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Optimization and Scheduling of HAZCHEM Logistics with Time Windows

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Abstract- This research addresses the optimization of Total Logistics Cost (TLC) and time incurred in logistics activity of the transportation of a liquid Hazardous Chemical (HAZCHEM) through road. The logistics of HAZCHEM is receiving considerable attention because of the increase in demand for various industries and the means of transport is also an important factor. In this paper, the total logistics activity for an industrial system is taken by considering the unloading of the chemical from the ship to the storage tank and the transportation from the storage tank to two different manufacturing plants through roadways. The problems faced are low rate of transportation of raw material and high cost of storage and transportation which affects the production rate and hence profit. The decision variables examined are the number and location of manufacturing plants in the logistics system, the flow of materials from storage to manufacturing plants, the quantity to be transported from storage terminal to plants, loading and unloading of raw materials, storage of raw materials, scheduling of trucks, transportation costs and maximizing fill rate. We are proposing a multi objective optimization model, considering all the constraints. The developed model is a MILP function. The model is solved using Lindo which uses simplex algorithm and Solver in Excel using Evolutionary GA to compare the optimality. The result indicates that the developed model produces considerable reduction in the total system wide logistics cost. We are considering the case of a chemical manufacturing plant which uses liquid HAZCHEM as a basic raw material.

Keywords– Mixed integer linear programming, HAZCHEM logistics, Transportation, scheduling

1. Introduction

The logistics costs of some chemical industries were found to be as high as 20% of the purchasing costs (Karimi, Srinivasan, & Por, 2002).

According to G. Stefansson (2006) logistics management is the process of planning, executing and regulating the efficient, effective flow and storage of raw materials, in process inventory, finished goods, services and related information from the point of origin to the point of consumption. The cost of logistics can be classified into two: direct and indirect costs. Direct costs comprise storage, loading, unloading and transportation of goods in the material flow along with the administration costs, whereas quantity and deficit costs are indirect costs. If the large portion of the logistics cost of an industry can reduce, the expenses will minimize significantly. Initially we have to study and analyze the present logistics system to reduce the large portion of logistics cost. The logistic operations in the transhipment area and the manufacturing divisions include weight checking of the trucks loaded with raw materials to their unloading in the point. A truck arriving at a manufacturing plant, have to go through various operations such as net weighing, content quality test, unloading on storage terminals (A P Iannoni & R Morabito, 2004). The longer waiting time of the trucks results in break downs in the production process due to shortage of raw material. The choice of transportation modes creates a bi objective optimization model when compared to deficit costs, such as to minimize cost and lead time. The different transportation modes can be considered are trucks, rail, barges or ships which may be own or contract which has cost and time functions associated with it.

Simplex algorithm is selected as one of the top ten algorithms of the twentieth century in optimization techniques. Here we use Lindo as the tool with simplex algorithm. Evolutionary algorithms perform well in multi objective models which can search the entire objective space while at the same time using small amounts of computation time. Solver in excel is used as the tool for evolutionary algorithm. The two results obtained are then compared to test the accuracy in the optimal value.

Our objective is to optimize the total logistic cost incurred in the transportation of a hazardous liquefied gas from the transhipment area to the manufacturing divisions. HAZCHEM transportation is having lots of environmental and safety regulations which affect the transportation mode and rate of transportation quantity. The available mode of transport is only through road. As it is a hazardous chemical certain time and load regulations are there for the transport through road.

We are considering the transportation of a Liquefied gas which is arriving at a port through ships and from there it is being transported to multiple manufacturing plants through roadways. Here the material is used in the chemical industry. Our aim is to minimize the total cost incurred in the transportation of material and to meet the demand by maximizing the transport rate.

