Design and Development of Milk-Run Material Supply System with Time Windows and Simultaneous Pickups and Deliveries

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Abstract

Material handling is one of the most crucial issues that should be taken into account for eliminating waste, reducing the cost and just in time based delivery of the product. Many industries spending millions of bucks for the transportation of the goods. An effective transportation management system has to be implemented to control the cost of transportation and inventory. Optimized milk-run concept can be utilize to overcome the issue related to the supply chain management system. Milk-run material supply system is the cyclic trips, where either goods are collected from several suppliers and delivered to one customer, or goods are collected from one supplier and delivered to several customers. The objective of this research is the minimization of the total material handling and inventory holding cost. It is also concentrated on just in time delivery to enhance the customer satisfaction. These saving of cost could be either use for reduction of the product cost, which will boost up the sales or to lift the profit margin of the organization. The purpose of this research is to develop a mathematical model and a heuristic approach, which is utilize to construct the routes, calculate the associated cost and determine the service period for the design of a milk-run material supply system with simultaneous pick-up and delivery. The material supply by this system occurs on a just-in-time basis from a regional offices to several stations of the courier service. Besides, the proposed heuristic approach intends to construct routes based on an initial service period value and attempts to improve the solution by considering different period values. Furthermore the scheduling of the vehicles is calculated based on demands and routes of network. The most optimum solution is decided on the basis of the least total transportation cost and minimum time. Genetic algorithm is proposed to solve the vehicle routing with simultaneous pickup and delivery within time frame (VRPTWSPD) problem related to milk-run concept. Algorithm is applied by the help of MATLAB and results are presented. The result showed the performance and effectiveness of the algorithm.

Keywords: Milk-run material supply system, Supply chain system, Genetic algorithm, Scheduling, Transportation cost

I. INTRODUCTION

Material handling is a field of growing interest of both industries and research institutions. Enormous rivalry in today's global markets, the range of products with shorter life cycles, and the higher expectations of consumer markets have enforced suppliers to concentration on their supply chains services. This, together with innovation and invention in communications and transportation technologies have encouraged the continuous evolution of the supply chain techniques. Consequently, to shrink cost and enhance service facility, operational supply chain policies need to take into account. The supply chain, which is also referred to as the logistics network involves bunch of varieties of management (suppliers, manufacturing unit, warehouses, distribution point, and retail outlets). The material supply system includes the movement of goods from a supplier to a customer, as well as any customer returns to the supplier in a logistic distribution network. It involves supply, storage and control of materials and products throughout distribution in the system. Material supply system plays an important role in manufacturing and logistic. The vehicle routing problem is a common central problem in operations research arise in various fields, required to optimally route a fleet of vehicle to several set of consumers with simultaneous pickup and delivery. The environment in which industries nowadays accomplish their supply chain is highly vigorous. If a good material handling system design is accomplished, it is claimed that the cost will be reduced in between 10% and 30% [2]. In a typical industry, material handling composes the 25% of the workers, 55% of the factory area, and 87% of the production time [3] as transportation cost has a significant impact in total production cost.

II. LITERATURE REVIEW

Just-in-time material supply system is the logistics measurement of the lean manufacturing [1]. It represents lean philosophy to logistic activities supported within the plant among the suppliers and the manufacturer. Vaidyanathan et al. [4] analysed the JITVRP (Just-in-time vehicle routing problem) and emphasized the unique characteristic of this problem. JITVRP requires that the quantity to be delivered at each of the demand nodes is a function of the route taken by the vehicle assigned to serve that node. The authors developed a non-linear mathematical model for this problem, relaxed it by making some assumptions and proposed a linear model that attempts to determine the lower bound for the number of vehicles required [4]. Moreover, a two-stage heuristic algorithm was proposed in proposed research work, for the optimal solution of the problem. Satoglu S. and Sahin E. [15] explained JIT periodic material supply system for assembly line. They approached heuristic algorithm and mathematical method for routing. However, the researchers did not attempt scheduling of the vehicles in their research. The objective of the proposed mathematical model is the minimization of the total material handling and inventory holding cost [15]. The proposed heuristic approach is anticipates for the construction of routes based on an initial service period value and attempts to improve the optimal solution by considering different period values.

