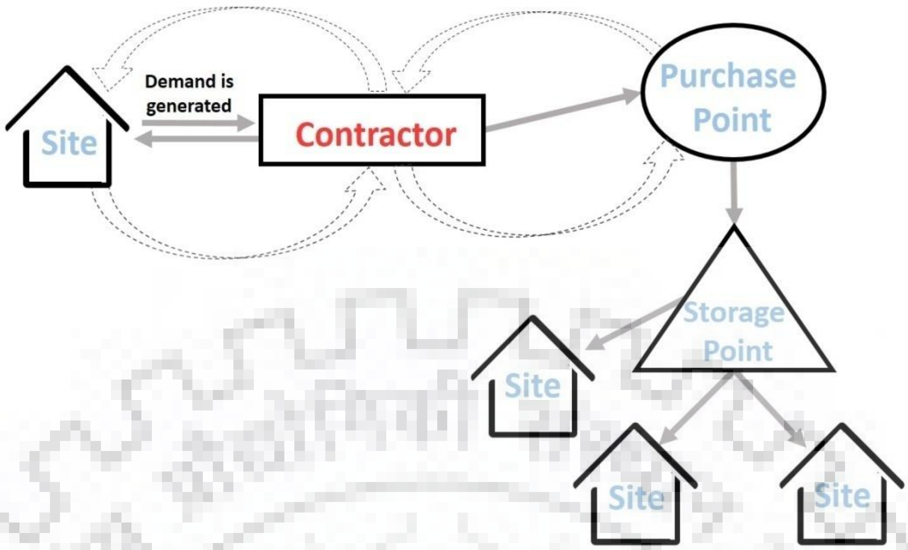


Figure 6: Proposed SC flow chart for construction company

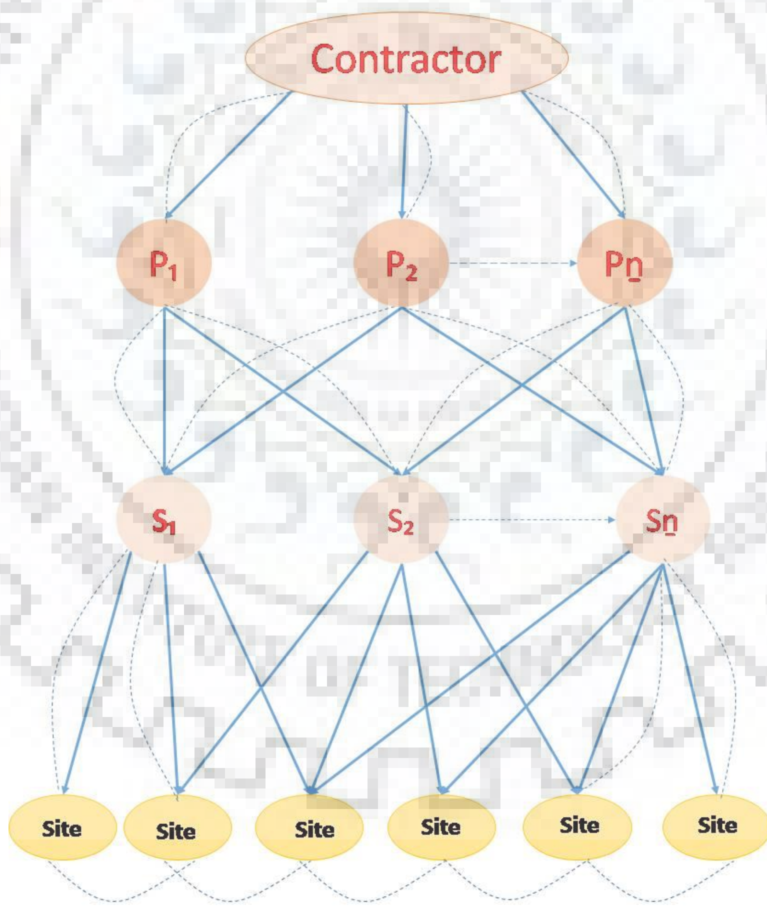


Figure 7: SC network topology

3.2. Assumptions

Following are the assumptions made for the development of the mathematical model.

- It is assumed that the demand on the site is completely fulfilled by the purchase points.
- There are options for selecting purchase and quantity of purchase.
- Capacity of storage point is variable. i.e. it can accommodate excess stock.
- Transportation and storage cost is taken as function of weight carrying and distance moved.
- Transportation and storage cost is linear in volume to be transported and stored.
- There is no capacity limit on each of the path and overall links, so that any amount of quantity could be transported.
- Demand forecasted at each site or consumption point is fulfilled by more than one purchase and storage points.