2. Literature Review

Although many works have been carried out on transportation and scheduling problems, comparatively the transportation of HAZCHEM optimization is very less, which addresses the loading and unloading functions along with storage and transportation costs. HAZCHEM transportation has received considerable attention in the past couple of decades. Most of the researches in HAZCHEM and HAZMAT transportation optimizations were mainly focused on routing and comparatively less works are considering storage costs along with transportation costs and time in transit. The cost affecting parameters in logistics system was mainly aimed at minimization of transportation cost. We are considering the optimization of logistics costs and maximizing the fill rate. In traditional supply chain management, research was mainly focused in the optimization of single objective models such as cost minimization and profit maximizations (Jayaraman & Pirkul, 2001; Jayaraman & Ross, 2003). Jeff Ferrio and John Wassick (2007) developed a MILP model for chemical supply chains which addresses cost as a function of quantity and transportation costs along with logistic costs, considering fill rate, volume, material balances and chain structure constraints. Now several researches consider the industry demanding objectives such as company's profit, the demand satisfaction rate of customer and the safe inventory level. A bi objective optimization model was developed by Pishvaee et al. (2010) for a forward/reverse logistics system considering the total system wide cost and the demand satisfaction and return rates. Chan et al. (2006) studied a multi-objective model which includes cost and time functions which considered transportation time also. Sadjady and Davoudpour (2012) discussed a problem for supply chain model where time and cost were included with transportation alternatives. The single objective optimization model considering the lead time in the transportation alternative was transformed into cost optimization model was solved using a Lagrangian relaxation method. A distribution problem was discussed by Dror and Ball (1987) where each consumer keeps a local inventory, a known quantity consumes each day and a minimum stock is ensured by a central supplier. Sigrid Knust and Elisabeth Schumacher (2009) developed a MILP model for the scheduling of tank trucks for an oil industry with the objective of assigning a suitable driver to each shift considering hard constraints. A maritime routing optimization was proposed by Miller (1987) where a certain level of inventory is maintained by the transportation of multiple chemicals from one terminal to multiple destinations. Li, Karimi and Srinivasan (2008) developed a mixed-integer linear programming formulation (MILP) for the inventory service problem with different materials, different loading terminals, different loading & unloading capacities, concurrent loading & unloading etc. focused on multiple ship reception and delivery of multiple liquid bulk cargoes. A mixed-integer linear programming (MILP) model is proposed by Jetlund and Karimi (2004) with variable length slots and heuristic decomposition algorithm which generates fleet schedules for multi commodity transportation. Mojtaba Shakeri, Malcolm Yoke Hean Low, Zhengping Li (2002) defines cross docking as a Just In Time (JIT) process of logistics where material is directly unloading from incoming ships and loading the materials into outgoing trucks or barges, with no intermediary storage. With the advantage of modern computational resources and new methods, the difficulty in solving multi objective optimization problems are reduced and helps the researchers to include more contributory objectives ad constraints. A Lagrangian decomposition approach was done by Luisa Equi, Giorgio Gal, Silvia Marziale and Andres Weintraub (1996) for combined transportation and scheduling problems. The commonly followed solution approaches for the multi objective optimization models are the goal programming method , weighted sum method, fuzzy method and the constraint method (Azapagic & Clift, 1999; Zhou, Cheng, & Hua, 2000; Chen,Wang, & Lee, 2003;Chen & Lee, 2004). Evolutionary Algorithms (EA) are more advisable for multi objective optimization because of their effectiveness in concurrent optimization of inconsistent objective functions and various alternative solutions can be generated in a single run (Zitzler and Thiele, 1999 , Zitzler et al., 2000 and Sarker et al., 2002). In this research we are studying the entire logistics activity and all the cost affecting parameters are incorporated in the developed optimization model.