Domingo et al. [9] explained a real implementation of milk-run material supply system that serves a lean assembly line. They followed a practical approach. Initially, the stock points where pickups and deliveries were determined. Then, the sequence of operations was defined and alternative feasible routes were identified. The stock points with high demand rates and those with lower demand rates were included in two separate routings. Then, the pickup and delivery schedule were developed. However, the researchers did not attempt to make an optimal milk-run delivery system design. Alvarez et al. [10] presented a case study of the redesign of an assembly line by using lean production tools. To reduce lead time and excessive stocks and improve material flow within the manufacturing system, Kanban-based production control and a milk-run material handling system were implemented. The authors realized that the design of Kanban production control system is insufficient without implementing an appropriate material handling vehicle [10]. Boysen and Bock [11] considered scheduling JIT part supply to a mixed-model assembly line where assembly line and the warehouse are at different factory floors. The authors used dynamic programming and simulated annealing for the solution of the problem. Hao and Shen [8] developed a prototype software system that integrates discrete event simulation with agent-based simulation technique to evaluate the performance of a Kanban-based milk-run system serving an assembly line. In addition, Nemoto et al. [16] explained JIT external milk-run applications of the Toyota automobile assembly factories located in Thailand. It has been revealed by the case study that implementing the milk-run supply system even under dense traffic conditions, Full control of the procurement process can be achieved by the supplier, which reduce the number vehicle in supply network by optimisation of the utilisation of the vehicles and resolve the traffic problem to some extent level in urban areas and highways.

III. FORMULATION OF MATHEMATICAL MODEL

The mathematical model of the milk-run supply system is formulated to analyse the problem, according to the necessity and application of the logistic chain of courier industry. The mathematical model helps to explain the system and to study the effect of different parameters in overall transportation cost.

A. Objective Function

The objective function of the mathematical model is to minimize the total cost. The first part of the objective function indicates total transportation cost. The second part explains the total fixed cost of the vehicle (Initial cost of vehicle, Taxes, Insurance charges, Vehicle permit charges etc.) according to the milk-run. The third part shows the penalty cost if the delivery time.

$$\text{Minimize } Z = \sum_{k=1}^{K}\sum_{i=0}^{n}\sum_{j=0}^{n} c_{ij}\, x_{ijk} + \sum_{k=1}^{K} c_{fk} + \sum_{i=1}^{n} p_i\, t_i \qquad (1)$$

B. Constraints

Subject to,

$$\sum_{k=1}^{K}\sum_{i=0}^{n} x_{ijk} \geq 1, \qquad i = 1,2,\ldots,n \qquad (2)$$

$$\sum_{k=1}^{K}\sum_{j=0}^{n} x_{ijk} \geq 1, \qquad j = 1,2,\ldots,n \qquad (3)$$

Each Point is visited by minimum one vehicle.

$$\sum_{i=0}^{n} x_{ijk} - \sum_{i=0}^{n} x_{jik} = 0, \qquad j = 0,1,\ldots,n \quad k = 1,2,\ldots,K \qquad (4)$$

Same vehicle arrive and depart from each point between the node i and j.

$$X_{ir} = X_{jr} \qquad (5)$$

The related stock point assigned to a same "r" route.

$$q_i = t_{fixed} . X_{ir} . \quad (6)$$

The total demand of a point "i" at "r" route is determined.

$$q_i \leq c_{k,} \quad \text{if } x_{ijk} = 1 \quad (7)$$

The vehicle capacity should be higher than demand.

$$q_i \leq c_{ik,} \quad \text{if } x_{ijk} = 1 \quad (8)$$

Each vehicle have free capacity at the arrival at point "i". It should be greater than pick up demand at that respective point.

$$b_o \leq a_i \leq t_o \quad (9)$$

Arrival time must be within time frame.

$$w_i = d_i - (a_i + s_i) \quad (10)$$

Calculate the waiting time before the departure at point "i".

C. *Notations*

The necessary notations are defined for the formulation of mathematical model, which are explained in following sections.