3.3. Problem Statement

The problem in this project is to study the real case practices in the construction firm and optimize the supply chain transport network to minimize the cost of logistics and also to minimize the emissions from the overall transportation involved in supply chain of the construction project. Variable cost is taken as cost function. The emissions from the supply chain is converted to cost function by multiplying with some weightage, weighted can be calculated by multiplying with emission factor and the cost per unit which the firm is willing to pay which can be tax on fuel consumption or the tax assigned by the government authority. In the case of variable cost, the cost incurred to move the vehicle from one place to other place and it totally depends on the number of kilometers driven and the volume of materials carried.

3.4. Proposed Mathematical Model

Following are the parameters that will be used to develop the mathematical formulation of the problem.

n_p – Number of purchase points

n_s - Number of storage points

n_d – Number of demand points (site)

$x_1, x_2, x_{3,}\ldots\ldots, x_n$ – Non-negative supply (flow of material on each path)

Paths are the set of links between two points or nodes

d_k – Demand (fixed/known)

d_l – Distance of link

l – Link between total supply and demand

f_l – Flow of material on link $'l'$

p – Path

c_l – Total cost on $'l'$ link (transportation)

Therefore, demand will be;

$$d_k = \sum x_p \quad \text{p = 1,2,3,.....,n}$$

Flow of material on path;

$$f_p = \sum x_p \delta_{l_p} \quad \text{p = 1,2,3,.....,n}$$

δ=1 – If the particular link is connected to path

δ=0 – If the particular link is not connected to path i.e. The total amount of material on path is equal to the sum of the flow of materials on all the links that utilizes that path.

The flow must be non-negative;

$$x_p \geq 0$$

Let,

c_l – Total cost on $'l'$ link (transportation)

$\hat{C}_l$ - Per unit cost

$$c_l = \hat{C}_l(f_l)d_l$$

i.e. The cost is function of flow of material and distance

When there are various options of links available, then the link is selected depending on the convenience.

Some of the materials can be shifted from one link to another link.

Let,

μ_l - Adding or shifting capacity on link $'l'$

d_{μ_l} - Extra distance traveled by shipment or the material

y_l – Total cost of adding or shifting μ_l capacity on link $'l'$

$\hat{y}_l$ - Unit cost of adding or shifting μ_l capacity on link $'l'$

$$y_l = \hat{y}_l(\mu_l)d_{\mu_l}$$

i.e. The cost of addition or shifting is the function of capacity of the link and the extra distance traveled by the materials.

The objective is to minimize the total cost.

Therefore;

$$\text{Min} \sum_{l \in p} \widehat{C_l}\,(f_l)d_l + \widehat{y_l}(\mu_l)d_{\mu_l}$$

Also the emission from the transportation is to be considered and minimized.

Let,

$\widehat{e_l}$ – Emission Factor (for vehicle/facility)

e_l - Emission generated

$e_l = \widehat{e_l}\,(f_l)\, d_l$ ---- Emission generated

$e_l = \widehat{e_l}(\mu_l)d_{\mu_l}$ ------- Emission generated due to shifting capacity of link

i.e. The emission generated is function of flow of material and distance traveled by the material.

The objective is to minimize the emission from the supply chain.

Therefore,

$$\text{Mini} \sum_{l \in p} e_l(f_l)d_l + \widehat{e_l}(\mu_l)d_{\mu_l}$$

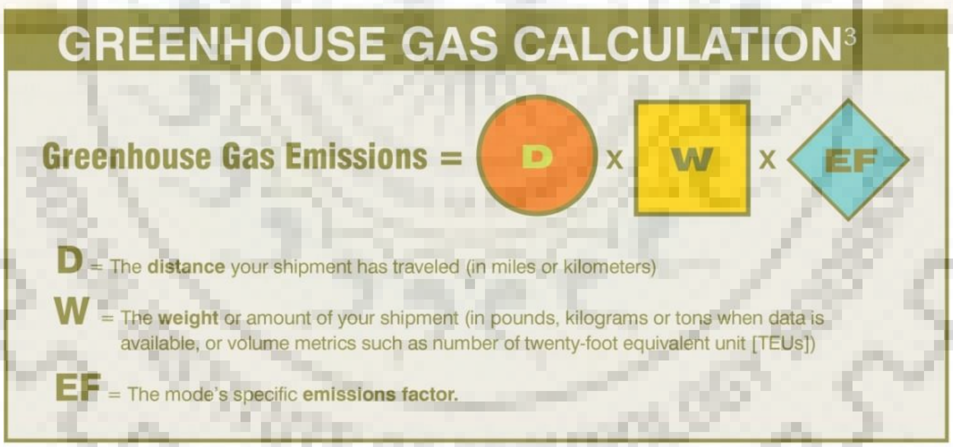
The emission is to be made measurable in terms of cost. Therefore, the non-negative constant 'T' is then assigned to emission-generation criterion. The constant 'T' is a weight that is assigned to the emission minimization criterion. This weight can be price over unit of emission that the firm is willing to pay, in terms of fuel tax or tax laid by government.