3. Problem Definition and Objective

In this section a formal description of problem is given, highlights its complexity, and states the modeling details. The aim of our research is to develop an optimization model of HAZCHEM transportation which addresses all the processes happening in a logistics activity from receiving the raw material to the delivery of the raw material to the plant while meeting the demand and on time delivery .In this we are addressing the cost and time functions in storage, raw material loading and unloading and transportation along with constraints. Also the inventory level should be kept at minimum level in the storage thereby minimizing the storage cost and maximize productivity by supplying the raw material according to the demand. It can be summarized as

i. To optimize the total system wide logistics cost
ii. Improve the transportation quantity
iii. Systematic scheduling of trucks
iv. Maximize the fill rate

3.1 Problem Formulation

The basic structure of the theory is based on Baumol and Vinod (1970). Assume that the per-period total logistics cost (TLC) for firm is given by the sum of the order cost, transport cost, capital cost on the inventory in transit and warehousing and capital costs on the inventory

$$\text{Total Logistics Coct (TLC)} = \text{order cost} + \text{transport cost} + \text{inventory cost} + \text{storage cost} \quad (1)$$

Our research proposes a bi objective MILP optimization model considering cost and time functions that occur in order, storage, transportation, loading and unloading that occurs in the logistic activity.

4. Modeling and Development

4.1 Objective Function

Minimization of

$$Z = C_o \sum_{lt=1}^{LT} \sum_{pt=1}^{PT} + C_t \sum_{lt=1}^{LT} \sum_{pt=1}^{PT} Q_{lt,pt} \cdot s_{lt,pt} + C_s \sum_{lt=1}^{LT} \sum_{pt=1}^{pt} Q_{lt,pt} \cdot d_{lt,pt} + C_{ul} \sum_{sh=1}^{SH} \sum_{lt=1}^{LT} (T_{f,sh,lt,} - T_{p,sh,lt}) + C_w \sum_{sh=1}^{SH} \sum_{lt=1}^{LT} (T_{p,sh,lt} - T_{ar,sh,lt}) + C_l \sum_{tr=1}^{TR} \sum_{lt=1}^{LT} (T_{f,tr,lt} - T_{p,tr,lt}) + C_w \sum_{tr=1}^{TR} \sum_{lt=1}^{LT} (T_{p,tr,lt} - T_{ar,tr,lt}) + C_{un} \sum_{tr=1}^{TR} \sum_{pt=1}^{PT} (T_{f,tr,pt} - T_{p,tr,pt}) + C_w \sum_{tr=1}^{TR} \sum_{pt=1}^{PT} \left(T_{p,tr,pt} - T_{ar,tr,pt}\right) \quad (2)$$

Nomenclature

A. Indices and Sets

lt =1,2,.... LT – logistic terminal

pt = 1, 2,.......PT – manufacturing plant

sh =1, 2,.......SH – ship

tr =1, 2,......TR – truck

t =1, 2,......T – time

B. Variables

C_o - Unit cost of ordering the raw material

C_t - Unit cost of transporting raw material from logistic terminal to plant

C_s - Unit cost of storage at logistic terminal

C_{ul} - Unit cost of unloading at logistic terminal and plant

C_w - Unit cost of waiting at logistic terminal and plant

C_l - Unit cost of loading at logistic terminal

D_{pt} - Demand of raw material at manufacturing plant

$Q_{lt,pt,tr}$ - Quantity of raw material transported from logistic terminal to plant through truck

$X_{t,tr,lt}$ - Availability of truck, tr at time, t in logistic terminal

$Y_{t,tr,pt}$ - Availability of truck, tr at time, t in plant

$T_{f,sh,lt}$ – Filling time storage tank in logistic terminal

$T_{p,sh,lt}$ – Time taken for unloading raw material from ship to storage tank

$T_{ar,tr}$- Arrival time of truck

4.2 Ordering Cost

The first part of the objective function (equation (2)) is the ordering cost. It is the unit cost, C_o incurred in ordering unit quantity of raw material from the suppliers through shipments.

4.3 Transportation Cost

Transportation cost is the second part of the equation (2). This is the unit cost of transporting raw material, Q from the storage area say a logistic terminal, LT to manufacturing plant, PT at a distance, 's' through contract carriages or own vehicles (Cost/tonnage).