1) Indices

k = Vehicle index
t = Time period
i, j = Pick-up and delivery point indexes
n = Set of clients
r = Route index
K = Maximum number of vehicles in distribution centres

2) Parameter

c_k = Capacity of vehicle "k"
c_{ik} = Free capacity of vehicle "k" on arrival at node "i"
q_i = Pick-up and delivery demand at point "i"
b_o = Bottom end of the time frame at point "i"
t_o = Top end of the time frame at point "i"
s_i = Service time at point "i"
d_o = The output and input ratio of point "i"
t_{fixed} = The determined time period

3) Variable

c_{ij} = Delivery cost between "i" and "j"
x_{ijk} = 1 if vehicle "k" departs point "i" to point "j"; 0 otherwise
c_{fk} = Fixed cost of the vehicle "k"
X_{ir} = Point "i" is assigned or not assigned to route "r" (1 or 0)
X_{jr} = Point "j" is assigned or not assigned to route "r" (1 or 0)
a_i = Arrival time at node "i"
w_i = Waiting time before departure
d_i = Departure time from point "i"
p_i = Penalty cost per unit time from tardiness of point "i"
t_i = Tardiness for point "i"

D. *Heuristic Approach*

As explained earlier, the design of the milk-run material supply system requires construction of routes, scheduling of vehicle and determination of the service period. Mathematical models are typically formulated and attempted to be solved by heuristics approach for the route construction. The proposed mathematical model of the JITVRPSPD is non-linear due to the continuous large scale demand of the each stations. Vaidyanathan et al. [4] described that the problem size increases exponentially with the increasing in number of vehicles and stations that makes even small scale problem difficult to solve. Hence, a heuristic approach is useful to reach at a close to optimal solution, through short computational times. An algorithm are developed based on the proposed approach. The assumptions of the mathematical model are valid also for the proposed heuristic approach.

Initially four various algorithms are tried and tested by considering the small region of the problem to find an optimal solution (Tabu search algorithm, Prim algorithm, simulated annealing and Genetic algorithm). The optimal solution achieved by each algorithms are evaluated and compared to choose the most suitable algorithm for the concern problem. Out of the four different algorithms, genetic algorithm are found to be more suitable and accurate for the nature of our problem. Based on the comparison, Genetic algorithm are selected to study and analyse the entire problem.

A genetic algorithm is a metaheuristic approach to solve mathematical optimization problems based on a natural selection process that based on biological evolution theory. The algorithm repeatedly modifies individual solutions by producing the children for the next generation from their parents called current generation. Genetic algorithms generates optimised solutions by relying

on bio-inspired operators such as mutation, crossover and selection. Over successive generations, the population "evolves" toward an optimal solution.

IV. RESULTS AND DISCUSSIONS

Genetic algorithm is applied to resolve the current routing problem in the courier industry using the milk-run material supply system. Input data are used to solve the problem are;

- Matrix of distance, position and travelling time of each stations zone wise
- Demand data of each station (Volume per cycle) with the cycle

A. Development of Routes

The routes have been constructed by genetic algorithm in matlab based on the geographical location and distance between each stations. The algorithm performed using graphic user interface to display the routes, scheduling, total cost, distance and time of travelling of each zone. The Gujarat state are considered for solving the vehicle routing problem in courier industry. The state are basically divided in five different zone based on location of the regional offices i.e. Mehsana, Ahmedabad, Rajkot, Vadodara and Surat. Each zonal offices covers the nearby stations or area. The routes are developed in cyclic manner based on milk-run material supply system for various zones. Fig. 1 shows the map of Gujarat with all major cities. The location of five regional offices cover almost all major area of state.

Fig. 1: Map of Gujarat

1) Mehsana Zone

Mehsana regional office covers the area of north Gujarat. It distributes and collect goods to 20 cities around the northern area of state. Couple of routes are developed by genetic algorithm based on location of stations. Following Fig. 2 to Fig. 4 show the routes, total cost, scheduling of vehicles, travelling distance and travelling time.

