Optimization of a Large-Scale Lunch Box Delivery System - A Simple, Serializable, Synchronous, Parallel Simulated Annealing, and Floyd-Warshall Approach

Suraj Patro and Motahar Reza

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Suraj Patro, Motahar Reza
High-Performance Computing Lab
School of Computer Science and Engineering Technology,
National Institute of Science and Technology Berhampur, India
spatro.cse.2017@nist.edu, reza@nist.edu

Abstract: In this research article, we studied the large-scale, eco-friendly lunch box delivery system of Mumbai, and identified that it's further possible to improve the collection and delivery processes by following new routes and evenly distributing the loads while collection, distribution and transportation of the lunch boxes. We propose implementing multiple depot vehicle routing concept for improving the lunchbox delivery system. We use a real-coded simple serializable set, synchronous, parallel simulated annealing algorithm for new routing paths and balancing the collection load decisions. And the Floyd-Warshall algorithm to find the shortest path between any two points. The novel results of this work gives suggestions for better improvement of Large-Scale Lunch Box Delivery system by taking care of the issues a) reduce the manpower needed to do the same job, b) provide service to places where it was earlies not feasible due to long-distance.

KEYWORDS: Transportation, Lunch Box Delivery, Multiple Depot Vehicle Routing Problem, Simple, Serializable, Synchronous, Parallel Simulated Annealing, Floyd-Warshall Algorithm.

1. INTRODUCTION

The lunch box delivery system of Mumbai is considered a classic example of a very large scale, eco-friendly transportation management problem (Baindur & Macário, 2013). It comprises of approximately 0.2 million lunchboxes being collected and transported from household and offices and the same being returned. The lunch box delivery system founded in Mumbai has many unique characteristics concerning its operation, services, management practices, and overall business model. It is a surprise to both educational and corporate worlds that how such a vast system operates almost perfectly with the help of the illiterate or semi-literate workforce (the average literacy criterion being 8th grade in school) without the use of any sophisticated technology. They have conferred to the corporate world that the system established is more critical than the workforce for achieving such astonishing results. The accuracy of delivery is Six Sigma certified. The accuracy level is no less than that achieved by Motorola or GE (Mallik Mukherjee, 2007).
Unfortunately, the system isn't widely studied extensively. The topic concept reports only of a limited number of studies. Only a handful number of research articles are available on this topic, namely by Mallik & Mukherjee, 2007; Pathak, 2010; Baindur & Macário, 2013; Chakraborty & Hague, 2015. A few case studies are also available on this topic, namely by that of Ravichandran, 2005; Thomke, 2012. In these case studies, authors have critically examined the system and tried to find out achievement factors, and the plausibility of replicating it to similar circumstances of any other region of the world.
Some case studies are also taught at the world's top Business Schools to explain how a simple operating process leads to such a superior level of service.

In this article, we review the lunch box delivery system of Mumbai and identified that the better collection and delivery routing decisions are possible. We expressed the collection and delivery processes as a multiple depot vehicle routing problem. With the help of a numerical example, we find that it is possible to reduce collection and delivery rates by following better routes. Simulated annealing is a stochastic algorithm for solving discrete optimization problems, and is used for landing at new routing decisions. Therefore, it is possible to bring improvement into an existing world-class system. Floyd-Warshall algorithm is adapted to find the shortest path between any two points.

2. LUNCH BOX DELIVERY SYSTEM OF MUMBAI

This massive system which is existing now has its origin way back in 1890. It started with one lunch box carrier delivering lunch to one person who had been a bank employee during the British era in India. The service had grown since and sustained over the last 130 years. The number of lunch box carriers has reached to around 5000 in 2019. Their collective effort amounts to approximately US$12 million annually.

The lunch box carriers are the smallest and the most important units of the system. They provide these services on all working days throughout the year. They start their operations by reaching residential areas to collect boxes either on foot or by bicycle. Each of them is responsible for collecting around 35 to 40 lunch boxes from pre-specified locations. The collection of lunch boxes is completed between 8:30 – 9:00 AM approximately. After collecting the boxes, they reach the designated railway station. Another group of chosen carriers serve at the railway station by sorting the lunch boxes. A unique coding scheme is used for this purpose. Immediately after the sorting, lunch boxes are bundled into groups as per their respective destinations. Designated carts are used for this purpose. This part of transportation is managed by selected carriers in a predetermined railway station. Another round of sorting is done after the lunch boxes reach destination railway stations. A new set of carriers perform this task and complete the delivery to the respective customers. This process is completed ere 01:00 PM. The collection of empty lunch boxes from offices and their delivery to the respective households are done following an exact contrary manner. This process is completed before 05:30 PM. The railway extends its support by providing areas required for sorting of lunch boxes at platforms as well as by running trains having special compartments suitable for loading carts containing lunch boxes during 10:00 to 11:30 AM in the south Mumbai direction.