4.4 Storage Cost

This is the third part of the objective function .It is the unit cost of storing the raw material quantity, 'Q' at 'd' number of days in the storage terminal, lt.

4.5 Loading and Unloading Cost

The fourth, sixth and eighth part of equation (2) discusses the loading and unloading costs. This cost includes the unit cost in loading, 'C_l' and unloading, 'C_{ul}' of the raw material. This includes loading the trucks, 'tr' and unloading the ship, 'sh' at logistic terminal, 'lt' and unloading trucks, 'tr' at manufacturing plants, 'pt'. This includes the pumping cost and other mechanical process cost and manpower cost involved in material transfer.

4.6 Waiting Cost

The waiting time of the ship in the logistic terminal, lt incurs a demurrage cost, if the unloading time takes more than the allowable limit. It also includes the waiting time due to high set up time in loading and unloading of the truck in logistic terminal and plant.

5. Constraints

5.1 Storage Tank Constraints

Quantity of raw material, 'Q' available at the logistic terminal, 'LT' should be greater than or equal to the demand, 'D' at the manufacturing plants, 'PT'.

$$\sum_{t=1}^{T}\sum_{lt}^{LT} Q_{t,lt} \geq D_{pt} \quad (3)$$

Raw material transported 'Q', from logistic terminal 'LT' to manufacturing plants 'PT', should be less than or equal to the maximum capacity of storage in the logistic terminal

$$\sum_{lt=1}^{LT}\sum_{pt=1}^{PT}\sum_{tr=1}^{TR}\sum_{t=1}^{T} Q_{lt,pt,tr,t} \leq \text{Max. capacity of storage} \quad (4)$$

5.2 Truck Constraints

The hazardous chemical transportation is having time constraints in transportation. The truck arrival time 'T_{ar}' should be in the allowable time limit

$$T_{ar,min\,tr} \leq T_{ar,tr} \leq T_{ar,max\,tr} \quad (5)$$

The quantity of raw material, 'Q' transported should be less than or equal to the maximum capacity of the trucks, 'TR'

$$\sum_{lt=1}^{LT}\sum_{pt}^{PT} Q_{lt,pt,tr,t} \leq Q_{tr\,max} \quad (6)$$

$$tr = 1,2 \ldots\ldots\ldots\ldots TR$$

5.3 Scheduling Constraints

5.3.1 Unloading from ship

$$T_{f,sh,lt} - T_{p,sh,lt} \leq 24 \quad (7)$$

The unloading time of the ship should be less than 24 hours which is the limited time for one schedule, because if unloading takes more time it will add demurrage cost.

5.3.2 Loading of truck

$X_{t,tr,lt} = 1$, If truck is available, (8)

= 0, if not available

This binary variable 'X' denotes the availability of truck 'tr' at time,'t' in the allotted loading bay.

5.3.3 Unloading at the manufacturing plant

$Y_{t,tr,pt} = 1$, if truck is avilable (9)

= 0, if truck is not available

This binary variable 'Y' denotes the availability of truck 'tr' at time, t in the allotted unloading bay.

5.4 Demand Constraint

The demand of the raw material, 'D' at the manufacturing divisions should meet the requirement by the quantity of raw material 'Q' transported from the storage tank

$$D_{pt} = \sum_{lt=1}^{LT}\sum_{pt=1}^{PT}\sum_{tr=1}^{TR} Q_{lt,pt,tr} \quad (10)$$

6. Case Study

Our research is studying the logistics activity of a chemical manufacturing company which is having multiple divisions of manufacturing plants. The liquid raw material for manufacturing, which is a HAZCHEM, is arriving through ship based on the order given by the company. It is stored in a storage tank located in the shipping port which is having a limited capacity and temperature constraints. The liquid raw material is transported to separate manufacturing divisions as per the requirement to meet the daily production capacity. The mode of transport chosen is truck which is operated by third party.