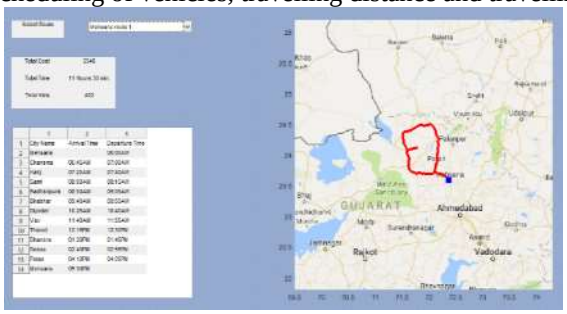

Fig. 2: Scheduling and routing of route 1

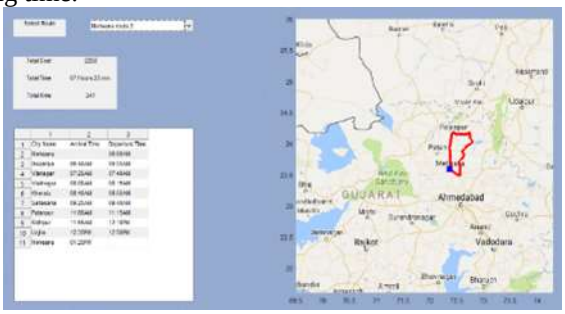

Fig. 3: Scheduling and routing of route 2

Fig. 4: Scheduling and routing of Mehsana zone

2) *Ahmedabad Zone*

Ahmedabad regional office is a heart of Gujarat state. It is one of the busiest station of state. It covers the area of middle Gujarat and Kutch region. It runs service to 29 cities around the middle-west area of state. Three routes are developed by genetic algorithm based on location of stations. Following Fig. 5 to Fig. 8 show all three routes, total cost, scheduling of vehicles, travelling distance and travelling time.

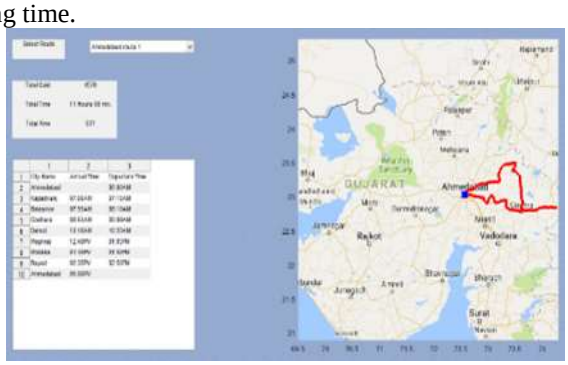

Fig. 5: Scheduling and routing of route 1

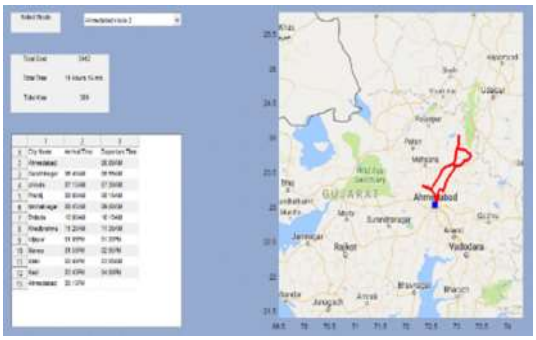

Fig. 6: Scheduling and routing of route 2

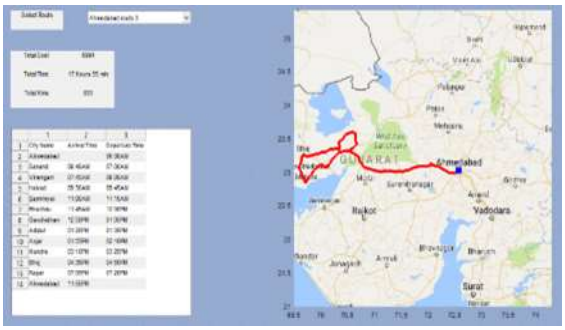

Fig. 7: Scheduling and routing of route 3

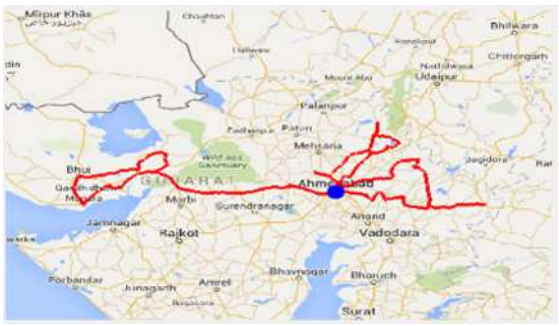

Fig. 8: Scheduling and routing of Ahmedabad zone

3) *Rajkot Zone*

Rajkot regional office covers the area of Saurastra region. It has to go through the longest travelling distance. It distributes and collects goods to 27 cities around the southern-east part of state. Four routes are developed by genetic algorithm based on location of stations. Following Fig. 9 to Fig. 13 show the routes, total cost, scheduling of vehicles, travelling distance and travelling time.