The efficient running of the system is largely credited to a simple and visual coding structure appropriate for the illiterate or semi-literate carriers. As the lunch boxes are transported through the local railway network, the coding structure must suitably relate to those railway stations. These two major concerns are very well incorporated while designing the coding structure. Figure 1 shows the lunch boxes with codes on the lid of each lunch box.

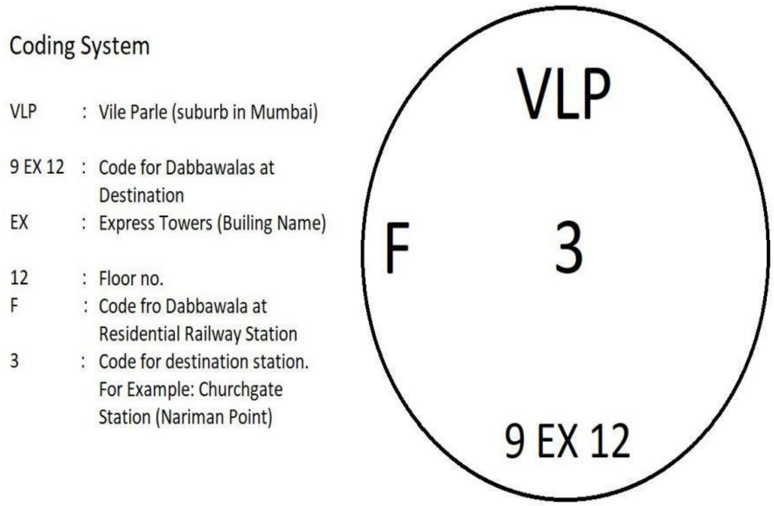

Figure 1: Coding structure of lunch box delivery system of Mumbai Dabbawalas

3. IMPROVING THE EFFICIENCY OF COLLECTION AND DELIVERY PROCESSES

There are two similar problems related to the collection and delivery processes of Lunch Box Delivery System. The first problem is concerned with the collection of lunch boxes from individual houses located in residential areas adjacent to different railway stations by the carriers and to accumulate them in the respective railway stations. The second problem is concerned with the delivery of lunch boxes to offices after the collection from different railway stations.

vehicle routing problem (Montoya-Torres et al., 2015). We consider the case of the collection process for illustration, to be solved by simulated annealing. The delivery process can similarly be illustrated.

The proposed mathematical model of the collection and delivery problem can be written as follows:

$$\min: \sum \sum \sum d_{ij} K_{k=1}\, y_{ijk}\, n{+}m_{\ j=1}\, n{+}m_{\ i=1} \quad (1)$$

Subject to the Conditions :

$$\sum \sum y_{ijk}\, K_{k=1}\, {}_{n+m}\, {}_{i=1} = 1, j = 1,2,...,n \quad (2)$$

$$\sum \sum y_{ijk}\, K_{k=1}\, {}_{n+m}\, {}_{j=1} = 1, j = 1,2,...,n \quad (3)$$

$$\sum y_{ihk}\, {}_{n+m}\, {}_{i=1} - \sum y_{hjk}\, {}_{n+m}\, {}_{j=1} = 1, k = 1,2,...,K; h = 1,2,...,n + m \quad (4)$$

$$\sum Q_i\, {}_{n+m}\, {}_{i=1} \sum y_{ijk}\, {}_{n+m}\, {}_{j=1} \leq P_k, k = 1,2,...,K \quad (5)$$

$$\sum \sum d_{ij} y_{ijk}\, {}_{n+m}\, {}_{j=1}\, {}_{n+m}\, {}_{i=1} \leq T_k, k = 1,2,...,K \quad (6)$$

$$\sum \sum y_{ijk}\, {}_{n}\, {}_{j=1}\, {}_{n+m}\, {}_{i=n+1} \leq 1, k = 1,2,...,K \quad (7)$$

$$\sum \sum y_{ijk}\, {}_{n}\, {}_{i=1}\, {}_{n+m}\, {}_{j=n+1} \leq 1, k = 1,2,...,K \quad (8)$$

$$x_i - x_j + (m + n) y_{ijk} \leq n + m - 1, \forall i,j \in [1,n], i \neq j;\ k \in [1,K] \quad (9)$$

$$y_{ijk} \in \{0,1\}, \forall i,j,k \quad (10)$$

In this formulation, y_{ijk} is the binary decision variable which has a value 1 if the arc connecting

(i, j) is served by the lunch box carrier k and otherwise 0. The objective function$_1$ minimizes the total distance travelled, constraints$_2$ and constrain$_3$ ensure that each residential area is served by one lunch box carrier, constraint$_4$ represents continuity of routes, constraint$_5$ represents the collection capacity of lunch box carriers, constraint$_6$ represents the restriction on route cost, constraints$_7$ and constraint$_8$ represent the availability of lunch box carriers, and constraint$_9$ represents the condition for eliminating sub tours. It is assumed that lunch boxes collected at each node doesn't exceed the carrying capacity of each carrier.