The total logistics cost here we considered is comprised of the unloading of the raw material from the ship, storage cost, transportation cost, loading cost and unloading at manufacturing plant. The factors which adds value to each and every cost affecting parameters is studied and identified the areas which needs improvement to reduce cost.

The storage is provided with refrigeration systems to maintain the temperature and pressure of the raw material in the storage. If we can increase the transportation rate the storage cost can also be minimized.

6.1 Raw Material Requirement

The maximum production capacity of the plant is 2500 T/day for which the quantity of raw material required is 820 T/day. So if the raw material availability is less the production rate will also comes down. With 500T of raw material the company can manufacture only 1750 T/day which does not meets the market demand. Even if the raw material supply is less the company has to run the plant with same operating cost for minimum production and it will result in loss. At present situation the only available mode of transportation is truck. The low rate of transportation is mainly due to the time window and the lack of systematic scheduling of the trucks by the third party contract. The increased loading, unloading and transportation time are also the reasons. Table 2 shows how the raw material shortage affects in the down time of the manufacturing plant.

Table 2: Raw material shortage vs downtime

Month	Oct 2014	Nov 2014	Dec 2014	Jan 2015
Productive Hours (in hours)	901	1085.25	1100	1250.75
Total Down Time (in hours)	587	354.75	388	234.25
Down time due to Material shortage (in hours)	225.5	239	162.25	73.75

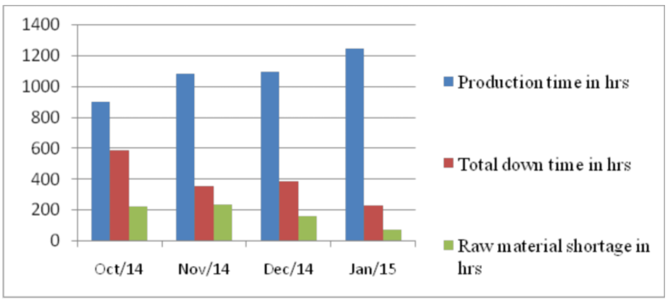

Fig1. Production hours vs shut down hours chart

6.2 Storage and Handling Facilities

The liquid chemical are stored in a low temperature store at 1ata pressure. Pressure and temperature is maintained constant by means of refrigerating compressors.

Liquid chemical is supplied in ship tankers of 8000 to 10000T capacity under almost equal conditions and is pumped into the store by means of pumps installed in the ship via transfer pipelines.

The ship arrives at the island according to the schedule given by the port. The liquid chemical is unloaded into two storage tanks which are having capacities of 5000T each using pumps. There will be a demurrage cost if unloading takes more than allowable time. If it takes more time than allowed, then the company will have to pay demurrage cost

There are four truck loading bays provided at storage & handling facility at storage terminal. The chemical is transferred to the trucks by means of pumps installed in the store via transfer lines. There are four truck unloading bays provided in the manufacturing plants.

6.3 Transportation

The only mode of transportation the company having is road ways. As the raw material is coming under the category of hazardous chemical, there are regulations in road transport. The permissible time of transport is only 12 hours a day. The company is giving annual third party contract based on the tonnage rate to supply the chemical as needed for production. Our aim is to meet the demand at the two divisions so that the plants can produce up to the maximum capacity, at minimum cost and no plant shut downs due to raw material shortage.

7. Optimization Methodology

The developed mathematical model is a MILP function. We are considering the optimization of the total system wide logistics cost from logistic terminal (LT) to manufacturing plant (PT) by considering unit cost of ordering (C_o), unloading cost (C_{ul}), cost of loading (C_l) and transportation cost from LT to PT (C_t) in the objective function (equation 2).

As the objective and constraints are linear functions of the decision variables, it is a linear programming problem and also a convex function. So the best algorithm we can go is Simplex. The optimization tool we use for Simplex algorithm is Lindo. Lindo guarantees globally optimum solutions to linear and non linear problems with continuous or discrete variables. Also we are using Solver in MS Excel with Evolutionary GA to compare the optimality. Excel solver can also perform well with MILP functions and produces a global optimum value. The obtained results shows large savings in total logistics cost.