Therefore, the final equation will be:

Minimize

$$\sum_{l \in p} \widehat{C}_l\,(f_l) d_l + \widehat{y}_l(\mu_l) d_{\mu_l} + T \sum_{l \in p} e_l(f_l) d_l + \widehat{e}_l(\mu_l) d_{\mu_l}$$

3.5. Transport Emission Calculation



http://business.edf.org/files/2014/07/EDF-Green-Freight-Handbook.pdf

Sr. No.	Category	Kg CO_2/Km	Kg CO_2/ton-Km
1	LDV (< 3.5 T)	0.3070	0.3070/ gross capacity of vehicle
2	MDV (< 12 T)	0.5928	0.5928/ gross capacity of vehicle
3	HDV (> 12 T)	0.7375	0.7375/ gross capacity of vehicle

http://www.ghgprotocol.org/programs-and-registries/india

3.6. A B C Classification of Construction Materials

ABC Classification of construction materials is used in this work to select the materials for which the demand and supply is known, purchase points are located and the transport network is designed base on the optimization results.

It is necessary to classify the construction materials because there are hundreds of materials used in the construction projects. To select the materials based on their value and rate and consumption it is necessary to classify them.

The materials required for the construction of a building are classifies as follows:

Table 1: ABC classification of construction materials

Category	Items	% of Items	% of Total Cost
Class A	Sand, Flooring, Steel	20%	43%
Class B	Bricks, Painting, Bathroom Fittings, Cement	30%	37%
Class C	Windows, Electrical Fittings, Aggregates, Formwork, Glass, Pipes	50%	20%

(Sayali Et. al 2017)

For better understanding of the share of each class in the construction of building, following pie charts will help