Fig. 9: Scheduling and routing of route 1

Fig. 10: Scheduling and routing of route 2

Fig. 11: Scheduling and routing of route 3

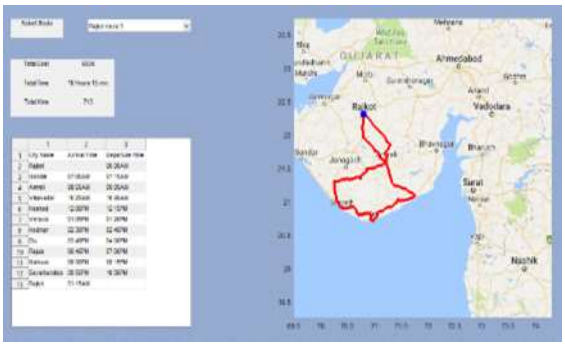

Fig. 12: Scheduling and routing of route 4

Fig. 13: Scheduling and routing of Rajkot zone

4) *Vadodara Zone*

Vadodara regional office covers the area of south Gujarat. It runs service to 16 cities around the southern part of state. Two routes are developed by genetic algorithm based on location of stations. Following Fig. 14 to Fig. 16 show the routes, total cost, scheduling of vehicles, travelling distance and travelling time.

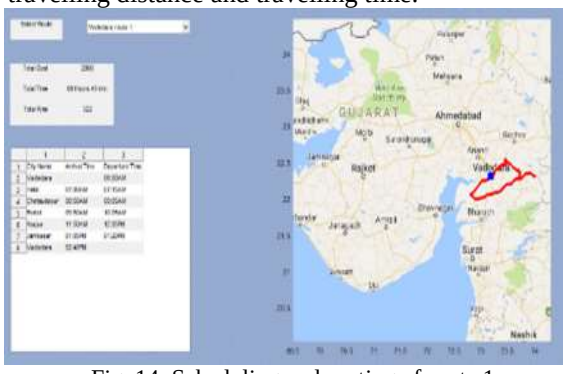
Fig. 14: Scheduling and routing of route 1


Fig. 15: Scheduling and routing of route 2

Fig. 16: Scheduling and routing of Vadodara zone

5) *Surat Zone*

Surat regional office covers the area of south Gujarat. It distributes and collects the goods to 10 cities around the southern part of state. Two routes are developed by genetic algorithm based on location of stations. Following Fig. 17 to Fig. 19 show the routes, total cost, scheduling of vehicles, travelling distance and travelling time.

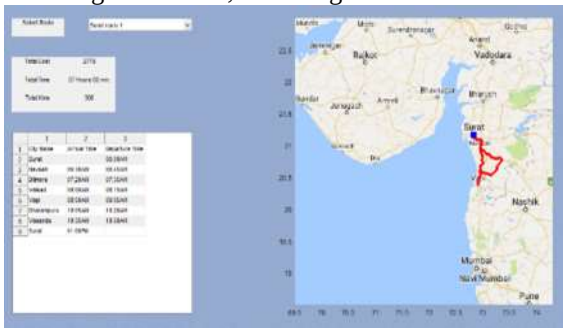
Fig. 17: Scheduling and routing of route 1

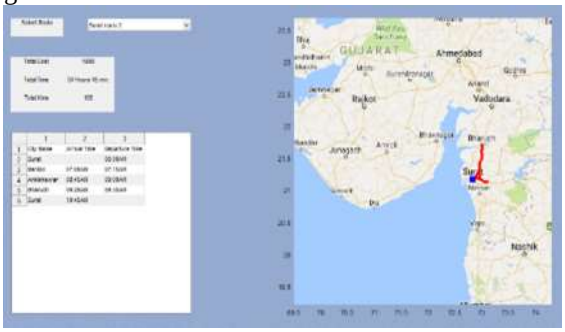
Fig. 18: Scheduling and routing of route 2

Fig. 19: Scheduling and routing of Surat zone

Based on output of the program, Table 1 shows the decreasing of total travelling distance and transportation cost per day for supplier location in all Gujarat region. The current transportation system has a total travelling distance and transportation cost are 7435 km. and Rs. 59480 per day in Gujarat state respectively. It is way too high as compare to the optimal total travelling distance and transportation cost which are 5555 km. and Rs. 48730 per day respectively by milk-run material system. It can be concluded form below table that milk-run supply system can optimized the travelling distance by 25.28 % or 1880 km. in a day and total transportation cost as Rs. 10750 or 18.07 % per day.