7.1 Computational Results

We are considering the minimum demand of raw material for manufacturing plants as 820T per day. The current maximum transportation rate is 509T per day and logistic cost is found to Rs. 1,81,210. The developed optimization model is solved with the minimum demand for two manufacturing plants which is 820T and with 1000T. Two optimization methodologies with two different algorithms are chosen for solving the model. The two results are then compared to analyze the optimality of the objective value.

7.1.1 Methodology - Lindo API With Simplex Algorithm
The objective function is minimization of total system wide logistics cost of the raw material. The unit cost of loading, unloading, storage and transportation parameters in the model is given as input in Lindo API with solver parameters. The average transportation rate in current system is not more than 500 T daily, which is far below the demand. The total logistics cost for the transportation on an average daily basis is observed to be Rs. 356.01 T per day. But with the developed model if the transportation quantity is meeting the demand of 820T, the cost per tonnage is reduced to Rs.315.80.Also the model optimizes the total logistics cost to Rs.303.57T/day with a transportation rate of 1000T per day. The results are shown in the table.

Table 3 Lindo results for optimized cost

Parameters	Cost in Rs
For 509T, (rate taken from one sample day)	
Total Logistic cost	1,81,210.00
Cost/ Tonne	356.01
For meeting a demand of 820T,	
Total Logistic Cost	2,58,960.00
Logistic Cost per Tonne	315.80
Savings / day	**32,972.20**
For 1000T,	
Logistic cost	303572.50
Cost / Tonne	303.57
Savings/day	**52,440.00**

From the figure 2 we can see that as the transportation quantity increases from 509 tons to 820 tons, the cost per ton of transportation is decreasing from Rs. 356.01 to Rs. 303.57.

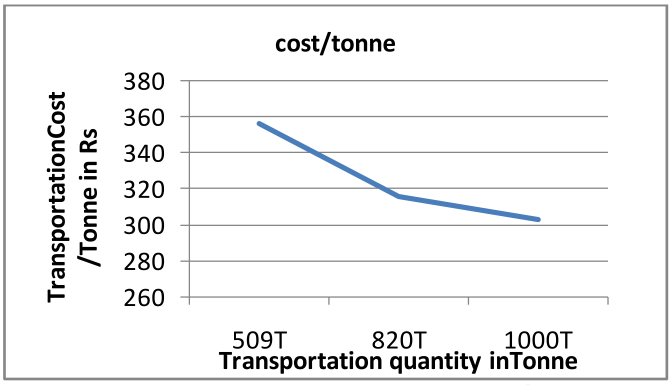

Fig. 2 Transportation quantity vs cost plot

The increased cost in current logistic system is mainly due to the high storage cost, because of the low rate of transportation from storage to manufacturing plants. This results in low rate of production in the manufacturing plants and plant shut downs due to raw material shortage. So the company cannot be able to supply according to the market demand and affects the profit. If there is ten tonne shortage of raw material supply to manufacturing plant, it will results in 40 tonne shortage of the final product. The storage cost is affected by increased power consumption in storage requirements such as refrigeration, so we have to keep minimum inventory in storage.

7.1.2 Methodology - Solver (Excel) With Evolutionary Ga
The model is solved again in Solver as a tool with Excel which uses evolutionary GA as the algorithm. The input parameters are the same as given in Lindo. The result obtained doesn't show much deviation as compared to Lindo solution. The results are shown in table 4

Table 4 Solver results for optimized cost

Parameters	Cost in Rs.
For 509T,	
Total Logistics Cost	1,81,538.44
Cost/Tonne	356.65
For 820T,	
Total Logistics Cost	2,59,288.40
Cost/Tonne	316.20
Savings/ Day	**33,169.00**
For 1000T,	
Total Logistics Cost	3,04,288.07
Cost / Tonne	304.29

7.1.3 Comparison of Results
The two solutions are compared to analyze the optimality of the obtained value from the developed model. The algorithm and solver parameters are the only things vary which are defaults. The obtained optimal cost values are precise.