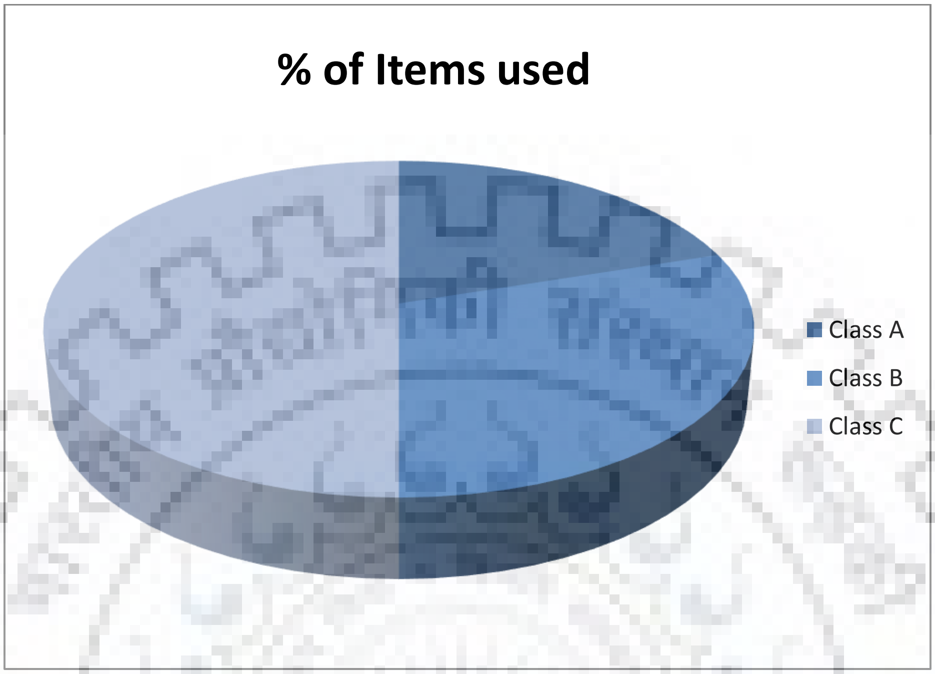


Figure 8: Percentage of items used by ABC classification

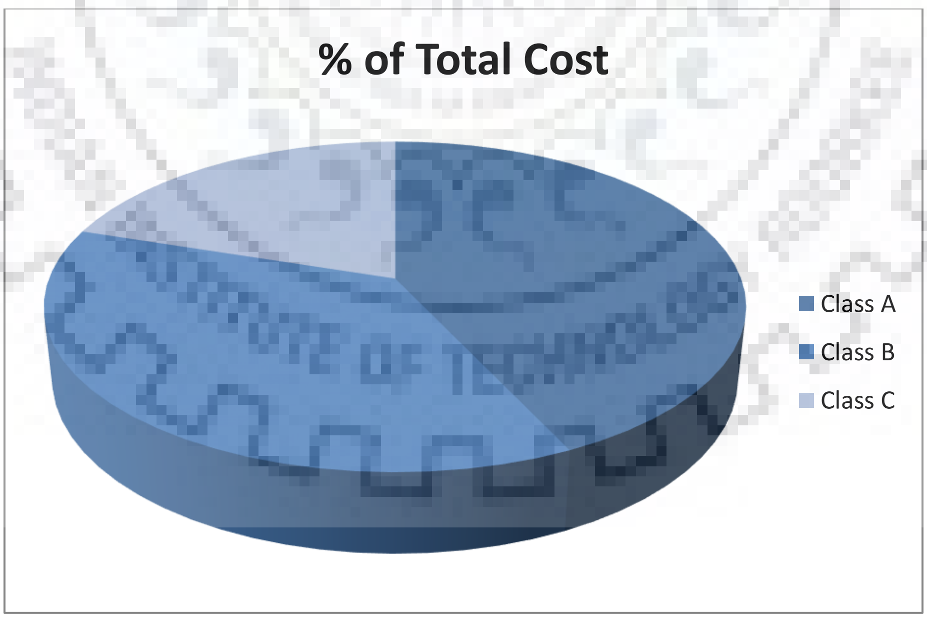


Figure 9: Total percentage of cost by ABC classification

Level of Service for materials categorically

Table 2: LOS for A, B and C class of materials

Particulars	A – Class Items	B – Class Items	C – Class Items
Control	High	Intermediate	Low
Requirement	Low	Intermediate	High
Check	Tight	Intermediate	Low
Safety stock	High	Low	Rare

(Sayali Et. al 2017)

From the above classification the importance and value of the major materials of construction can be understood. It is decided to consider three materials (one from each class) for this work. Steel from Class A, Cement from Class B and Aggregate from Class C.

Chapter 4: Problem Description

To demonstrate the model, study concentrates on the Supply Chain of the building construction projects in Roorkee and Haridwar. In which the construction materials are procured from the nearby areas for the construction of building projects. To limit the extent of calculation the materials which are selected on the basis of ABC classification are cement and aggregates which are required throughout the construction of building. The maximum monthly demand is considered. The information is derived from various interviews with the project manager and site engineers of one of the reputed construction company.

The company handling the huge projects of residential and hospital building at the same time and also the sites are located in remote areas, their demands of construction materials are not satisfied by the small local vendors. Therefore they get their materials direct from the manufacturing plants or the crushers in case of cement and aggregates. These plants are located at a distance due to which the risk of unavailability of materials is very less or the demand is satisfied properly but the transportation cost is increased.

They have some nearby options for purchase points, so the mathematical model will help the contractor to consider all the nearby options and satisfy their demand of materials and also with minimum transportation and handling cost. Also the emission from the transportation of the materials will be minimized as the emission is the function of the distance traveled by the shipment.

The demand locations are at Roorkee and Haridwar and the supply locations are at Delhi, Dehradun, Bahadrabad, Meerut and Haridwar.

4.1. Location Map

The map bellow shows the location of the supply chain network i.e. the location of the vendors or the purchase points and the location of the construction sites.