Table – 1
Comparison of Conventional Supply System and Milk-Run Material Supply System (Distance and Overall Cost)

Sr. No.	*Conventional supply system (Time)*	*Milk-run supply system (Time)*
Mehsana Zone	*26.40 Hrs.*	*18.55 Hrs.*
Ahmedabad Zone	*49.10 Hrs.*	*40.10 Hrs.*
Rajkot Zone	*60.10 Hrs.*	*50.10 Hrs.*
Vadodara Zone	*28.20 Hrs.*	*19.05 Hrs.*
Surat Zone	*20.40 Hrs.*	*11.45 Hrs.*
Total	*184.20 Hrs.*	*139.25 Hrs.*

Table – 2
Comparison of Conventional Supply System and Milk-Run Material Supply System (Travelling Time)

Sr. No.	*Conventional supply system (km.)*	*Milk-run supply system (km.)*
Mehsana Zone	*1020*	*643*
Ahmedabad Zone	*2000*	*1753*
Rajkot Zone	*2580*	*2047*
Vadodara Zone	*965*	*611*
Surat Zone	*870*	*501*
Total Distance	*7435*	*5555*
Transportation Cost (Rs./Day)	*59480*	*48730*

In linear correlation between travelling distance and travelling time, Table 2 represents reduction in total travelling time. It can be seen form below table that milk-run supply system can optimized the travelling time by 24.40 % in a day in all zones. According to current material supply system the total travelling time is 184.20 Hrs., which can be reduce to 139.25 Hrs**.** by successfully implementing milk-run material supply system.

V. CONCLUSIONS AND FUTURE SCOPE

As per the study of vehicle routing problem in supply chain management the Gujarat state is considered to implement the milk run material supply system in courier industries, as courier industries has a major involvement in logistic industry. GA is employed in matlab to solve the current travelling salesman problem. Total 17 routes are constructed according to the concept of milk-run material supply system, which cover 110 cities across the Gujarat states.

It has been observed from the result, that the reduction of the overall cost, time and distance will be have a major impact in supply chain industry.

A. Conclusion

Following conclusion can be drawn from this research work;

- In this study, the mathematical formulation and genetic algorithm is proposed for the solution of homogeneous and heterogeneous fleets for VRPSPDTW encountered in real life situations, where routes are constructed, service and delivery period are determined and schedule is obtained. Hence overcoming the limitation of current literature that usually employ for one or few products. Computational results and proposed procedure represents an excellent performance.
- The overall supply chain cost has been minimized by using milk-run system in transportation instead of direct shipment.

- The result shows reduction in the carbon dioxide emission from the transportation system by improving the vehicle utilization.
- Hence implementation of the milk-run efficiently can compress cycle time, minimize distance, decrease total cost, reduce carbon emission, increase vehicle utilization and improve profitability.
- It has been seen form the result that decreased of vehicle's travelling distance is 1880 kms or by 25.28 % in a day.
- With the linear connection between vehicle's travelled distance and travelled time, the reduction of vehicle's travelled time is 44.95 hrs. or by 24.40 %.
- The optimized model has achieved reduction of the overall cost at an extent level, that is Rs. 10750 or by 18.07 % in a day.
- The overall reduction of CO2 emission is by 24.94 % in the environment.

B. Future Scope

- Future research will be mainly addressed towards extending the application of the algorithm to various manufacturing environments to test its suitability and foster the necessary improvements.
- There are many uncertainties existing in practical environment, such as delivery reliability, stochastic customer demand, dynamic environment etc. These uncertainties influence much on vehicle scheduling and transportation cost. Further research will be focus on modification of genetic algorithm in vehicle routing problem with uncertain environment.

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