The simulated annealing used being of synchronous nature, ensures the cost functions to be accurate as the route is needed to be optimised. Since the collection is carried out in the form of nodes which comprises of houses being closely placed and therefore it gives an improvement on the overall performance.

The proposed appropriate algorithm for the above parallel simulated annealing is given below:

```
shared variable s, semaphore sema;
parallelised loop for i = 1 to P;
    loop for j = 0 to ∞
        wait( sema );
        s_old = s;
        signal(sema);
        (s_expected, E_diff) = generate(S_old)
        if accept(E_diff, T) then
            wait(sema);
            if S_old = s then
                s = s_expected;
                T = T_new;
            end if;
        signal(sema);
        end if;
    change T, evaluate stop criterion, etc.
    end loop;
end parallelised loop;
```

Along with this, we propose ways to collect lunch boxes from places far from the railway stations and make the service available to people far away from the railway stations who were earlier deprived of this service of enjoying hot, homemade food made by their loved and beloved ones and that too of their desired choice and taste. This service not being previously served due to its infeasible nature and scarcity of time for collection and distribution of lunch boxes.

We suggest providing this service as an improvement to the previous lunch box delivery system by optimising the route between the far places to the destined railway stations so as to make the service feasible to provide. And our proposed method follows the above mentioned simulated annealing approach for the collection and distribution of lunchboxes in the far regions, and to use Floyd-Warshall algorithm for finding the shortest path from the last client in that region to the pre-designated railway station as well as from the destination railway station to the offices.

The proposed appropriate algorithm for the above mentioned Floyd-Warshall algorithm is as follows:

```
let distance be an 2-array of  V×V consisting minimum distances initialized to ∞
for each edge (u,v)
        distance[u][v] = weight(u,v)  // the weight of the edge (u,v)
for each vertex v
        distance[v][v] = 0
for k from 1 to V
        for i from 1 to V
                for j from 1 to V
                if distance[i][j] > distance[i][k] + distance[k][j]
                        distance[i][j] ← distance[i][k] + distance[k][j]
                end if
```

This algorithm works for determining shortest routes between any two vertices or places but we prefer to apply it only between the last transition point in the node and the designated railway station.

4. NUMERICAL EXAMPLE

We consider a collection of 370 lunch boxes from 31 residential areas located around the Boriville railway station at Mumbai. At the end of collections, lunch box carriers will bring them to the same designated railway station which in this case is Boriville railway station. Table 1 represents the longitude, latitude, the number of lunch boxes scheduled to be collected at residential areas namely 2 to 32. The railway station is denoted as 1.

Number	Latitude	Longitude	No. of lunch boxes available for collection
1	19.22938	72.856998	0
2	19.229598	72.838105	11
3	19.220730	72.854694	7
4	19.238912	72.864214	10
5	19.242959	72.838453	12
6	19.243015	72.854779	15
7	19.236298	72.848048	8
8	19.239732	72.842170	8
9	19.226823	72.840754	9
10	19.241580	72.851033	7
11	19.233122	72.843478	9
12	19.235389	72.852582	15
13	19.219192	72.845072	13
14	19.226405	72.861590	13
15	19.222681	72.845413	8
16	19.225826	72.849635	9
17	19.235619	72.856406	35

18	19.240763	72.843777	10
19	19.234617	72.839127	12
20	19.242121	72.859455	15
21	19.222511	72.849721	12
22	19.221976	72.841156	7
23	19.242214	72.844861	9
24	19.229522	72.861034	8
25	19.222981	72.860013	16
26	19.228668	72.844680	12
27	19.236964	72.861369	11
28	19.222998	72.846692	20
29	19.231496	72.851250	15
30	19.220080	72.842804	8
31	19.243523	72.853008	14
32	19.242987	72.849063	12

Table 1: Lunch box collection related data

5. RESULTS AND ANALYSIS

Currently, the residential areas around the Boriville railway station are divided into few zones. One carrier is entrusted with the responsibility of collecting boxes from each zone. The zones are shown in Figure 2.