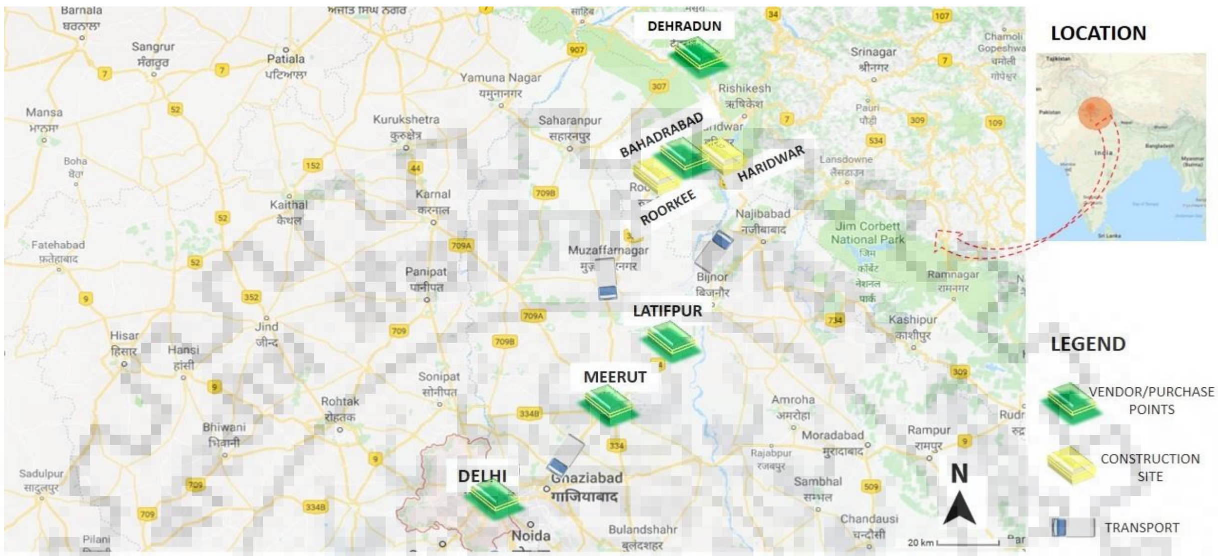


Figure 10: Location map of SC network

4.2. Supply Chain Data

Based on the interviews of the Project manager, Site Engineer and contractor of the construction company following data has been gathered regarding the demand of materials, cost of transportation etc.

4.2.1. Distance Matrix

Road distance in KM from various supply points to demand points. Distance where calculated for expected delivery distance.

Table 3: Distance matrix between supply and demand points

From / To	Roorkee	Haridwar
Delhi	193	225
Dehradun	71	52.9
Haridwar	31.3	0
Meerut	109	140
Bahadrabad	18.5	13.2
Latifpur	169.5	200

4.2.2. Transportation Cost

Cost per metric ton per kilometer for moving materials from supply points to demand point.

Table 4: Transportation cost per KM per MT

From / To	Roorkee	Haridwar
Delhi	₹5.2	₹5.2
Dehradun	₹4.8	₹4.5
Haridwar	₹4.8	₹0
Meerut	₹5.2	₹5.2
Bahadrabad	₹4.8	₹4.5
Latifpur	₹5.25	₹5.25

Cost per metric ton for moving materials from supply points to demand point.

Table 5: Transportation cost per MT

From / To	Roorkee	Haridwar
Delhi	₹1003.6	₹1170
Dehradun	₹340.8	₹238.05
Haridwar	₹150.24	₹0
Meerut	₹5.2	₹5.2
Bahadrabad	₹4.8	₹4.5
Latifpur	₹889.875	₹1050

4.2.3. Monthly Demand

Maximum monthly demand in metric tons for the sites in Roorkee and Haridwar.

Table 6: Monthly demand in MT

Material	Roorkee	Haridwar
Cement	700	600
Aggregate	500	400

4.2.4. Other Required Data

Transportation emission data

Table 7: Transportation emission data

Carbon Tax/Metric ton	**₹400**
Emission factor of vehicle ton CO_2/Metric ton	0.00006

Chapter 5: Computational Experiment, Results and Discussion

5.1. Introduction

As explained in last chapter the problem is formulated in such a manner that it can supply product to multiple sites from different vendors while calculating the total supply chain cost and emission.

For the given problem mathematical model developed is demonstrated for the observed situation to give the optimal solution

The model consist of the following components in it:

Decision variables: These are the variables representing the unknown quantities i..e. the quantity of the materials to be transported from different supply points to different construction sites.

Objective Function: The objective of the problem is expressed as mathematical equation of decision variables. The objective in this problem is to minimize the transportation cost and the emissions from the observed network, considering the distance of shipment and the, volume of shipment and the emission factor of the mode of transportation.

Constraints: The constraints are the limitations or requirements of the problem and are expressed as equalities, inequalities or equations in decision variables.

5.2. Elucidate the Mathematical Model Using Excel Solver

Microsoft Excel solver helps to understand the mathematical model and physical meaning of the model. To solve the linear model simplex algorithm will be used.

Enter the input details in the excel sheet for different vendors or the supply points (4) and different sites (2), then 4*2 matrix will be formed. Then all the required calculation will be done as per the constraints given.