Table 5 Comparison of results in Lindo and Solver

Software	**Lindo API**	**Solver (Excel)**
Algorithm	Simplex	Evolutionary GA
Objective value	Rs. 2,58,960.00	Rs. 2,59,288.40
Cost/Tonne	Rs. 315.80	Rs. 316.20
Savings/Day	Rs. 32972.00	Rs. 33,169.00

8. Optimized Transportation Schedule
The scheduling of the trucks should be done in such a way that transportation quantity should meet the demand of the manufacturing plants in required time. The loading and unloading bays should not remain idle and the transportation time should be within limit. The number of trucks and number of trips required should be capable of transporting the demanded quantity. The one cycle time i.e. from loading at logistic terminal to unloading at manufacturing plant of trucks should be 4 hours. This time is taken from the analysis of current truck running system and selected from the best. The cycle time comprises of loading time, to and fro running time and unloading time. The third party contract should be given in such a way that the number of vehicles and number of trips should be capable of transporting a minimum quantity of 1000 Tonnes/day at optimum cost. For transporting a minimum quantity of 820 Tonnes per day 55 trips is required. Based on the best cycle time for 55 trips a minimum of 24 trucks are required, such that some trucks can take up to three trips per day to supply according to the demand. The scheduling should ensure all the loading and unloading bays should be engaged in the allowable time and no bay remains idle. The thing is that all the requirements inside the company

such as loading time, set up time for loading and unloading should be optimum.

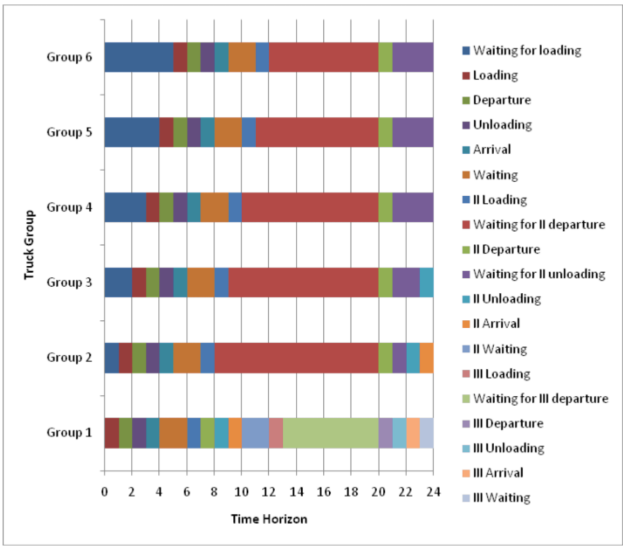

Fig. 3 Gantt chart for Optimized Truck Schedule for a day

9. Conclusions

A MILP logistics optimization model has been developed for HAZCHEM transportation. The optimization of the logistics model for minimizing the cost has been done using Lindo and Solver software. The obtained objective values are compared and both solvers confirm the optimality of logistics cost. The model incorporates various costs such as shipping, storage, loading and unloading. In the case study considered in this paper, the current transportation through roadways results in inadequate transfer of raw materials. As a result, the productivity is less and hence the inventory cost is high. This also results in high storage costs and not being able to produce according to the demand which in turn results in low profit for the company. The proposed model produced an optimized operation schedule for the raw material transfer that is able to meet the demand at all the manufacturing plants. Thus this paper proposed a model that minimizes the logistics costs and the company can supply the chemical product as per the demand of the market. The obtained optimum value shows that if the company can transport the required quantity of raw material, 820 T /day then the production will increase to 2500 Tonnes per day. The total savings is found to be Rs. 32,972 per day from logistics with the increased transportation rate. The scheduling is done in such a way to transport 820 tonnes per day with 55 trips by 24 trucks.

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