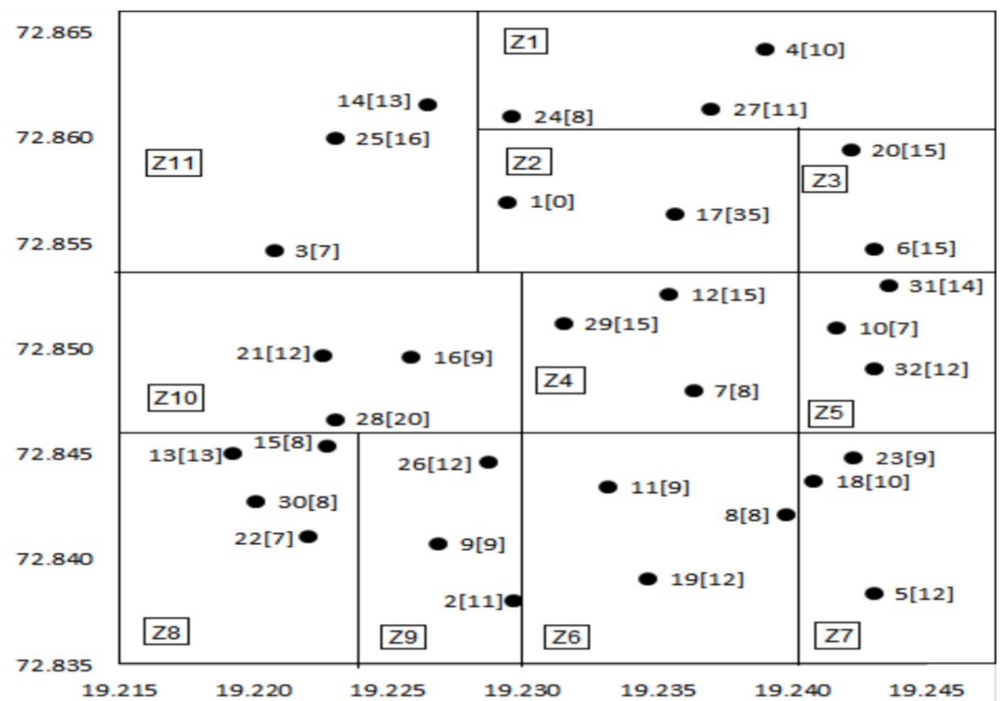

Figure 2: Existing lunch box collection zones

In Figure 2, longitudes are expressed along the x-axis, and the latitudes are expressed along the y-axis. For the considered example, a real-coded simple synchronous, parallel, simulated annealing approach is used, which is coded in MATLAB as well as in Octave. A comparison of the existing and suggested solutions is presented in Table 2.

Existing Routes			Proposed Routes		
Route	No. Of Lunch Box Collected	Distance Travelled (KM.)	Routes	No. of Lunch Box Collected	Distance Travelled (KM.)
1	29	2.85	1	37	1.97
2	35	1.39	2	40	4.24
3	30	3.47	3	37	2.87
4	38	2.58	4	39	4.81
5	33	3.80	5	36	3.93
6	29	4.55	6	38	4.96
7	31	5.08	7	36	4.10
8	36	4.10	8	36	3.52
9	32	4.15	9	35	1.39
10	41	2.71	10	36	3.38
11	36	2.61	Total	370	35.16
Total	370	37.29			

Table 2. Existing and proposed routes

The existing solution proposes for the requirement of 11 lunch box carriers, one for each zone. However, our suggested solution proposes the requirement of 10 lunch box carriers. The total distance travelled along by all the carriers is 37.29 km via the existing solution and 35.16 km by our proposed algorithm, respectively. This implies that our proposed approach suggests a saving of 5.71% in terms of distance covered. The speedup achieved due to the parallelization of the simulated annealing is 3 times to that being done in a non-parallelization manner. The lunch box carriers do follow an extremely busy schedule during their hours of operations. The reduction in distance travelled will provide some more time gap to have a bit of rest and relax, even being in an extremely busy schedule, especially for the elderly lunch box carriers. In terms of carrying the number of boxes, the suggested solution is more rational. The Floyd-Warshall algorithm suggested is being used in zones far away from the pre-designated railway station for optimal route.

6. CONCLUSIONS

We reviewed the Lunch Box Delivery System of Mumbai from the transportation perspective and studied its vast scale of operation, environment friendliness, cost efficiency, supervision of the system at different nodes of operations. It is observed that the accuracy of delivery of lunch boxes is near perfect and may not be possible to improve further. The coding structure followed in the system is a major element for the success of the overall transportation process. The part of semi or illiterate lunch box carriers is extremely important for the proper delivery and optimum functioning of the transportation system. The possible and feasible improvements observed were in the course of the routes followed during the collection and delivery processes of lunch boxes. The outcomes indicate the possibility of reducing the collection as well as the distribution time by about 6% compared to the existing one.

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