Table 8: Decision quantities of cement from different vendors

From / To	Roorkee	Haridwar
Delhi	0	0
Dehradun	400	400
Haridwar	0	200
Latifpur	300	0

Table 9: Cost of SC of cement

Total cost of transportation	498503
Total emission	6.0246 (MT)
Total cost of emission	2409.84
Total cost	**500912**

Table 10: Decision quantities of aggregates from different vendors

From / To	Roorkee	Haridwar
Bahadrabad	100	400
Meerut	450	0

Table 11: Cost of SC of aggregates

Total cost of transportation	287700
Total emission	3.3708 (MT)
Total cost of emission	1348.32
Total cost	**289048.3**

From the results of the excel solver we got the decision values of the quantities of cement and aggregates to be purchased and transported from the purchase points to the construction site so that the objective value i.e. the cost of transportation and the cost of emission is minimum, considering all the options of links available and selecting the most efficient and optimum link.

Conventionally the contractor used to get the materials form the single vendor who can fulfill the demand completely and neglected the small local vendors located nearby. This cost the contractor in terms of more transportation cost. As the central goods and services tax is implemented completely in the country therefore the cost of material is same and does not vary much. Therefore the optimization model allows the contractor to consider all the nearby small vendors at a time and make decisions of purchasing the quantity of materials from them. This reduces the transportation handling cost by optimization.

Following charts and figures shows the share of vendors in fulfilling the demand of contractor or the construction project. Model ensures that all the available options of vendors and links are considered.

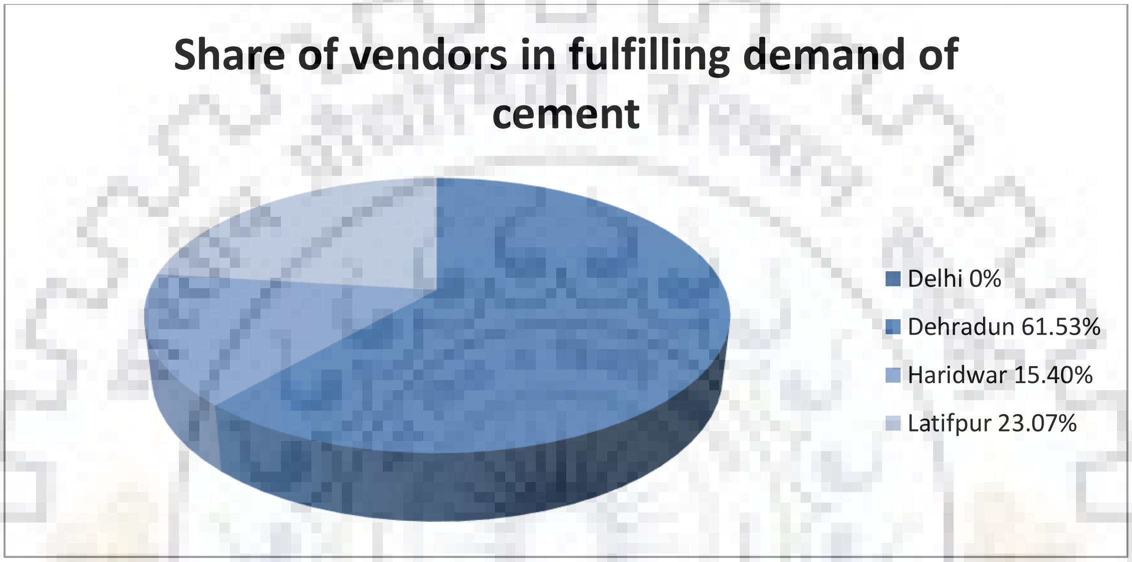


Figure 11: Share distribution of vendors in fulfilling demand of cement

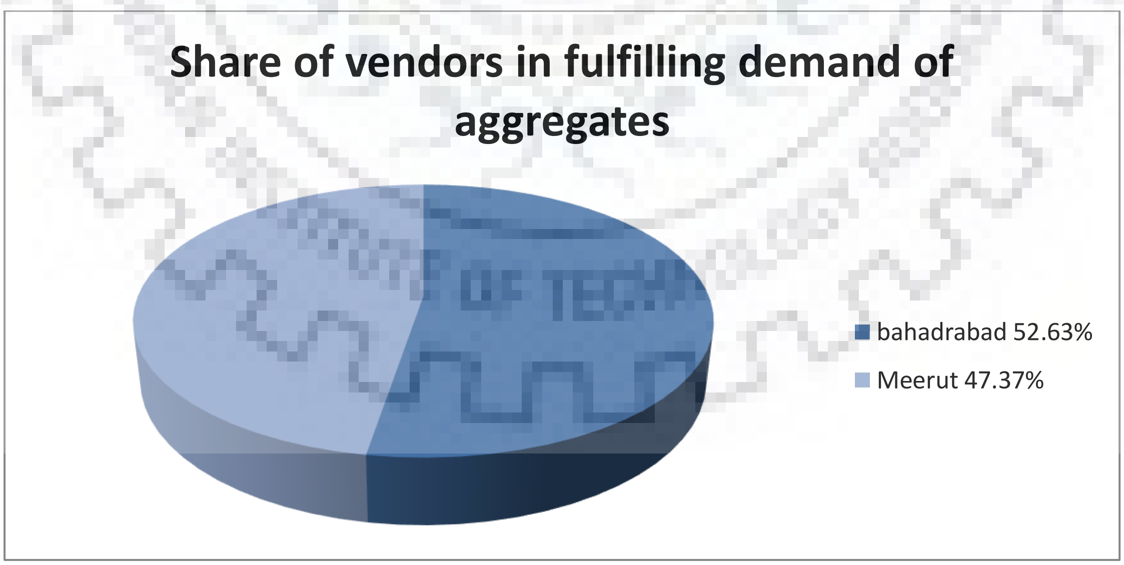


Figure 12: Share distribution of vendors in fulfilling demand of aggregates

5.3. Benefits of Considering Various Nearby Vendors

- Reduction in Transportation cost.
- Reduction in emission from transportation.
- Reduces the risk of unavailability of materials on site.
- Creates options for procurement in case of emergency demand on site.

5.4. Reduction in Costs

There is more than 50% reduction in cost of transportation and emission cost in case of cement and aggregates required for the construction of projects. Following figures show the comparisons of cost in conventional condition and after considering various small local vendors with the help of optimization model.

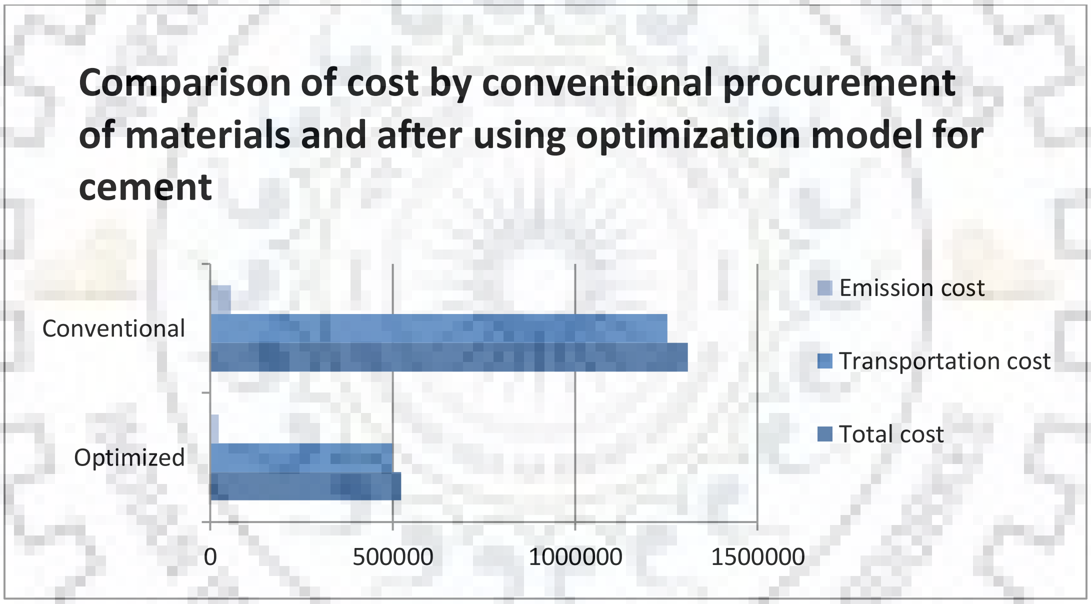


Figure 13: Comparison of cost before and after optimization of cement transport network

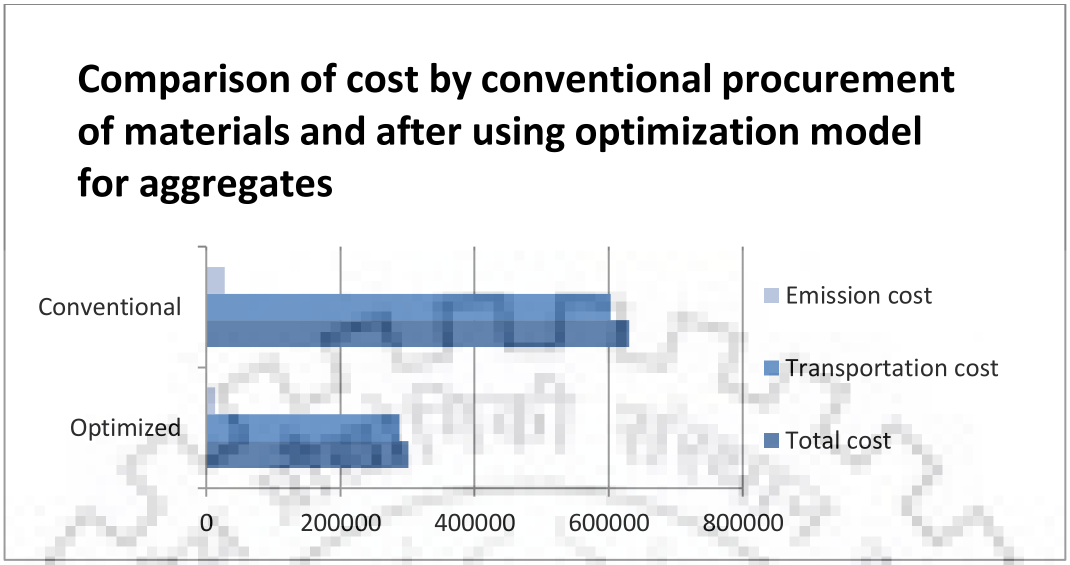


Figure 14: Comparison of costs before and after optimization of aggregate transport network

Conventionally contractor used to get the materials from single source which was at distance from site just to make sure that the total demand of site is fulfilled by that source. But by considering various small local vendors, it is found that there is more than 50% saving in cost of transportation and emission cost.

Chapter 6: Conclusion

Construction Industry being an open environment work and consisting set of various complex activities, it is little difficult to track and control all the activities. Contractor is the centre point of the project and has to coordinate with all the stakeholders of the project, right from the owner, designers, engineers, suppliers and service providers. Major cost and time overrun in the construction project is caused due lack of coordination and poor management. Supply chain and logistic contributes the major share in the cost of construction project therefore it becomes necessary to implement supply chain management in the construction industry. Considering construction materials, raw materials to manufacturing plant to warehouse to site to construction work all is about logistics which include transportation and handling cost. Proper logistic planning can increase the efficiency of the construction work and reduces the overall cost.

From literature it is found that carbon emission from the logistics involved in construction project is more than actual construction work. Mathematical modeling comes out to be powerful tool in optimization of the logistic networks. Presently contractors or construction companies procure the material from the single source which can completely fulfill their demand and neglect various small local vendors. This increases the distance of transportation of materials and thus increase in cost of transportation and also increase in the emission from the transportation.

Mathematical optimization model helps the contractor in making decision of procurement and reduces the distance of transportation and thus decreasing the cost of transportation and emission from the transportation.

Mathematical model and equation also considers all the available options of various small local vendors near the site location and helps in decision making of the contractor for the procurement of materials. Due to optimization transport network there is more than 50% of saving in the cost of transportation and emission cost from the transportation of materials.

There are also various benefits of considering various small local vendors with the help of optimization network model. There are chances of emergence demand arising on the construction site at that time these local small vendors can be beneficial in fulfilling that demand. Also the mathematical transport model has a provision of considering the link with the help of which, different sites are connected and some emergency demand can be satisfied from the neighboring site for time being.

6.1. Limitations and Future Scope

There are various mathematical modeling techniques available to integrate the supply chain and optimization e.g. convex programming, linear programming, mixed integer linear programming, multi objective optimization, multi model optimization, etc. Linear programming is used to optimize the transportation network of construction materials in this study, which gives the decision quantities of the materials to be procured from various sources to minimize the cost of transportation and the emissions from particular mode of transportation.

There may be some quantity advantages given or offered by the suppliers to the customer or the construction company in case of some construction materials. These offers may be in terms of discounts or saving of transportation cost on large orders, these are not considered in the model developed. The model can be modified accordingly to consider such discounts, offers or savings while optimization.

The model is demonstrated for one of the well known construction company in India. Construction companies may have their owen ways of planning and procurements, the model can be modified accordingly.

There is scope for collaboration of two or more contractors or construction companies and combining their planning and procurement strategies for maximizing the profits and reducing the carbon emission from their supply chain. The model is demonstrated for the optimization of two construction materials i.e. cement and aggregates, similarly the optimization model can be used for the planning of procurement strategies of other construction materials.

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